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Forgetting in Recognition Memory for Emotional Environmental Sounds

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An abstract of a thesis submitted to the Faculty of the

James T. Laney School of Graduate Studies at Emory University

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Abstract

Emotional events tend to be more memorable than neutral ones, and this memory advantage often increases over time. While the slower forgetting of emotional episodic memories has been found in many studies that have used visual stimuli (e.g., pictures and visually presented words), little is known about whether emotional auditory stimuli are forgotten slower than neutral auditory stimuli. Here we examined whether emotion slowed the forgetting of environmental sounds and to what extent emotional effects on recognition memory and forgetting were reflected in two key components of episodic memory: recollection (successful recognition accompanied by the ability to retrieve contextual information about an item's prior occurrence) and familiarity (memory strength, in the absence of recollection). Participants listened to sets of negative and neutral environmental sounds and rated their emotional reactions to each sound on each trial. Recognition memory was assessed using a remember-familiar recognition memory paradigm after 15-min and 24-hr delays, to assess forgetting for overall recognition memory performance and for estimates of recollection and familiarity. The results revealed that overall recognition memory was enhanced for negative relative to neutral environmental sounds at both delay intervals, and this enhancement was found for both the recollection and familiarity components of recognition memory. Forgetting for negative environmental sounds was slower for recollection relative to neutral sounds, but forgetting for familiarity was similar for both negative and neutral sounds. In summary, the current study found that emotional arousal can enhance both recollection and familiarity-based recognition of environmental sounds and that forgetting was selectively slower for negative vs. neutral sounds for recollection. Relative to previous findings with emotional neutral stimuli, our findings suggest that emotional effects on memory and forgetting vary across auditory and visual

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modalities, a finding which has potential implications for the existing theoretical models of forgetting.

Forgetting in Recognition Memory for Emotional Environmental Sounds

Episodic memories (memory for specific events) are distinct from other types of memory in that they allow us to feel as though we have returned to the place and time of a prior experience and consciously "re-live" the event (Tulving, 2002). An adaptive feature of episodic memory is the ability to preferentially remember events that elicit emotional arousal (intensity of emotion) long after an event occurs. Compared to non-emotional (neutral) memories, emotional episodic memories are often stronger, more perceptually vivid, and accompanied by a greater ability to recollect the context of the original event (Ochsner, 2000; Hamann, 2001; Talarico & Rubin, 2003; Labar & Cabeza, 2006; Bowen et al., 2018). These emotional enhancement effects occur at various stages of episodic memory, starting from the encoding of new memory traces, throughout post-encoding processes (e.g., the stabilization and persistence of these traces and the subsequent retrieval).

Emotional events recruit more cognitive resources at encoding than neutral events, resulting in boosted memory for emotional events (Dolcos et al., 2004; Kensinger, 2004). Enhanced encoding of emotional stimuli is in part attributable to their tendency to capture greater attentional and perceptual resources than neutral stimuli and benefit from prioritized processing (Christian & Loftus, 1991; Anderson & Phelps, 2001; Anderson, 2005; Phelps et al., 2006; Talmi et al., 2008). Additionally, because emotional stimuli tend to be more distinctive and have more inter-semantic links relative to neutral stimuli, they elicit more semantic elaboration and organizational processes during encoding, which further contribute to their mnemonic advantage (Dewhurst & Parry, 2000; Kensinger & Corkin, 2004; Talmi et al., 2007; Talmi & McGarry, 2012).

After encoding, separate processes continue to enhance memory. Post-encoding effects of emotion are evident in studies showing that emotional memories are forgotten slower than neutral ones, with the beneficial effects of emotional arousal on memory increasing over time (e.g., Sharot et al., 2007; Sharot & Yonelinas, 2008). The slowed forgetting of emotional memories is widely attributed to the effect of arousal on long-term memory consolidation, a process that gradually strengthens and stabilizes memory over the hours, weeks, and years after initial encoding, occurring to a greater extent during sleep (*modulation hypothesis;* McGaugh, 2000, 2004). Thus, the pronounced enhancement of emotional memory over time aligns with the unfolding of consolidation processes. Moreover, consistent with the idea that consolidation occurs to a greater extent during sleep, behavioral evidence indicates that the mnemonic advantage for emotional stimuli becomes particularly pronounced after sleep, even in short durations (e.g., 3 hours; Wagner & Born, 2006; Nishida et al., 2009; Payne & Kensinger, 2018; Diekelmann & Born, 2010).

The hippocampus plays a crucial role in the consolidation of episodic memory. When a memory is first encoded, it is initially stored in both the neocortex and the hippocampus. Over time, the memory is replayed and reorganized such that it gradually is redistributed into the neocortex regions, becoming less dependent on the hippocampus as time passes (McGaugh, 2000; Squire et al., 2015; Squire & Zola-Morgan 1991). The modulation model (McGaugh, 2000) proposes that arousal triggers activation of the amygdala, a subcortical brain structure that plays a crucial role in emotion processing, which in turn modulates consolidation in the hippocampus. Empirical support for this model in human studies comes from neuroimaging evidence indicating that amygdala-hippocampal connectivity and co-activation of the amygdala and hippocampus are enhanced during the encoding of emotional memories, and can predict persistence and successful memory for emotional events after long delays (e.g., Cahill et al., 2003; Richardson et al., 2004; Dolcos et al., 2004; Ritchey et al., 2008). Notably, minimizing cognitive factors can eliminate the emotional effects in long-term memory given tests shortly after encoding (e.g., 10 minutes; Talmi & McGarry 2012); however, in keeping with the enhanced consolidation processes described in the modulation model, even when emotional and neutral stimuli are initially remembered to the same extent at short delays, emotional enhancement effects on memory emerge over time (e.g., Labar & Phelps, 1998; Sharot & Phelps, 2004; Anderson et al., 2006; Sharot & Yonelinas, 2008).

While the existing literature on forgetting for emotional memories is consistent with the modulation model, it does not fully explain the complexities of emotional episodic memory. One limitation is its inability to account for the extensive evidence that emotion does not uniformly enhance all the components of episodic memory. Most contemporary models of episodic memory distinguish between two key components: *recollection* and *familiarity* (Diana et al., 2007; Yonelinas, 2002; Tulving, 1985; Mandler, 1980). Recollection involves recognition accompanied by the retrieval of specific qualitative information from the time of encoding, such as the spatial location, temporal context, associated thoughts, or perceptual details of the previous encounter. By contrast, familiarity involves knowing that something was previously experienced, without the ability to recollect qualitative information from the original episode. Familiarity is proposed to vary continuously from weak to strong feelings that something has been previously experienced (Yonelinas, 2001a; Migo et al., 2012). Neuroimaging evidence supports the dissociation between these two processes, whereby the hippocampus plays a central role in recollection by encoding the relation between memory items (i.e., binding of item and context information). In contrast, the perirhinal cortex is involved in encoding individual items without necessarily binding them to specific contextual details and is therefore capable of supporting familiarity-based recognition (Brown & Aggleton, 2001; Eichenbaum et al., 2007; Squire et al. 2007; Diana et al., 2007).

One of the most direct methods used by researchers to examine the roles of recollection and familiarity in memory performance is the "remember-know" recognition paradigm (Tulving, 1985; Yonelinas & Jacoby, 1995). In the standard remember-know task, participants are asked to provide a "remember" judgment if a stimulus evokes a specific memory for the episodic context from the encoding episode, indicating recollection, and a "know" judgment if the participant felt that the stimulus had been encountered before but could not remember qualitative information, indicating familiarity (Tulving, 1985; Rajaram, 1993; Yonelinas, 2002; Yonelinas et al., 2010). Numerous studies using this paradigm have found that emotion enhances recollection-based recognition rather than familiarity, and this emotional enhancement increases over time (e.g., Kensinger & Corkin, 2003; Oschner, 2000; Sharot et al., 2004; Sharot et al., 2007; Dolcos et al., 2005; Ritchey et al., 2008; Yonelinas & Ritchey, 2015).

An alternative view of recollection and familiarity processes posits that the distinction between recollection and familiarity reflects differences in memory strength rather than a qualitative difference in the type of memory process involved, with recollection proposed to reflect stronger memory than familiarity (Wixted & Squire, 2011). Although some studies suggest that the hippocampus (and perirhinal cortex) are involved in both recollection and familiarity (e.g., Eldridge et al., 2000; Manns et al., 2003; Wais et al., 2006), a large literature supports a behavioral and neural dissociations between these two processes (see Yonelinas et al., 2022 for a review). Furthermore, the findings that emotional effects are specific to recollection further support this dissociation (see Yonelinas & Ritchey, 2015, for a review).

Emotion does not merely enhance recollection for all aspects of an event. Recollection is often viewed as an all-or-nothing phenomenon in which episodic content is either retrieved or not. However, when recollection occurs, the episodic content can vary in terms of the confidence and accuracy of what is recollected and the types and number of details remembered. Various distinctions have been proposed regarding the episodic content involved in recollection, and they generally converge on the idea that emotion selectively enhances memory of emotional items and their associated details (Mather & Sutherland, 2011; Yonelinas & Ritchey, 2015; Bowen et al., 2018).

For instance, early evidence for selective memory enhancements has come from studies showing that individuals tend to remember details central to an emotional event at the expense of the peripheral context (e.g., Kensinger & Schacter, 2006; Talarico et al., 2009). Some models emphasize that emotion biases memory for the content of the highest priority, such as those most emotionally salient or goal relevant (Mather & Sutherland, 2011; Mather et al., 2016; Clewett & Murty, 2019). Moreover, individuals are more likely to remember features inherent to an emotional stimulus or perceptually bound to it (i.e., item color), whereas other contextual aspects (e.g., encoding task and item-location associations) are less affected (e.g., Mather, 2007; Kensinger et al., 2007; Sharot & Yonelinas, 2008; Murray & Kensinger, 2014). This selective memory enhancement may also be related to enhanced sensory processing, as emotional items are encoded and retrieved with more sensory information than neutral items are. (e.g., Mackay et al., 2004; Mather & Nesmith, 2008).

One recent prominent model, the emotional binding account (Yonelinas & Ritchey, 2015), has been proposed to explain why the effects of emotion on memory are specific to recollection and intrinsic item details. According to their model, slowed forgetting is not attributable to amygdala and hippocampal interactions, but rather to amygdala mediation of the perirhinal cortex. Specifically, they propose that the amygdala supports the binding of emotion information to an item's representation in the perirhinal cortex, creating a vivid memory trace (i.e., item-emotion binding). That is, while recollection for both emotional and neutral memories involve item-context bindings supported by the hippocampus, emotional memory recollection is uniquely supported by item-emotion bindings more resistant to forgetting. Moreover, while familiarity for both emotional and neutral memories relies on the perirhinal cortex, emotional memory recollection is uniquely supported by interactions between the amygdala and the perirhinal cortex.

An additional possibility is that retention of more intrinsic and perceptual details, along with enhanced sensory processing, plays a central role in the persistence of emotional memories. The vividness of emotional memories have been linked to interactions between sensory processing and the amygdala (e.g., Vuilleumier et al., 2004; Kensinger et al., 2007; Kark & Kensinger, 2019). Several recent studies have revealed that when emotional stimuli elicit greater activation of the ventral visual processing stream during encoding and retrieval, those stimuli are more likely to be successfully recollected, accompanied by better memory of visual sensory details (Kark & Kensinger, 2015; Bowen & Kensinger, 2017a; 2017b).

Building on previous research that suggests a connection between recollection and the recapitulation of sensory activations at the time of encoding (e.g., Wheeler et al., 2000; Danker & Anderson, 2010; Waldhauser et al., 2016), the NEVER forget model (Bowen et al., 2018) proposes that the heightened reactivation and recapitulation of sensory activation during encoding enhances the storage and retrieval of emotional memories, resulting in a more robust memory trace that is more likely to be recollected with increased vividness and a stronger subjective sense of recollection. Supporting this hypothesis, neuroimaging studies provide converging evidence that emotion enhances the engagement of sensory regions at encoding and retrieval (e.g. Mickley Steinmetz & Kensinger, 2009; Murty et al., 2011; Payne & Kensinger, 2011). Additionally, these findings suggest that emotion strengthens the degree to which sensory regions are recapitulated during retrieval (Bowen & Kensinger, 2017a; Kark & Kensinger, 2015). While there is a substantial body of literature supporting the idea that emotional memories are associated with enhanced sensory processing, Bowen et al. (2018) highlighted several unresolved questions about how sensory processing precisely influences recollection for sensory details over time.

Although slowed forgetting for emotional stimuli is a widely observed empirical finding that several theoretical frameworks have sought to explain (McGaugh, 2000; Hamann et al., 2001; Labar & Cabeza, 2006; Yonelinas & Ritchey, 2015; Bowen et al., 2018), empirical support for this phenomenon is limited to studies that use visually presented stimuli, such as pictures and words. As a result, the nature of emotional effects on memory beyond the visual domain remains unclear. Indeed, considering the efforts to develop theoretical frameworks that account for the slowed forgetting of emotional stimuli, understanding how emotion interacts with sensory processes to modulate memory retention and the subjective sense of recollection remains an important point for further research. To advance in this direction, a necessary step is to investigate emotional memory enhancement in new sensory modalities.

Similarly to visual stimuli, auditory stimuli can convey complex affective information about the environment (Verona et al., 2004). By definition, emotional environmental sounds are complex sounds that consistently carry specific meanings and provide information about events and objects in the personal environment (Ballas & Howard, 1987). For instance, environmental sounds such as car crashes, explosions, animal cries, and human screams, convey valuable information about potential threats or dangers in the environment. Emotional environmental sounds can elicit high levels of arousal, as evidenced by subjective ratings and physiological markers (e.g., Bradley & Lang, 2000; Zhou et al., 2014; Yang et al., 2018). Moreover, previous research has shown that emotional environmental sounds elicit increased amygdala activation (Sandar & Scheich, 2001; Kumar, 2012). Given that the modulation model predicts that amygdala activation triggers the release of stress hormones that then modulate hippocampal consolidation over time, it follows that emotional environmental sounds would be forgotten slower than neutral environmental sounds.

Only two studies have examined episodic memory of emotional environmental sounds in adults. Bradley and Lang (2000) reported that negative environmental sounds were more easily recalled than neutral environmental sounds after a 10-minute delay. Similarly, Morrow et al. (2022) found that emotional environmental sounds were better remembered than neutral environmental sounds 15 minutes after encoding as assessed through the remember-know task, and this effect was seen in recollection and not familiarity. However, because both studies only tested memory at one point in time, they were unable to determine whether the rate of forgetting differed between emotional and neutral environmental sounds.

In the present study, we examined whether emotional environmental sounds exhibit slower forgetting compared to neutral sounds, and whether emotional effects differ for the recollection and familiarity components that support recognition memory. In the encoding phase, participants listened to negative and neutral environmental sounds one at a time and rated their emotional responses to the sounds using valence and arousal scales. Recognition memory for negative and neutral environmental sounds was tested at two delays, 15 minutes and 24 hours after encoding. We used a remember-familiar recognition memory task, which allowed us to examine the overall recognition memory performance and separate the effects of recollection and familiarity. Participants were instructed to determine whether they could recollect specific details from when they heard the sound earlier in the experiment or, if unable to do so, to judge whether the sound was more or less familiar (e.g., McCullough & Yonelinas, 2013; Sharot et al., 2007; Ritchey et al., 2015). At each delay, the participants made recognition judgments for half of the encoded negative and neutral sounds, intermixed with an equal number of distractor sounds of each valence. Thus, after completing both recognition tests, participants had made recognition judgments on all sounds presented at encoding. To investigate the effects of emotion on memory over time, we examined overall recognition memory performance and estimates of recollection and familiarity for negative and neutral environmental sounds across the 15-minute and 24-hour delays.

The primary goal of this study was to determine whether forgetting for recognition memory differed between negative and neutral environmental sounds. Based on previous findings that emotion selectively enhances recollection, we predicted that overall recognition memory for negative environmental sounds would be superior to that for neutral environmental sounds at both the short and long delays and that this effect would be driven by the recollection component of recognition memory, with no differences in familiarity across valence conditions. Moreover, based on evidence demonstrating that emotion slows forgetting for emotional relative to neutral visual stimuli, we predicted that forgetting for overall recognition memory would be slower for emotional environmental sounds relative to neutral environmental sounds, and moreover, forgetting for recollection would be slower for emotional sounds compared to neutral sounds, whereas forgetting for familiarity would not differ between neutral and emotional sounds.

Methods

Participants

Forty-six undergraduate students from Emory University participated in this study. All participants provided informed consent for the study procedures approved by the Emory University Institutional Review Board and received course credit for their participation. Six participants were excluded from analyses because they reported that they had not understood the retrieval task instructions upon completion of the study. Two additional participants were excluded from the analyses because they did not attend the second experimental session. Finally, three participants were excluded from the analyses because their retrieval task data was lost due to software malfunction. The data for the 35 remaining participants was used for subsequent analyses in this study (17 female, 16 male, two non-binary; mean age = 19.06 years, SD =1.17).

Stimuli

Stimulus Selection

The experimental stimuli consisted of negative and neutral environmental sounds. We specifically focused on negative valence emotional environmental sounds because, while prior evidence consistently shows that emotion enhances memory for negative stimuli, there is limited research using positive stimuli, and existing studies have yielded mixed results that remain unexplained (Bowen et al., 2018; Clewett & Murty, 2019). Stimuli were selected from the International Affective Digitized Sounds databases (Bradley & Lang, 1999 [IADS], Bradley & Lang, 2007 [IADS-2]; Yang et al., 2018 [IADS-E]) as well as several online sound-sharing sites (pixabay.com, freesoundlibrary.com, epidemicsound.com, freesfx.com, youtube.com, and zapsplat.com), which allowed us to select sounds that represented a wide array of semantic categories (e.g., nature sounds, animals, human vocalizations, and technology). We initially collected 408 sounds (233 negative and 205 neutral) from these databases for stimulus selection. Because the duration of a sound determines the time that participants can attend to and encode the sound, the durations of the sounds from online sources were trimmed to 6 s to match the duration of the IADS sounds.

Sound Identification. Because we aimed to test participants' memory of the perceptual characteristics of sounds, rather than the verbal labels they may have used during encoding (such as "dog barking"), each sound was matched with a conceptually similar but perceptually different sound (e.g., a target sound of dog barking was matched with a distractor sound of a different dog barking) and both sounds were randomly presented during the recognition memory task. Therefore, to distinguish between old (i.e., target) and new (i.e., distractor) sounds, participants needed to recognize the perceptual features of the target sound.

To identify verbal labels for the initial 408 sounds, six Emory University students completed a sound-identification task in which they provided short verbal descriptions of each sound. Each 6 s sound was presented in the identification task, followed by a prompt for participants to describe the sound (“use one or two words to describe what you heard”). The participants were given 10 s to type their verbal descriptions. However, if a participant failed to type a response before the next stimulus, we interpreted it as indicating that the sound was not quickly identifiable and considered their answer “incorrect.”

The identification rate of each sound was defined as the proportion of raters that identified the sound using the same or a semantically similar verbal label. The full scoring guidelines for determining whether verbal labels were semantically similar are described in Appendix A. Only sounds that were identified with a similar verbal label by at least half of the participants (identification rate > .5) were considered when selecting the final stimulus set (Chiu & Schacter, 1995; Roder & Rosler, 2003; Marcell, 2000; 2007).

Two sounds for each verbal label ("sound pairs") were selected for the final stimulus set. Therefore, one sound of each pair would serve as a target, and the other sound would serve as a distractor in the recognition memory task, counterbalancing whether a sound within a pair appeared on the recognition test as a target or distractor. The final stimulus set was selected such that the average identification rate did not significantly differ between negative and neutral environmental sounds, $t(190) = 1.40$; $p = 0.16$ (see Table 1 for average ratings). The average identification rate for each sound is shown in Appendix B.

Perceptual Similarity. To effectively assess recognition memory, participants needed to be able to discriminate between the target and distractor sound within each sound pair at test. Thus, we selected sound pairs such that the two sounds in each pair were as acoustically dissimilar as possible within the range of available sounds from the IADS and online databases. To assess the perceptual similarity between the two sounds of each pair, nine Emory University students completed a perceptual similarity task whereby they listened to both sounds of each pair and then rated the sound pair on a scale of 1 ("not perceptually similar at all") to 5 ("very perceptually similar") (Gygi et al., 2007).

For the final stimulus set, sounds rated as very perceptually similar (rated as greater than four across participants) were excluded from the final stimulus set. The 96 final stimuli pairs (48 negative, 48 neutral) were selected such that there was no difference between perceptual similarity ratings across valence conditions $t(94) = 0.45$; $p = 0.65$ (Table 1 for average ratings).

The average perceptual similarity ratings for each negative and neutral sound pair are provided in Appendix C.

Arousal and Valence Ratings. Sound selection procedures yielded a set of 253 potential sounds (126 negative, 127 neutral) that met the criteria for identifiability and perceptual similarity. To select the final stimulus set, normative ratings of arousal and valence were collected to assess whether the valence condition of the proposed stimuli matched the intended valence condition. Thirteen Emory University students (10 female, 3 male, mean age = 18.54, *SD* = 0.5) rated all sounds for emotional arousal and valence using the Self-Assessment Manikin (SAM) rating scale, a 9-point non-verbal pictorial assessment devised to measure participants' emotional responses (Bradley & Lang, 1994).

The rating task began with instructions and a practice phase, in which the rating scales were explained. The instructions for this task were adapted from the standard instructions described by Bradley and Lang (1994) (see Appendix D). Participants were instructed to rate arousal and valence on a pictorial scale (1-9) from least arousing to most arousing for arousal, and from most negative to most positive for valence. Following the instructions, participants completed two practice trials. In the rating task, stimuli were presented in a pseudorandom order, such that no more than two sounds of the same valence were consecutively presented. The stimulus order was counterbalanced across participants, whereby the order of stimulus presentation was reversed for half of the participants. The trials were separated into four blocks, with a break between each block. The first and third breaks were 20 s each, and the second break was three minutes to reduce fatigue.

Sounds were assigned to negative and neutral conditions based on normative valence and arousal ratings. Negative sounds were rated low in valence (less than 4) and high in arousal (greater than 4.5). The neutral sounds were rated in the midrange for valence (rated 4–6; i.e., neither negative nor positive) and low in arousal (rated less than 4). In accordance with the sound selection procedure, the final set of negative sounds was rated significantly lower in valence, $t(190) = -26.39$; $p < .001$, and higher in arousal, $t(190) = 25$; $p < .001$, than neutral sounds (see Table 1 for average ratings). The average valence and arousal ratings for each sound are presented in Appendix B.

Final Stimuli Characteristics

The 192 final stimuli comprised 96 pairs of sounds (48 negative pairs, 48 neutral pairs), such that the two items in each pair could be identified using the same verbal label (e.g., two dog barks) but were perceptually distinct (e.g., a single, lower-pitched dog park and a series of quick, high-pitched dog barks). Of the selected stimuli, 6.8% were from the IADS-2 database, 6.3% were from the IAD-E database, and the remaining 87% were from online sources. In addition, the experimenter manually recorded one of the 192 sounds. The source for each sound is listed in Appendix B.

Table 1.

Characteristics of Negative and Environmental Neutral Sounds

	Negative		Neutral	
	M	*SD*	*M*	*SD*
Arousal	5.87	0.75	3.32	0.43
Valence	2.68	0.57	4.98	0.41
Perceptual Similarity	2.96	0.53	2.89	0.52
Identification Rate	.86	.16	.82	.18

Note. Normative ratings are from from Emory University students who did not participate in the main study.

Stimuli were equated based on two physical properties: peak amplitude and sound sampling resolution. All sound manipulations were conducted using Audacity 3.2.4 software (http://www.audacityteam.org). Louder sounds attract attention faster and more efficiently than softer sounds do, potentially affecting subsequent memory. Peak amplitude normalization is a technique that sets the most piercing point of all sounds to the same level while preserving the dynamic range (the proportional distance between the loudest and softest end of the sound), thus maintaining the ecological validity of the sound. Equating emotional and neutral sounds on peak amplitude reduces attentional effects without affecting emotional reactions (Thierry & Roberts, 2007; Bradley & Lang, 2000). In this study, we normalized the peak amplitude of our stimuli to 0.1dB, a modest amplitude associated with minimal distortion.

The quality or fidelity (i.e., good resolution) of sounds can influence how listeners perceive them. Low-quality sounds, which may be muffled or have restricted frequency ranges, are harder to identify and tend to elicit weaker emotional reactions than high-quality recordings of the same sound (e.g., Lolli et al., 2015). Proper resolution can be equated by digitizing the sounds at a consistent sampling rate, which determines how frequently the amplitude of a sound wave is measured and directly affects the accuracy of the represented frequency in a digital audio signal. We digitized the final stimuli to a frequency range of 44,100 Hz which is commonly used for high-quality digital audio recordings because it can capture the full range of frequencies audible to humans. However, it is important to note that changing the sampling rate only guarantees resolution for sounds equal to or greater than the chosen rate. Among the 192 selected stimuli, 63 had sampling rates below 44,100 Hz, which means that complete control over resolution was not achieved for those stimuli. As a final step, given that changing the sampling rate of an audio file can potentially alter the frequency content of the sound and introduce unwanted distortions, all sounds underwent individual checks for distortion effects by the experimenter.

Pilot Studies

To ensure that memory scores were not near ceiling or floor levels, which would limit our ability to evaluate forgetting, we conducted several rounds of piloting before the main study. During these pilot studies, we manipulated the number of times sounds were presented during encoding and the length of the delay period between encoding and the second recognition test. In all pilot studies the first recognition memory task was given 15 minutes after encoding. One pilot study involved presenting sounds only once during encoding and conducting the second recognition memory task 72 hours after encoding ($n = 6$). This resulted in floor effects for the neutral sounds during the second recognition memory task. In another pilot study, sounds were presented three times during encoding, and the second recognition memory task was conducted 24 hours after encoding ($n = 9$). This resulted in ceiling effects for the negative sounds during the first recognition memory task. Our third round of piloting, which involved presenting sounds twice during encoding and conducting the second recognition memory task 24 hours after encoding ($n = 5$), showed no floor or ceiling effects. Therefore, this design was adopted for the main study.

Experimental Tasks and Study Design

The study consisted of two experimental sessions separated by 24 hours. For instance, if a participant had their first session on Tuesday at 10 a.m., then their second session was at 10 a.m. on Wednesday. On the first day, participants encoded negative and neutral environmental sounds, completed a 15-minute delay task, and underwent the first recognition memory task. Participants provided valence and arousal ratings for each target sound during the encoding task. On the second day, the participants completed a second recognition memory task, rated the valence and arousal of the distractor sounds, and completed a post-test survey.

Experimental tasks were administered using Psychopy 2022.2.5 software (Pierce et al., 2019) on Dell computers with 23” monitors in a research laboratory. Sounds were 32-bit stereo WAV files presented through Sennheiser HD 206 headphones at a fixed volume (volume of 20 on a Dell Computer) throughout the study procedures.

Encoding Phase

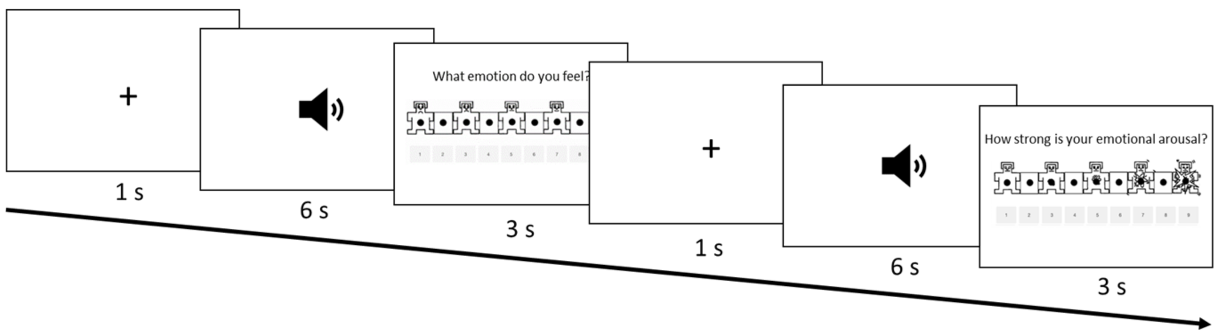
During the encoding phase, the target sounds were presented individually for 6 s each. The target sounds were presented to the participants twice consecutively. Participants were instructed to rate the valence and arousal of the sound using the SAM scale after the first and second presentation of each sound, respectively. Each rating scale was presented for 3 s, followed by a 1 s fixation cross before the next sound was presented. The encoding phase procedure is illustrated in Figure 1.

For every sound pair (48 negative pairs and 48 neutral pairs), sounds were assigned to either group A or B such that one sound from every sound pair was assigned to each group (A or B). Thus, each group consisted of 96 sounds (48 negative and 48 neutral). Negative and neutral sounds in each group were equated to arousal, valence, and identifiability, respectively. For example, the 48 negative sounds in group A did not significantly differ in arousal, valence, or identifiability from the 48 negative sounds in group B. These groups were counterbalanced across participants to determine whether a sound was presented as a target or a distractor. Half of the participants encoded sounds from group A, and the other half encoded sounds from group B.

Two lists of intermixed negative and neutral sounds were created for each group (A and B), each in a different presentation order. To prevent the induction of long-lasting mood states, the order of sound presentation was pseudorandomized such that no more than two sounds of the same valence were consecutively presented. Four lists of sounds were created by reversing the first four lists of sounds. As a result, the participants encoded one of the eight lists, each comprising 96 target sounds (48 negative and 48 neutral).

Figure 1.

Encoding Phase Procedure



Note. For each encoding trial, the same sound was presented twice. After the first presentation, the participants rated the valence of the sound. Following the valence rating, the same sound was given a second time, after which participants rated the arousal of the sound.

Participants received identical instructions for the SAM scale as provided during the norming phase for stimulus selection (see Appendix D for specific instructions). After the instruction, two practice trials were conducted. Participants used keyboard number keys (1-9) to rate valence and arousal, and their responses were recorded until the onset of the next stimulus. Most participants had sufficient time to rate the stimuli within the allotted period. If the participant failed to provide a rating before the onset of the next stimulus, the target sound was again presented at the end of the second testing session. Participants only provided a missed rating (either valence or arousal). For instance, if a participant missed rating the valence of a sound during encoding, the same sound was presented in a self-paced task at the end of the second session and the participant provided their valence rating. This process ensured that subjective valence and arousal ratings were obtained from all participants for each sound.

The encoding phase consisted of four blocks of 24 sounds, across which negative and neutral sounds were evenly divided. To reduce primacy and recency effects, each study block was preceded by a neutral buffer sound that did not otherwise appear in the study. A break was given to participants between each block to reduce fatigue. The first and third breaks lasted for 20 s, allowing participants to stretch and look away from the screen briefly before reorienting to the task. The second break (i.e., halfway through the encoding task) was for two minutes to provide participants with a more substantial break. For the two-minute break, the participants were asked to complete a difficult maze ("Super Tough Mazes" from Krazydad.com) as a filler task. Mazes were selected to be difficult such that no participant could solve the maze in the two minutes to increase the participant's engagement in the task and prevent the participant from rehearsing the encoded sounds during the delay. The encoding task took approximately 35 minutes to complete.

Delay Phase

Delay Task. After the encoding phase, participants were asked to complete another difficult maze puzzle ("Super Tough Mazes" from Krazydad.com) for eight minutes as a filler task. Mazes were selected to be difficult so that participants would be more engaged. If a participant completed a maze, they were given another maze so that they could solve it for the entire filler task.

Retrieval Task Instructions. Participants were then given instructions for a remember-familiar recognition memory task, which is a variant of the remember-know recognition memory task. In the remember-familiar recognition memory task, "familiar" is used in the instructions instead of "know," which could be interpreted to mean, "No, I have not heard that sound before." Moreover, because it has been argued that the differences between remember and know judgments better reflect varying levels of recognition memory confidence (Wixted & Squire, 2011), we used a confidence scale to distinguish between strong familiarity and recollection (e.g., McCullough & Yonelinas, 2003; Sharot et al., 2007; Ritchey et al., 2015).

Specifically, participants were instructed to indicate whether they recollected the presented sound (6 = remember) or alternately judged the sound to be more or less familiar using a 1 to 5 scale (1 = definitely new, 2 = probably new, 3 = not sure, 4 = probably old, 5 = definitely old). Participants were informed that a "remember" response should be given if they could recall a specific detail about the sound from the encoding phase. On the other hand, a "definitely old" response should be given if they recognize that the sound was presented during encoding but could not recall any specific details. Participants were asked to explain their understanding of the difference between a "definitely old" and a "remember" response aloud. If the participant could not correctly explain their understanding of the task responses, the experimenter corrected the participant and reviewed the instructions with the participant a second time. More detailed instructions for the recognition memory task as provided in Appendix E.

Additionally, the participants were tested to determine whether they understood the task instructions during the practice phase. Participants were asked to encode three neutral sounds and then provide their recognition judgment for target sounds intermixed with the corresponding distractor sounds. Participants were asked to explain why they made their judgment to ensure an adequate understanding of the instructions; responses were verified or corrected by the experimenter. If the participant demonstrated that they did not understand the task, the experimenter corrected the participant, reviewed the instructions with the participant again, and provided additional clarification (e.g., an example of a correct response) as necessary (Yonelinas, 2001b; Rajaram, 1993).

After the practice phase, the participant completed another maze puzzle until 15 minutes had passed since the end of the encoding phase, such that all participants began the first retrieval phase after the same duration.

Retrieval Phase

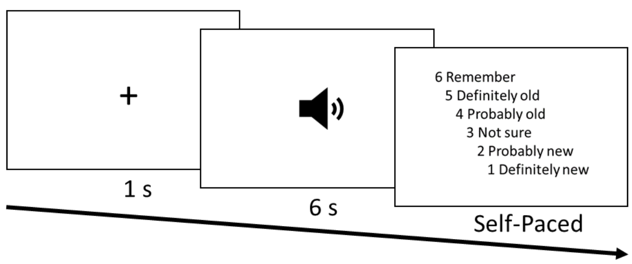
There were two separate retrieval phases. The first occurred immediately after the delay phase, at 15 minutes after the end of the encoding phase. The second retrieval phase occurred 24 hours after the first session. For each retrieval phase, participants completed a recognition memory task for half of the encoded sounds (24 negative targets and 24 neutral targets) intermixed with an equal number of distractor sounds from each corresponding sound pair.

Sounds were presented one at a time for 6 s, followed by a self-paced remember-familiar recognition memory task to assess recognition (see Figure 2). Participants used the keyboard's number keys (1-6) to indicate whether they recollected details from when they heard the sound earlier in the experiment (6) or, if they could not recollect details, judged the sound to be more or less familiar (1-5). Each trial was separated by a 1 s fixation cross to orient the participants for the next sound. The sounds were presented in two blocks, each consisting of 48 sounds (24 negative and 24 neutral). Participants were given a 20 s rest break between the blocks. Twenty-four hours later, participants completed a second recognition memory task for the remaining targets. The retrieval phase procedure for each delay was identical in the design.

For each of the eight encoding lists, target sounds were assigned to two retrieval lists (48 target sounds per list), and these lists were counterbalanced across subjects to determine whether they were presented with the 15-minute or 24-hour delay. Thus, there were 16 counterbalance groups during retrieval. For each of the 16 lists, the presentation order of the sounds was pseudorandomized such that no more than two sounds of the same valence and no more than two targets or distractors were consecutively presented.

Figure 2.

Retrieval Phase Procedure



Note. Each sound was presented once, followed by a self-paced, remember/familiar/new task. The next trial began after the participant entered their keypress response (1-6).

Post-test Survey

After completing the study, participants completed a post-test survey on Qualtrics to assess their understanding of the remember/familiar task instructions, their thoughts about the purpose of the experiment, how often they had thought about the sounds (and if so, which sounds) during the 24-hour interval before the second recognition test, and the amount of effort they felt they expended during the study. Participants were also asked to report additional information, such as their stress levels during each recognition memory task and how long they slept in the 24-hour interval before the second recognition test (see Appendix F for the full survey questions). Of the 35 participants, 32 completed the post-test survey. The remaining three participants did not complete the survey due to scheduled commitments following the second experimental session. Appendix G provides a report on the stress levels and sleep duration of the 32 participants who completed the post-test survey.

These three participants were included in the main analyses; however, we were unable to verify their understanding of the remember/familiar task instructions at the end of the second session because of missing survey data. Throughout both experimental sessions, we implemented several manipulation checks to ensure that the participants understood the instructions, such as asking them to restate the instructions in their own words before each retrieval task. Nonetheless, the absence of Information from the final check leaves some uncertainty regarding their understanding of task requirements, potentially introducing confounding factors into the findings. Future analyses of this data should be performed without these three participants to strengthen the robustness of the conclusions.

Data Analysis

All statistical comparisons of the behavioral data were conducted using R (version 4.2.1; http://www.R-project.org). We computed the mean valence and arousal ratings for each stimulus separately for negative and neutral environmental sounds based on participant responses during the encoding and distractor rating tasks. To compare the ratings of negative and neutral sounds, we performed pairwise t-tests and determined Cohen's d as a measure of the effect size.

Overall recognition memory was assessed using the d' sensitivity statistic and corrected recognition memory accuracy (hit rate minus false alarm rate). The d' sensitivity statistic is a measure that differentiates memory accuracy (sensitivity) from the bias for a participant to judge an item as old or new (response criterion c) (MacMillan & Creelman, 2004). D' scores range from zero to infinity, where higher values indicate increased sensitivity in distinguishing between old and new items (i.e., greater recognition accuracy). To clarify the results obtained for the d' sensitivity statistic and corrected recognition, hit rates, false alarm rates, and response criterion c were also examined.

Recognition memory was further broken down into parameter estimates of recollection and familiarity. 'Recollection' responses were defined as sounds that were endorsed as recognized with memory for contextual details from the time of original sound presentation (i.e., remember response). 'Familiarity' responses were defined as sounds endorsed as recognized but without recollection (i.e., probably old or definitely old responses). Parameter estimates of recollection and familiarity were calculated using the independent K (IRK) procedure (Yonelinas & Jacoby, 1995; Yonelinas & Levy, 2002). Recollection estimates were calculated by subtracting the proportion of recollection responses for old (target) sounds from the proportion of recollection responses for new (distractor) sounds (i.e., recollection estimate = hit rate for recollection responses – false alarm rate for recollection responses). Familiarity was calculated using the following formula: familiarity = ((hit rate for "familiar" items)/(1 – hit rate for "remember" items)) – ((false alarm rate for "familiar" items)/ (1- false alarm rate for "remember" items)).

To assess forgetting, researchers often analyze the interaction between experimental conditions (e.g., negative vs. neutral stimuli) and delay intervals (e.g., 15 minutes vs. 24 hours) for each memory measure. However, scaling problems can arise when memory performance at an initial time point differs across conditions (Loftus, 1985; Wixted, 1990). The discrepancy in initial memory performance can determine the degree to which memory can decline over time is determined by the initial memory performance, which can make direct comparisons of forgetting between conditions difficult (Loftus, 1985; Wixted, 1990). To address this issue, it is recommended to convert memory scores for later delay intervals into a proportion of the initial memory performance, as this proportional measure is less affected by scaling effects.

Therefore, for each memory measure in our analyses, if memory performance differed at the initial 15-minute delay, we used the proportional forgetting method as the primary analysis for forgetting. To calculate proportional forgetting, we combined estimates from each delay into a single measure (i.e., (memory performance at 15 min – memory performance at 24 hr / memory performance at 15 min). A proportional forgetting scale of zero corresponds to when memory performance at the 24-hour delay is as high as memory performance after the 15-minute delay. We performed simple comparisons (pairwise t-tests) between proportional forgetting for negative and neutral sounds, and calculated Cohen's d to evaluate the effect size.

To examine forgetting for each memory measure that did not differ at the 15-minute delay, we performed a repeated measures analysis of variance (ANOVA) using Delay (15 min, 24 hr) and Valence (negative, neutral) as within-subjects factors. Forgetting rates were assessed by examining the interaction between valence conditions across delay intervals. To evaluate the effect size, partial Eta Squared (h^2_p) was calculated (Olejnik & Algina, 2003), and family-wise Bonferroni corrections were performed to control for Type 1 errors when testing simple main effects. Although proportional forgetting scores were necessary to examine forgetting when there were differences at the 15-minute delay interval, we also conducted ANOVAs on the original memory measures to facilitate comparisons with studies that did not use proportional forgetting scores.

Results

Arousal and Valence Ratings

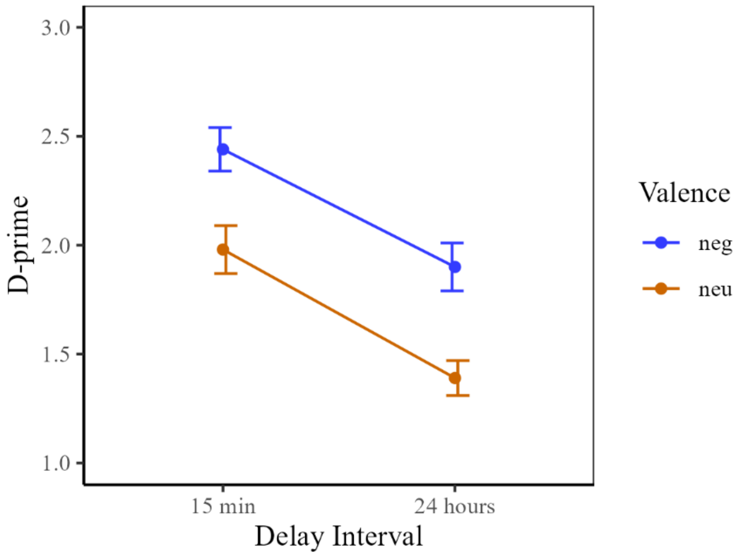
Pairwise comparisons of arousal ratings found that participants rated negative environmental sounds (M=5.51, SD=0.77) as more arousing than neutral sounds (*M*=3.35, *SD*=0.57); $t(95) = 84.55$, $p<.001$, $d = 8.63$. Negative environmental sounds (*M*=3.32, *SD*=0.63) were also rated lower in valence than neutral sounds (*M*=5.21, *SD*=0.52); $t(95) = -17.06$, $p<.001$, $d = -1.74$. These results are consistent with patterns observed in normative databases like the IADS (Bradley & Lang, 2000; Yang et al., 2018), where higher arousal ratings are associated with lower valence ratings. A visual representation of this distribution can be found in Appendix H. Overall, these findings indicate that participants, on average, perceived negative sounds as more emotionally arousing and negative than neutral sounds.

Overall Recognition

To assess the predictions that overall recognition memory for emotional sounds would show less forgetting than neutral sounds, we examined differences in forgetting across valence conditions for the d' sensitivity statistic and corrected recognition accuracy. Consistent with prior work (Morrow et al., 2022), simple comparisons of d' scores found that memory for negative sounds was significantly higher than neutral sounds at the 15-minute delay interval, $t(34) = 3.15$, $p = .003$, and 24-hour delay, $t(34) = 4.68$, $p <.001$ (See Figure 3).

Figure 3.

D-prime Over Time

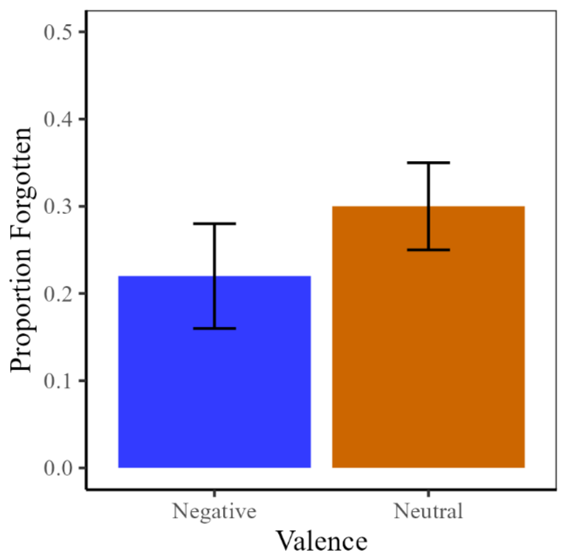


Note. D-prime performance for each valence condition across delay intervals. Error bars denote the standard error of the mean.

Because there was a significant difference at the initial 15-minute delay interval, we converted the d' scores at each delay interval into proportional forgetting scores. Contrary to our prediction, simple comparisons of proportional d' scores found no significant differences in forgetting between negative and neutral sounds, $t(34) = -0.66$, $p = .51$, $d = -0.11$ (see Figure 4), indicating that forgetting for d' scores did not differ across negative and neutral sounds.

Figure 4.

Proportional Forgetting for D-prime



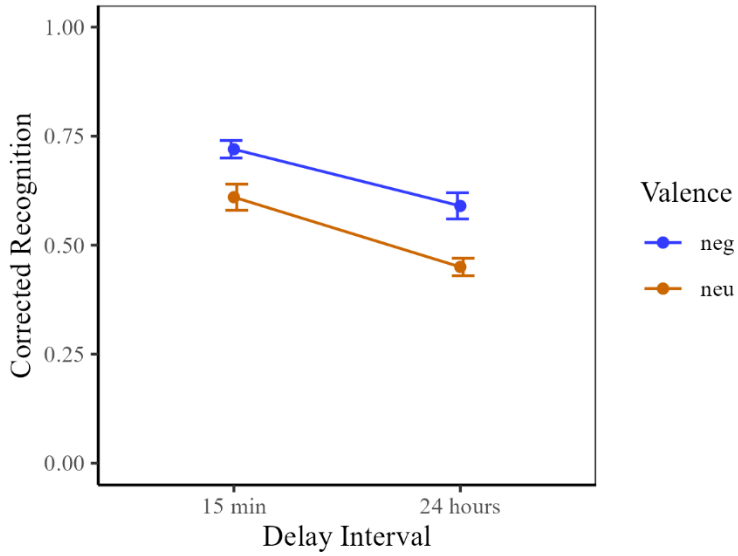
Note. Error bars denote the standard error of the mean.

For comparison with prior studies that did not use proportional forgetting measures to assess forgetting, we performed a repeated measures ANOVA with factors for Delay and Valence on the original d' scores. The interaction between Delay and Valence was not significant, $F(1, 34) = 0.06$ $p = .81$, $\eta^2_p = .002$ (see Figure 4B). There were main effects of Valence, $F(1, 34) = 38.25$, $p < .001$, $\eta^2_p = .53$ and Delay, $F(1, 34) = 41.2$, $p < .001$, $\eta^2_p = .55$.

In addition to the d' statistic, the same statistical analysis was conducted for corrected recognition. Simple comparisons of corrected recognition found that memory for negative sounds was significantly higher than that for neutral sounds at the 15-minute delay interval, $t(34) = 4.32$, $p < .001$, and the 24-hour delay, $t(34) = 5.45$, $p < .001$ (see Figure 5).

Figure 5.

Corrected Recognition Over Time

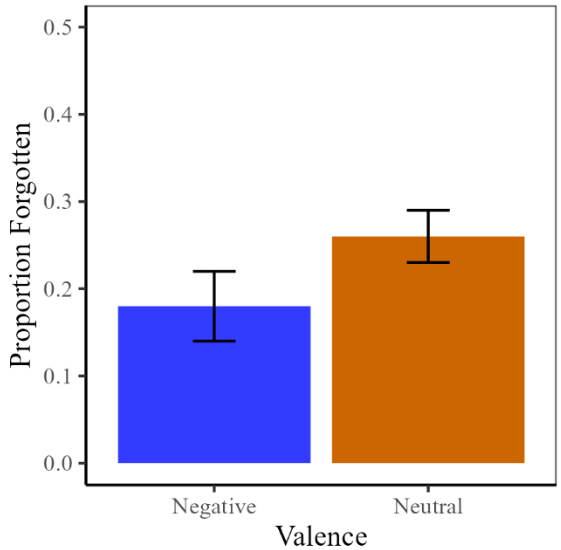


Note. Corrected recognition performance for each valence condition across the delay intervals. Error bars denote the standard error of the mean.

Because there was a significant difference between the valence conditions at the initial 15-minute delay interval, we converted the corrected recognition scores at each delay interval into proportional forgetting scores. Contrary to our prediction, simple comparisons found no significant difference between the valence conditions for proportional corrected recognition, $t(34) = -1.16$, $p = .26$, $d = -0.2$, indicating that forgetting of corrected recognition did not differ across negative and neutral sounds (see Figure 6)

Figure 6.

Proportional Forgetting for Corrected Recognition



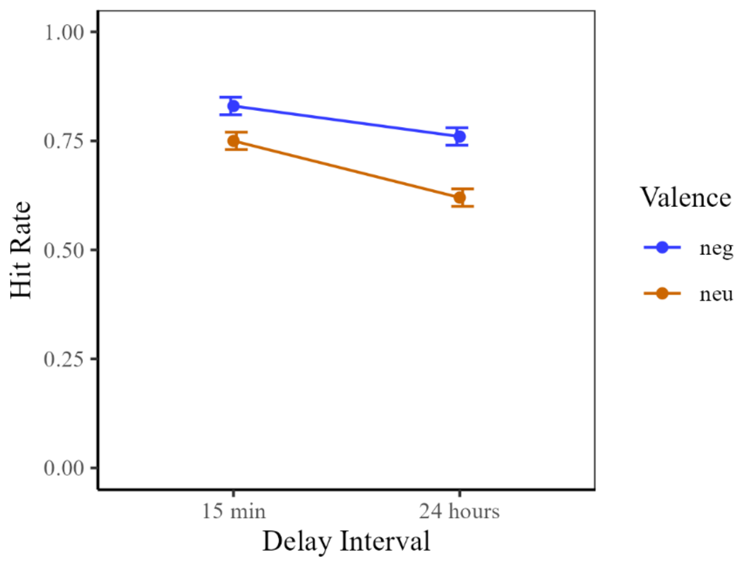
Note. Error bars denote the standard error of the mean.

In the repeated measures ANOVA with factors for Delay and Valence on the original corrected recognition scores, the interaction was not significant, $F(1, 34) = 0.33$, $p = .57$, $\eta^2_p = .01$, showing that there was no significant difference in forgetting for corrected recognition across valence conditions (see Figure 3B). There were significant main effects for both Valence $F(1, 34) = 52.63$, $p < .001$, $\eta^2_p = .61$, and Delay $F(1, 34) = 55.9$, $p < .001$, $\eta^2_p = .62$.

For hit rate, simple comparisons between the negative and neutral conditions revealed a significant difference between these two conditions at the 15-minute delay interval, $t(34) = 3.86$, $p < .001$, and 24-hour delay interval, $t(34) = 6.09$, $p < .001$(See Figure 7).

Figure 7.

Hit Rate Over Time

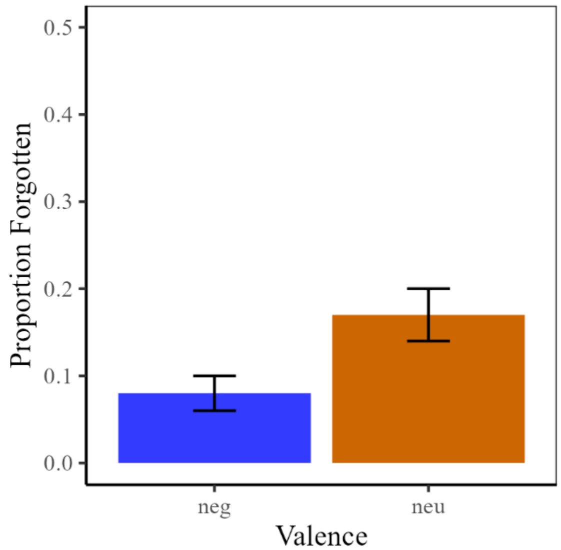


Note. Hit rates for each valence condition across delay intervals. Error bars denote the standard error of the mean.

Because there was a significant difference in the initial 15-minute delay interval, we converted the hit rate scores into proportional forgetting scores. Simple comparisons of proportional hit rate revealed a significant difference between these two conditions, $t(34) = -2.35$, $p = .03$, $d = -0.40$ (see Figure 8).

Figure 8.

Proportional Forgetting for Hit Rate



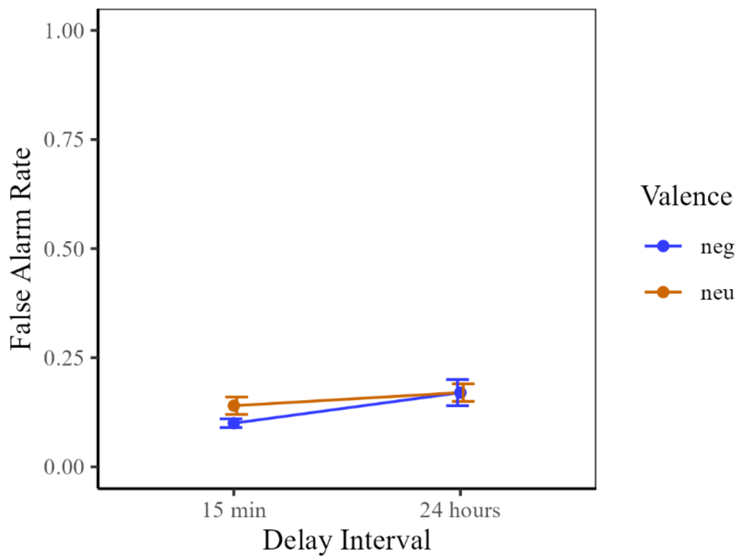
Note. Error bars denote the standard error of the mean.

For the ANOVA with the original hit rates, for comparison with prior studies that did not use proportional forgetting, there was no significant interaction between Delay and Valence on hit rate, $F(1, 34) = 0.06$, $p = .81$, $\eta^2_p = .002$,(see Figure 9). There were also main effects of both Valence, $F(1, 39.85) = 58.46$, $p < .001$, $\eta^2_p = .59$, and Delay, $F(1, 39.6) = 20.57$ $p < .001$, $\eta^2_p = .34$.

For the false alarm rate, simple comparisons between the negative and neutral conditions found no significant difference at the 15-minute delay interval, $t(34) = -1.89$, $p = .07$, indicating that a proportional forgetting analysis was not required to control for scaling distortions. In the ANOVA using Delay (15 min, 24 hr) and Valence (negative, neutral) as within-subjects factors, there was no significant interaction between Delay and Valence, $F(1, 34.92) = 0.28$, $p = .6$, $\eta^2_p = .01$, (see Figure 9), indicating no significant differences in forgetting across valence conditions. In addition, there were marginally insignificant main effects of Valence, $F(1, 34.92) = 3.38$, $p = .07$, $\eta^2_p = .09$, and Delay, $F(1, 33.45) = 3.27$, $p = .08$, $\eta^2_p = .09$.

Figure 9.

False Alarm Rate Over Time



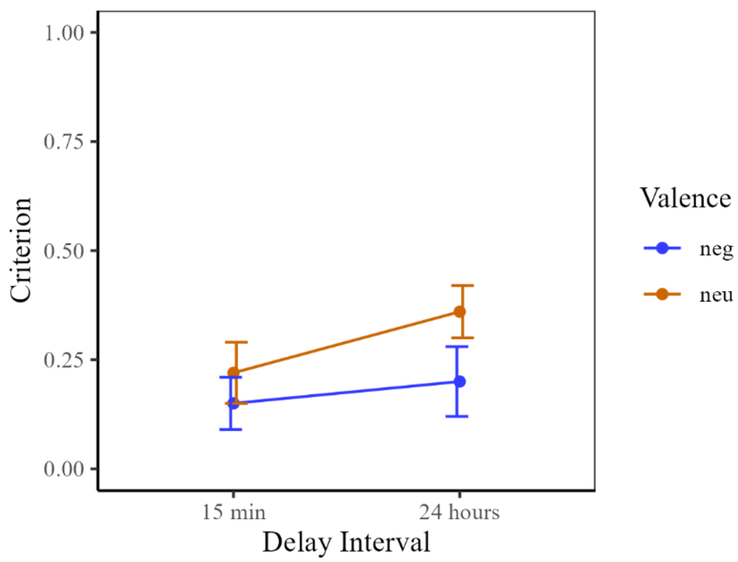
Note. False alarm rates for each valence condition across delay intervals. Error bars denote the standard error of the mean.

As previously mentioned, the response criterion reflects an individual's bias in categorizing an item as old or new in a recognition test (MacMillan & Creelman, 2004), where higher values indicate a more conservative criterion (i.e., a greater tendency to judge items as new). As the delay between encoding and retrieval increases, participants' response criteria generally become more lenient, indicating a greater tendency to judge items as old (Singer & Wixted, 2006).

In the 2 (Valence) x 2 (Delay) ANOVA with the response criterion as the dependent variable, there was no significant interaction between Delay and Valence, $F(1, 39.97) = 0.14$ $p = .70$, $\eta^2_p = .003$ (see Figure 10). There was a significant main effect of Valence, $F(1, 39.97) = 5.93$, $p = .02$, $\eta^2_p = .13$, but no main effect of delay, $F(1, 38.3) = 1.56$ $p = .21$, $\eta^2_p = .04$. There was no significant difference in response criterion between valence conditions at the 15-minute delay, $t(34) = -0.92$, $p = .37$. However, the response criterion for neutral valence was greater than that for negative valence at the 24-hour delay $t(34) = -2.07$, $p = .05$, indicating that participants' response criteria for neutral environmental sounds were more conservative than those for negative environmental sounds.

Figure 10.

Response Criterion Over Time



Note. Response criterion *c* for each valence condition across delay intervals. Error bars denote the standard error of the mean.

Analysis of Recollection and Familiarity

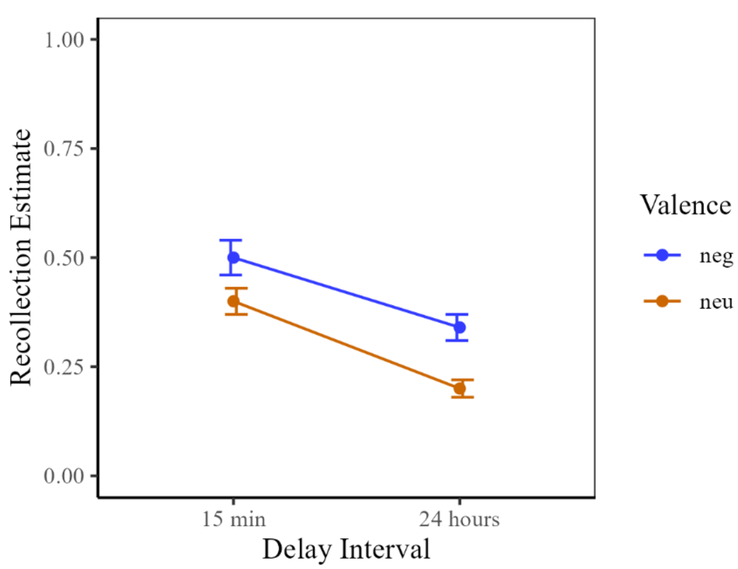
To assess our prediction that forgetting for recollection, but not familiarity, would be slowed for emotional sounds relative to neutral sounds, we examined differences in forgetting across valence groups for estimates of recollection and familiarity. We excluded data from any participants who had initial estimates near floor (<.2) at the 15-minute delay as an initial step in the analysis because there is a restricted ability to detect forgetting when initial memory scores are low.

Recollection

We first excluded seven participants from the analyses for recollection because they had initial recollection estimates near floor (< .2) at the 15-minute delay. The data for the remaining 28 participants was included in analyses for recollection. Consistent with a previous study of emotional sounds (Morrow et al., 2022), simple comparisons found that recollection estimates were higher for negative sounds than for neutral sounds at the initial 15-minute delay interval, $t(27) = 3.31$, $p = .003$. Additionally, there was no significant difference in recollection estimates across valence conditions at the 24-hour delay interval, $t(27) = 5.1$, $p < .001$(see Figure 11).

Figure 11.

Recollection Over Time

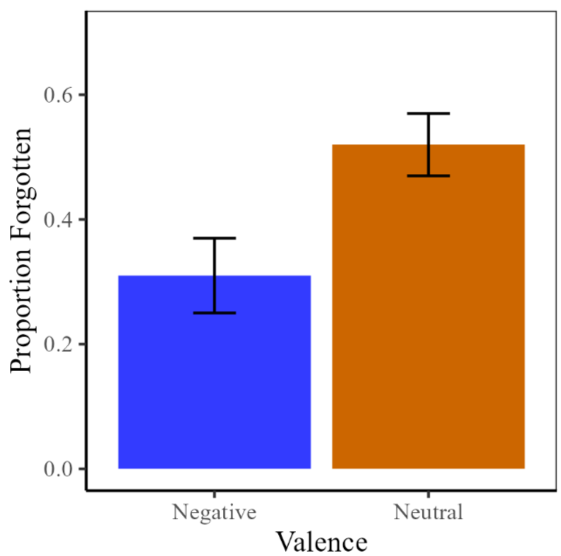


Note. Recollection estimates for each valence condition across delay intervals. Error bars denote the standard error of the mean.

We assessed proportional forgetting for recollection estimates because of these significant differences at the initial 15-minute delay interval. Consistent with our prediction, there was significantly less forgetting for negative environmental sounds relative to neutral environmental sounds, $t(27) = -3.03$, $p = .005$, $d = -0.57$ (see Figure 12).

Figure 12.

Proportional Forgetting for Recollection



Note. Proportional forgetting for recollection estimates. Error bars denote the standard error of the mean.

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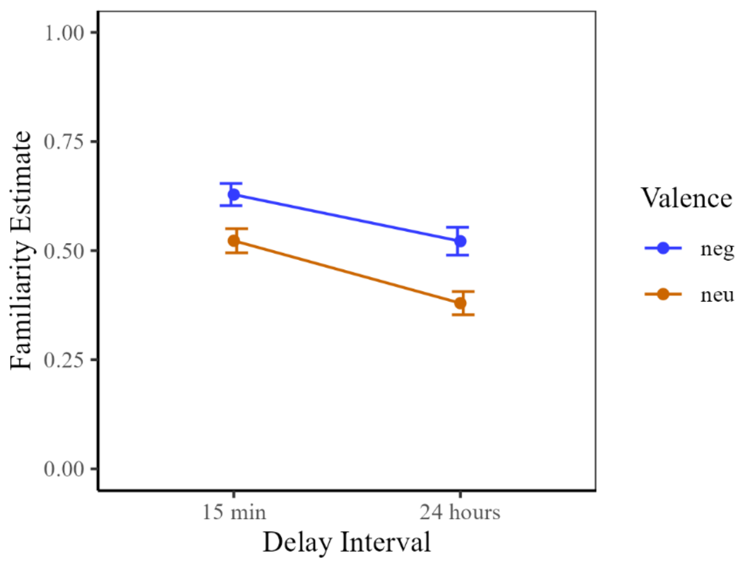
The ANOVA of the original recollection estimates found no significant interaction between Valence and Delay, $F(1,27) = 2.2$, $p = .15$, $\eta^2_p = .07$. There were significant main effects for both Valence, $F(1, 27) = 27.91$, $p < .001$, $\eta^2_p = .51$, and Delay, $F(1, 36.15) = 86.11$, $p < .001$, $\eta^2_p = .76$.

Familiarity

We first excluded nine participants with initial familiarity estimates near floor (< .2) at the 15-minute delay because initial near-floor memory scores restricted the ability to detect forgetting across the subsequent two delay intervals. The data for the remaining 26 participants was included in analyses for familiarity. Familiarity estimates were higher for negative than for neutral sounds at the initial 15-minute delay interval, $t(25) = 3.3$, $p < .001$, and at the 24-hour delay interval, $t(25) = 3.3$, $p < .001$ (see Figure 13).

Figure 13.

Familiarity Over Time



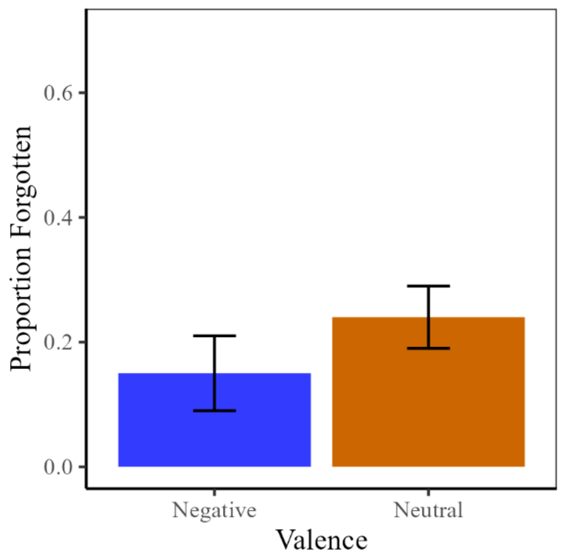
Note. Familiarity estimates for each valence condition across delay intervals. Error bars denote the standard error of the mean.

Because familiarity estimates differed at the initial time point, we assessed proportional forgetting scores. Consistent with our prediction, there was no significant difference in proportional forgetting for familiarity estimates between the negative and neutral conditions,

$t(25) = -1.02$, $p = .32$, $d = -0.2$, indicating that forgetting for familiarity was similar for negative and neutral environmental sounds (see Figure 14).

Figure 14.

Proportional Forgetting for Familiarity



Note. Error bars denote the standard error of the mean.

For the ANOVA with the original familiarity estimates as the dependent variable, there was no significant interaction between Valence and Delay, $F(1, 25) = 0.52$, $p = .48$, $\eta^2_p = .02$ (see Figure 13. There were significant main effects for both Valence $F(1, 25) = 30.98$, $p < .001$, $\eta^2_p = .55$ and Delay, $F(1, 25) = 33.23$, $p < .001$, $\eta^2_p = .57$.

Discussion

In the current study, we examined the extent to which emotional environmental sounds are forgotten more slowly than neutral ones by assessing recognition memory after both a 15-minute and 24-hour delay. Emotion enhanced recognition memory for environmental sounds, and this effect was evident in both recollection and familiarity measures. Negative environmental sounds exhibited slower forgetting relative to neutral sounds for the recollection component of recognition memory, whereas forgetting rate did not differ for the familiarity component. Our study was not designed to test specific theories regarding the mechanisms driving slowed forgetting (e.g., McGaugh, 2004; Yonelinas & Ritchey, 2015; Bowen et al., 2018). However, as there is limited empirical data on emotional memory for auditory stimuli, the current findings contribute to knowledge of memory and forgetting for emotional auditory environmental sounds. In the following section, we discuss these findings with regard to our predictions and the previous relevant literature.

Concerning the effect of emotion on recognition memory for environmental sounds, we observed that overall recognition memory performance was higher for negative sounds compared to neutral sounds, both the 15-minute and 24-hour delays. This enhancement effect was evident in both d’ and corrected recognition, in line with our initial predictions and corroborating the findings of Morrow et al. (2022). This memory advantage for negative environmental sounds is also consistent with the broader literature on emotional memory that has found that emotion enhances recognition memory in a wide variety of experimental contexts in studies that have used visual stimuli (Hamann, 2001; Labar & Cabeza, 2006).

Our finding that emotional effects on memory were found for both recollection and familiarity components of recognition is less consistent with the prior literature. The finding of enhanced familiarity for negative vs. neutral environmental sounds contrasts with the findings of Morrow et al. (2022), whose methodology closely resembled ours. Given that the present study and Morrow et al., (2022) are the only studies that have examined recollection and familiarity for emotional environmental sounds, it remains unclear why our study found the enhanced familiarity for emotional environmental sounds. Possible explanations for this effect could be related to differences in experimental procedures, stimuli characteristics, or an inherent tendency of emotional environmental sounds to be remembered with a sense of familiarity (Bigelow & Poremba, 2014; Burrell et al., 2016; Gloede & Gregg, 2017; 2019).

Because the emotional enhancement of memory we observed at the short delay interval occurred at a delay that was too short for consolidation processes to have played a significant role, this memory enhancement for emotional environmental sounds is likely due to the processes that have previously been proposed to enhance memory at the time of encoding, including increased attention and semantic elaboration compared to neutral sound stimuli (Talmi, 2013; Mather & Sutherland, 2011).

Concerning the effect of emotion on forgetting for recognition memory of environmental sounds, contrary to our initial prediction and the findings from numerous behavioral studies using visual stimuli, which have found that emotion slows forgetting in recognition memory (Yonelinas & Ritchey, 2015), our investigation revealed no significant difference in forgetting between negative and neutral environmental sounds on measures of overall recognition memory performance (corrected recognition and d’). While slowed forgetting in recognition memory for visual emotional stimuli is readily observed after 24 hours (Yonelinas & Ritchey, 2015), it is also possible that the emotional enhancement of recognition memory for environmental sounds may not emerge until more time passes, such as 72 hours or 1 week. This would suggest that modulatory effect of emotion on auditory stimuli may be less pronounced compared to visual stimuli. Researchers should use several variations of recognition paradigms to understand the nature of these effects fully.

Concerning the effect of emotion on forgetting in the recollection and familiarity components of recognition memory, we found that emotion had different effects on forgetting for the recollection and familiarity components of recognition. Specifically, negative environmental sounds were forgotten slower than neutral sounds, but this effect was specific to recollection, and no significant differences were observed in forgetting for familiarity across valence conditions. This pattern is consistent with previous research on visual stimuli, suggesting that emotion may selectively slow forgetting for recollection, but not familiarity. The finding of emotion slowing forgetting for recollection appears consistent with the proposals of the emotional binding account (Yonelinas & Ritchey, 2015) and the NEVER forget model (Bowen et al., 2018).

Both models (Yonelinas & Ritchey, 2015; Bowen et al., 2018) emphasize that recollection for visual emotional stimuli is accompanied by memory for specific details, item-intrinsic and sensory details respectively. Particularly, the NEVER forget model (Bowen et al., 2018) predicts that enhanced sensory processing at the encoding, and reactivation and recapitulation of sensory activations during the storage and retrieval, of negative emotional memories modulates the slowed forgetting for recollection. With regard to emotional environmental sounds, neuroimaging findings indicate that, during encoding, environmental sounds that are vocal (e.g., crying) and non-vocal (e.g., breaking glass) elicit heightened co-activation and connectivity between the amygdala and auditory cortex (Kumar et al., 2012; Fruhholz et al., 2013; 2015). Moreover, it has been suggested that amygdala connectivity with sensory regions is critical for the storage and retrieval of auditory emotional memories, whereby activation in the auditory cortex can modulate amygdala activity and increase the likelihood that the auditory emotional memory is retrieved (Grosso et al., 2015). If enhanced sensory processing facilitates the slowed forgetting for recollection, as predicted in the NEVER forget model

(Bowen et al., 2018), then it follows that recollection for negative environmental sounds would enhanced and accompanied by memory of more sensory details relative to neutral environmental sounds. However, ultimately, since our study did not examine the specific details being remembered, we cannot make any direct claims regarding whether recollection for emotional environmental sounds is accompanied by greater memory for sensory details (Bowen et al., 2018) or item-intrinsic details (Yonelinas & Ritchey, 2015) that may contribute to the slowed forgetting for recollection.

Notably, slowed forgetting for recollection for emotional environmental sounds was only evident in the proportional forgetting analyses and not in the ANOVA, which contrasts with previous literature showing significant effects of emotion on study-test delay interval in ANOVA analyses. Therefore, although we interpret the proportional forgetting results as suggestive of slowed forgetting for recollection for emotional environmental sounds relative to neutral ones, reconciling the proportional forgetting results with the ANOVA results complicates the interpretation of the findings.

One factor contributing to the discrepancy between the two analyses is the scaling effects associated with ANOVA when initial memory performance varies between conditions. When using ANOVA, for the condition that exhibits higher initial memory performance, the subsequent decline in memory over time may appear steeper even if the rate of forgetting is similar to or slower than in conditions with lower initial memory performance. Future studies should reexamine this question under conditions where matched initial recollection levels are matched across valence conditions, without converting to proportional forgetting scores, for a more robust understanding of the effect of emotion on forgetting for recollection.

Another significant factor to consider when interpreting our findings, particularly regarding recollection and familiarity, is the potential confound of memory strength with the distinction between recollection and familiarity. Some behavioral studies using the remember-know paradigm have reported that Remember judgments are associated with higher confidence and accuracy compared to Know judgments (Tulving, 1985; Dunn, 2004; Wixted & Stretch, 2004; Wixted & Squire, 2010). These findings have led to discussions regarding potential methodological confounds (e.g., the instructions for the remember-know paradigm) or and consideration of whether recollection and familiarity are not dissociable processes and instead represent a continuum of memory strength (Migo et al., 2012; Wixted & Squire, 2011). While we interpret the slowed forgetting for negative sounds to be recollection-specific, additional measures or analyses would be necessary assess whether there are emotion effects on memory strength for environmental sounds and the extent to which they can be differentiated from emotion effects on recollection and familiarity for environmental sounds.

The current study has several limitations. First, there was considerable variability in initial memory performance across participants. While some individuals demonstrated nearly perfect memory performance (near-ceiling levels) for recollection or familiarity during the initial recognition test, others demonstrated very poor memory performance (near-floor levels). To address this issue, we omitted participants with near-floor memory estimates for recollection (6 participants) and familiarity (9 participants) from their respective analyses, and kept those participants' data included in the analyses for all other memory analyses. However, including participants with low memory performance in all other analyses can introduce a confounding effect that may bias the results of those analyses. In future analyses of this data, a more comprehensive approach would be to exclude participants from all memory measures if they exhibit near-floor memory performance on any memory measure at the short delay. It is worth noting that the participants excluded from recollection analyses differed from those excluded from familiarity analyses, and vice versa; thus, 15 participants would be removed from the analyses, reducing the sample size to 20. Thus, for future analyses, increasing the sample size would also be necessary to ensure sufficient statistical power.

Second, the fact that memory performance at the shortest delay interval was higher for negative vs. neutral environmental stimuli complicates the interpretation of emotion effects on forgetting due to well-known issues related to scaling effects in forgetting studies (Wixted, 2004). Future studies should examine forgetting for environmental sounds under conditions where initial memory performance across all memory measures are matched across valence conditions. Given previous research indicating that cognitive factors associated with emotional stimuli enhance encoding processes, matching initial memory performance would likely require researchers to identify and control for the stimuli characteristics that may enhance encoding processes for emotional environmental sounds, as done in previous studies with visual stimuli (e.g., Talmi & McGarry, 2012).

Finally, there is a limited number of emotional environmental sounds from standardized affective databases, which made it difficult to equate stimuli characteristics and ensure semantically diverse stimuli across valence conditions. While there are several normed databases of emotional pictures and words commonly used in memory studies to assess emotional effects (e.g., Lang et al., 1997 [IAPS], Kurdi et al., 2017 [OASIS], Marchewka et al., 2014 [NAPS]), the IADS is currently the only database with normative arousal and valence ratings for affective environmental sounds (Bradley & Lang, 1999 [IADS], Bradley & Lang, 2007 [IADS-2]; Yang et al., 2018 [IADS-E]). Even with the most recent expansion of IADS (Yang, 2018), there is a scarcity of semantically distinct environmental sounds. Considering these constraints, we selected stimuli from online sources that did not have prior normative ratings. Therefore, it is possible that stimuli did not consistently elicit the intended emotional responses in some subjects or that perceptual or semantic features of some stimuli disproportionally biased memory. Future empirical efforts should go towards developing a more comprehensive standardized database of affective environmental sounds to facilitate research that would allow for consistent and credible comparisons among researchers (Yang, 2018).

In summary, our study extends the existing literature on emotional effects on recognition memory with visual stimuli by providing evidence of emotional effects on these processes using auditory stimuli. The current study contributes to the understanding of forgetting in emotional episodic memory. The current results corroborate prior findings that emotion boosts recollection for environmental sounds at an immediate delay (Morrow et al., 2022), However, some of our findings, that familiarity was enhanced for emotional environmental sounds and that forgetting was not slowed for environmental sounds, are not consistent with existing theoretical frameworks (McGaugh, 2000; Yonelinas & Ritchey, 2015). Finally, our study provides preliminary evidence that emotional environmental sounds are forgotten slower than neutral environmental stimuli, but slower forgetting is only evident in the recollection component of recognition memory. These findings indicate that existing theories of forgetting for emotional episodic memory in humans, which are primarily derived from evidence in the visual modality, should take into account the influence of domain-specific sensory processing in the emotional enhancement of memory.

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Appendix A

Sound Identification Criteria (adapted from Marcell, 2000)

A description of a sound was judged as correct when the response was one of the following:

(1) A synonym for the sound label (e.g., "tea pot" for "tea kettle;" "mule" for "donkey").

(2) A description that accurately captured the meaning of the sound source or the conceptual nature of the sound (e.g., "bomb" or "cannon" for "explosion;" "bouncing ball" for "basketball").

(3) An obvious misspelling (e.g., "cash registrar" for "cash register;" "symbol" for "cymbal").

(4) A variation in word order (e.g., "crying baby" for "baby crying;" "breaking of glass" for "glass breaking").

(5) A word or phrase with a different grammatical ending but the correct root word (e.g., a plural version of a singular sound source such as "ducks" for "duck;" a variation in tense such as "a car crashed" for "*cars* crashing;" other root-preserving grammatical modifications such as "bag piper" for "bagpipes")

(6) A correct identification with extraneous information (e.g., "moving train whistle" for "train;" "person whistling to dog" for "whistle").

(7) An acceptable label given as the second of two different responses (e.g., "either drums or bongos" for "bongos")

(8) An unanticipated description that was subsequently judged as an acoustically precise alternative interpretation (e.g., "fish tank air pump" for "water bubbling;" "metronome" for "clock ticking").

Appendix B

Table D1. *Sound Stimuli Characteristics*

Negative Sounds: Stimuli Sources and Normative Valence, Arousal, and Identification Rate

Negative Sound Pair	Pair Letter	Stimulus Source	Valence Rating (n = 13)	Arousal Rating (n = 13)	Identification Rate (n = 6)
Alert	a	Pixabay	2.46	5.85	0.83
Alert	b	Youtube	2.46	6.23	0.67
Angry cat	b	Youtube	2.77	6.15	1.00
Angry cat	a	Pixabay	2.46	5.46	1.00
Annoying kid	b	Recorded by Sara Wong	3.08	6.00	0.50
Annoying kid	a	IADS-E	3.08	4.92	0.50
Banging door	b	Freesound	3.46	5.00	0.83
Banging door	a	Youtube	2.54	7.00	0.83
Belch	b	Youtube	2.69	5.23	0.83
Belch	a	IADS-2	2.92	4.54	1.00
Bird squawk	b	Pixabay	3.77	4.77	1.00
Bird squawk	a	Pixabay	2.15	6.85	0.50
Broken radio	a	Pixabay	3.31	5.62	0.83
Broken radio	b	Pixabay	3.08	5.92	1.00
Car crash	a	Youtube	3.23	5.00	1.00
Car crash	b	IADS-2	1.69	7.62	1.00
Chewing	a	Pixabay	2.77	5.69	1.00
Chewing	b	Pixabay	2.23	6.08	1.00
Cough	a	Pixabay	1.62	6.77	1.00
Cough	b	Pixabay	3.15	4.62	1.00
Crowd panicking	b	Youtube	2.38	6.23	1.00
Crowd panicking	a	FreeSound	2.85	6.15	0.83
Crying	a	IADS-2	1.77	6.69	1.00
Crying	b	Youtube	2.77	5.54	1.00
Donkey	b	FreeSFX	2.69	5.54	0.67
Donkey	a	FreeSFX	3.85	5.00	0.67
Drill	a	EpicSounds	2.54	5.85	0.83
Drill	b	EpicSounds	2.92	6.00	1.00
Drowning	b	Zapsplat	1.69	6.23	0.83
Drowning	a	FreeSFX	2.31	6.38	0.83
Emergency vehicle	a	IADS-2	2.69	6.38	1.00
Emergency vehicle	b	Pixabay	2.08	6.46	1.00
Explosion	b	EpicSounds	2.85	5.38	1.00
Explosion	a	IADS-2	2.23	6.85	0.83
Flatline	a	Pixabay	2.62	6.23	0.83
Flatline	b	Freesound	2.31	6.23	0.67
Flies	a	Pixabay	2.54	6.23	1.00
Flies	b	IADS-2	2.54	5.46	1.00
Fussy baby	b	Pixabay	3.62	4.85	1.00
Fussy baby	a	FreeSFX	3.31	5.77	1.00
Glass shattering	a	Youtube	3.46	4.69	1.00
Glass shattering	b	Pixabay	3.15	5.38	1.00
Glitch	a	EpicSounds	2.92	5.31	0.67
Glitch	b	Pixabay	2.54	5.00	1.00
Groan	b	Pixabay	1.77	7.00	0.67
Groan	a	Pixabay	2.31	5.92	0.67
Growl	b	Pixabay	3.15	5.54	0.67
Growl	a	IADS-E	2.38	6.69	0.67
Gun shots	a	Pixabay	2.15	6.54	1.00
Gun shots	b	EpicSounds	2.08	6.46	1.00

Hospital	a	Pixabay	2.69	6.62	0.83
Hospital	a	FreeSound	2.77	5.54	0.67
Human Fight	a	EpicSounds	2.23	5.69	1.00
Human Fight	b	Pixabay	2.46	5.92	1.00
Metal gate	a	FreeSFX	2.00	6.15	0.67
Metal gate	b	FreeSound	3.08	4.69	0.83
Monkey screech	b	Youtube	2.54	5.62	1.00
Monkey screech	b	Pixabay	3.92	5.38	1.00
Objects crashing	b	Youtube	2.23	5.77	0.50
Objects crashing	a	IADS-2	3.46	5.31	0.67
Panting	b	EpicSounds	2.62	6.46	1.00
Panting	a	EpicSounds	4.00	5.38	1.00
Pig grunts	b	Youtube	2.62	5.77	0.83
Pig grunts	a	EpicSounds	2.23	6.00	1.00
Pooping	a	Youtube	2.00	6.00	0.83
Pooping	b	Pixabay	2.31	5.00	0.67
Revving engine	a	EpicSounds	2.31	5.85	0.83
Revving engine	b	EpicSounds	3.77	5.15	1.00
Scraping utensils	b	FreeSound	2.15	6.08	0.50
Scraping utensils	b	Freesound	2.23	6.00	0.67
Scream	a	IADS-2	1.85	6.92	0.67
Scream	b	IADS-2	1.69	7.00	0.83
Sharpening knife	a	Pixabay	3.85	4.85	1.00
Sharpening knife	b	Zapsplat	2.54	6.31	0.83
Slurping	b	Pixabay	3.23	5.38	1.00
Slurping	a	Youtube	2.62	5.92	0.67
Snot	b	Pixabay	2.38	5.08	0.67
Snot	a	Pixabay	2.31	5.54	0.67
Spitting	a	Pixabay	2.77	5.08	1.00
Spitting	b	Youtube	3.08	5.08	1.00
Squeaky glass	a	EpicSounds	2.08	7.69	0.83
Squeaky glass	a	FreeSound	2.23	6.00	1.00
Strangle	b	Youtube	2.15	6.77	1.00
Strangle	a	Youtube	2.15	7.54	0.83
Tantrum	a	Youtube	2.31	6.15	0.67
Tantrum	a	Youtube	2.23	6.77	0.50
Traffic	a	FreeSound	3.54	5.23	1.00
Traffic	b	EpicSounds	3.23	6.46	1.00
Vomit	a	IADS-2	1.54	6.92	1.00
Vomit	b	Pixabay	1.62	6.92	1.00
Whimpering	a	EpicSounds	2.46	5.38	0.83
Whimpering	b	Freesound	3.00	4.69	1.00
Whip	b	FreeSFX	3.31	5.23	0.67
Whip	b	Pixabay	2.77	5.85	0.67
Whispering	b	Youtube	2.00	8.00	1.00
Whispering	a	Youtube	2.38	6.92	1.00

Note. IADS-2 = The International Affective Digitized Sounds 2; IADS-E = The International Affective Digitized Sounds, Expanded Version; Pixabay = 72ixabay.com; FreeSound = freesound.org; Youtube = youtube.com; EpicSounds = epidemicsound.com; FreeSFX = freesfx.com; Zapsplat = zapsplat.com

Table D2. *Neutral Sounds: Stimuli Sources and Normative Valence, Arousal, and Identification Rate*

Neutral Sound Pair	Pair Letter	Stimulus Source	Valence Rating (n = 13)	Arousal Rating (n = 13)	Identification Rate (n = 6)
Ball bouncing	a	Pixabay	5.62	3.46	1.00
Ball bouncing	b	Pixabay	5.62	3.38	0.83
Bells	a	IADS-E	5.00	3.69	1.00
Bells	b	EpicSounds	5.85	3.23	1.00
Brushing teeth	a	Pixabay	4.92	2.85	1.00
Brushing teeth	b	Pixabay	4.62	3.38	1.00
Bubbles	a	Pixabay	4.31	2.15	1.00
Bubbles	b	IADS-2	5.23	3.00	0.83
Camera	a	Pixabay	5.62	3.69	0.83
Camera	b	Pixabay	5.54	3.54	0.83
Car door	a	FreeSFX	5.00	2.46	1.00
Car door	b	Pixabay	5.46	2.92	1.00
CD	a	FreeSound	5.38	2.62	0.50
CD	b	Pixabay	4.38	3.85	0.67
Chair sliding	a	Pixabay	4.31	2.77	1.00
Chair sliding	b	Pixabay	4.62	2.69	0.67
Chickens	a	Pixabay	4.77	3.46	1.00
Chickens	b	Freesound	5.23	3.08	1.00
Chopping food	a	EpicSounds	5.46	2.77	1.00
Chopping food	b	IADS-E	5.62	2.85	1.00
Clanking cans	a	Zapsplat	4.85	3.15	1.00
Clanking cans	b	Zapsplat	5.23	3.00	0.67
Clock	a	Pixabay	4.77	2.85	0.83
Clock	b	Pixabay	4.77	2.85	0.83
Coins	a	FreeSound	4.77	3.00	0.67
Coins	b	Pixabay	5.38	2.62	0.50
Cow	a	IADS-2	4.69	3.54	0.83
Cow	b	IADS-E	5.00	3.69	1.00
Crickets	a	IADS-2	5.08	3.62	0.50
Crickets	b	IADS-E	5.77	3.85	1.00
Dog	a	Pixabay	5.77	3.69	1.00
Dog	b	IADS-E	4.54	3.92	1.00
Dripping water	a	EpicSounds	5.46	3.62	1.00
Dripping water	b	Pixabay	5.85	3.31	0.50
Elevator	a	Pixabay	5.38	2.92	0.67
Elevator	b	EpicSounds	4.62	3.00	0.50
Flushing	a	IADS-E	4.31	3.00	0.83
Flushing	b	EpicSounds	4.08	3.69	0.50
Footsteps	a	IADS-E	4.62	3.62	1.00
Footsteps	b	IADS-E	4.85	4.00	0.50
Horse gallop	a	EpicSounds	5.62	3.46	1.00
Horse gallop	b	Pixabay	5.31	3.46	1.00
Lighter	a	Pixabay	4.92	3.92	0.67
Lighter	b	Pixabay	5.23	2.92	1.00
Lock	a	Pixabay	4.77	3.23	0.83
Lock	b	IADS-E	4.38	2.69	1.00
Microwave	a	Pixabay	5.77	3.54	0.67
Microwave	b	Pixabay	5.00	2.77	1.00
Motor	a	Pixabay	5.15	3.00	0.67
Motor	b	Youtube	4.62	3.85	1.00
Opening window	a	Pixabay	4.62	3.15	0.50
Opening window	b	Pixabay	5.00	2.77	0.50
Page Flip	a	EpicSounds	4.92	3.23	0.83
Page Flip	b	Pixabay	4.77	3.62	1.00
Phone dial	a	Pixabay	4.46	3.62	1.00

Phone dial	b	FreeSFX	5.38	2.62	0.50
Phone Ring	a	Pixabay	4.62	3.92	0.83
Phone Ring	b	EpicSounds	5.08	3.31	1.00
Plane	a	IADS-E	4.46	3.69	0.67
Plane	b	Youtube	5.31	3.92	0.83
Pour	a	FreeSFX	5.15	3.62	0.67
Pour	b	EpicSounds	5.54	2.46	0.83
Printer	a	Pixabay	5.15	3.15	0.83
Printer	b	Pixabay	5.23	3.46	1.00
Ratchet	a	Pixabay	4.85	3.00	1.00
Ratchet	b	Pixabay	4.85	4.00	0.50
Rattle	a	Pixabay	5.00	3.54	0.67
Rattle	b	Pixabay	4.85	3.31	0.67
Rewind	a	Youtube	5.31	3.69	0.83
Rewind	b	Pixabay	4.62	3.46	0.83
Ripping	a	Pixabay	4.46	3.46	0.83
Ripping	b	Pixabay	4.77	3.46	1.00
Rolling object	a	Pixabay	4.54	3.54	0.67
Rolling object	b	Pixabay	4.54	3.23	1.00
Scrubbing	a	Pixabay	5.15	4.00	0.67
Scrubbing	b	Pixabay	5.31	2.77	0.83
Sheep	a	Pixabay	5.77	3.00	0.83
Sheep	b	Pixabay	4.77	3.85	1.00
Shovel	a	Youtube	5.08	2.54	0.50
Shovel	b	Pixabay	4.69	3.31	0.83
Spray	a	Pixabay	5.62	3.00	0.67
Spray	b	IADS-2	5.31	3.62	0.83
Tape	a	Pixabay	5.69	2.46	0.67
Tape	b	FreeSound	4.62	3.15	0.83
Train	a	Pixabay	5.15	3.38	1.00
Train	b	Pixabay	5.23	3.46	1.00
Truck	a	Pixabay	4.77	3.54	1.00
Truck	b	Pixabay	4.77	3.08	0.50
Typing	a	Pixabay	5.08	3.08	0.83
Typing	b	EpicSounds	4.77	2.92	1.00
Vending machine	a	Pixabay	4.92	3.77	0.67
Vending machine	b	IADS-E	5.08	3.23	1.00
Writing	a	FreeSound	5.54	3.38	0.50
Writing	b	Pixabay	5.00	4.00	0.67
Zipper	a	Pixabay	4.85	2.54	0.67
Zipper	b	Pixabay	5.31	3.62	1.00

Note. IADS-2 = The International Affective Digitized Sounds 2; IADS-E = The International Affective Digitized Sounds, Expanded Version; Pixabay = 74ixabay.com; FreeSound = freesound.org; Youtube = youtube.com; EpicSounds = epidemicsound.com; FreeSFX = freesfx.com; Zapsplat = zapsplat.com

Appendix C

Table D3*: Sound Pairs Listed in Descending Order of Perceptual Similarity*

Negative Sound Pair	Mean Rating	Neutral Sound Pair	Mean Rating
Groan	3.89	Ratchet	3.89
Donkey	3.83	Cow	3.83
Cough	3.67	Sheep	3.67
Metal gate	3.67	Shovel	3.67
Pig grunts	3.67	Clanking cans	3.56
Spitting	3.67	Printer	3.56
Tantrum	3.67	Pour	3.50
Flatline	3.56	Coins	3.44
Flies	3.56	Chopping food	3.33
Fussy baby	3.56	Tape	3.33
Snot	3.50	Brushing teeth	3.33
Angry cat	3.44	Page Flip	3.22
Emergency vehicle	3.44	Chickens	3.17
Sharpening knife	3.44	Horse gallop	3.11
Belch	3.22	Rattle	3.11
Crying	3.22	Ripping	3.11
Drill	3.22	Vending machine	3.11
Hospital	3.22	Car door	3.00
Panting	3.22	Clock	3.00
Scream	3.22	Elevator	3.00
Car crash	3.11	Motor	3.00
Human Fight	3.11	Truck	3.00
Alert	3.00	Zipper	3.00
Banging door	3.00	CD	2.89
Scraping utensils	3.00	Flushing	2.89
Bird squawk	2.89	Lock	2.89
Revving engine	2.89	Spray	2.89
Whimpering	2.89	Dog	2.83
Crowd panicking	2.83	Microwave	2.78
Pooping	2.78	Dripping water	2.67
Chewing	2.67	Scrubbing	2.67
Monkey screech	2.67	Train	2.67
Strangle	2.67	Camera	2.56
Traffic	2.67	Plane	2.56
Vomit	2.67	Typing	2.56
Broken radio	2.56	Footsteps	2.56
Objects crashing	2.56	Writing	2.56
Slurping	2.50	Bells	2.50
Squeaky glass	2.50	Rolling object	2.44
Drowning	2.44	Opening window	2.44
Explosion	2.44	Chair sliding	2.33
Growl	2.44	Lighter	2.33
Whip	2.44	Rewind	2.33
Annoying kid	2.33	Ball bouncing	2.22
Gun shots	2.33	Bubbles	2.17
Whispering	2.33	Crickets	2.11
Glass shattering	1.78	Phone dial	1.67
Glitch	1.50	Ringing	1.50

Appendix D

SAM Scale Instructions (Encoding Task)

In this task, you will be rating your emotional response to various sounds using two rating scales. These two scales show figures displaying feelings that vary along a continuum. For each rating, please select the number between 1 and 9 that corresponds to how you feel when listening to the sound.

The first scale asks about how positive or negative you feel when listening to the sound. Depending on how the sound makes you feel, you'll select a number between 1 and 9 with 1 indicating that you feel "Very Negative", 5 indicating feeling "Neutral", and 9 indicating feeling "Very Positive". By negative, I mean feeling any kind of negative emotion such as sadness, disgust, fear, anger, discomfort, etc. By positive, I mean feeling any kind of positive emotion such as happy, pleased, satisfied, contented, or hopeful. Please feel free to use all of the ratings, including both ends of the scale. Also, remember that you can select numbers between the figures to make more precise ratings.

The second scale asks about the level of emotional arousal you feel when hearing the sound. What we mean by emotional arousal is that we'd like you to decide how strong your emotional feelings are when you hear the sound, using this scale that goes from 1, lowest arousal, to 9, highest arousal. Higher numbers mean that you're feeling stronger emotional arousal, regardless of whether it's positive or negative emotion .

If you feel a STRONG EMOTION when you hear the sound, then you would choose a number towards the higher end of the scale, like a 7, 8, or 9. And if you feel WEAK OR NO EMOTION when you hear the sound, then you would choose a number towards the lower end of the scale, like a 3, 2, or 1. If you feel MEDIUM or MODERATE levels of EMOTION, then you would choose a number near the middle of the scale, like 4, 5, or 6.

So, high emotional arousal means that the sound makes you feel a strong pleasant OR an unpleasant emotion, or some other mix of strong emotions. Strong happiness as well as strong sadness, disgust, or anger, or other emotion would also correspond to high emotional arousal. People usually say they are stimulated, wide-awake, or excited when they're feeling high emotional arousal. On the other hand, people usually say they relaxed, calm, or unaroused when they're feeling low emotional arousal. Please feel free to use all of the ratings, including both ends of the scale. Also, remember that you can select numbers between the figures to make more precise ratings.

Appendix E

Remember-Familiar Recognition Memory Test Instructions

Now we have a third task. Sounds will play again one at a time. Some sounds were presented to you earlier in the study and some sounds are new. After each sound plays, you will indicate whether or not you recognize the sound as one you heard earlier in this session. You'll choose between 6 options: For Definitely new, press 1. Probably new, press 2. Not sure, press 3. Probably old, press 4. Definitely old, press 5. Remember, press 6.

You should respond "Remember," or 6, if you think the sound is one you heard before in the study, AND you can recollect any information about what happened at the time you heard the sound. A "Remember" response means you can recollect at least one thing from when the sound was presented before. For example, maybe you can recollect how it made you feel, what you were thinking about at that time, or something that happened in the room. In other words, you should respond "Remember" if the sound brings back to mind any particular association, feeling, thought, or detail from when you heard the sound before. For example, if you hear a song on the radio, you may think, "What is this song? Oh yes, it is the song that was playing when I was at the grocery store." That would be a "Remember" response. In the context of this task, if you hear the sound of kids laughing, you may think . "oh yes, I remember hearing this in the first task we did and thinking of my little sister on the playground"

You should respond with the other 5 options depending on how confident you are that you have heard the sound before. You would select one of the "new" options if you think you have not heard the sound before. You would select one of the "old" options if you think you have heard the sound before but you can't consciously recollect anything about the details of its actual occurrence or what you experienced from when it was presented.

So the difference between “Definitely old” and “Remember” is that “Definitely old” would mean that you are highly confident that you have heard the sound before but you cannot recollect any details from when the sound was presented before, while “Remember” would mean that you think you have heard the sound before and you can recollect any particular association, feeling, thought, or detail from when you heard the sound before.

Please be sure to try to use all of the response options at some point during the study. Some of the sounds presented during this task may sound similar to each other, so it is important to listen closely when making your memory judgment.

Appendix F

Post-Test Survey Questions

1. How many hours of sleep did you get last night?
2. How stressed are you today?
3. How stressed were you yesterday?
4. How much effort did you put into this experiment?
5. Did you expect there to be a memory test during session 1?
6. Did you expect there to be a memory test during session 2?
7. Did you try to prepare or study for the memory test in session 2?
8. Did you feel like you could hear all the sounds clearly?
9. If so, what percentage of the sounds were difficult to hear? – Percent
10. In the study you were asked to make a memory judgment. #5 indicated the sound was definitely old and #6 indicated Remember. How would you describe the difference between these two choices?
11. Was there anything about the experiment instructions that you found confusing?
12. When you felt yourself unsure if the sound was new or old, was there something about the sounds or the experiment's design that made you feel that way?
13. When you were remembering the videos, did you find yourself remembering the specific visual or auditory details from the video or did you find yourself remembering the general topic/meaning/gist of the rest of the video?
14. Have you had any musical training?
15. If you have had musical training, for how many years?
16. How many sounds did you recognize what it was of? – Percent

17. After you left the lab yesterday, did you think back about your experience?
18. Did you talk about your experience with friends or family?
19. Did you write about your experience, e.g. in social media?
20. Can you tell me a little about what you thought, talked about, or wrote about?
21. Did you think, talk about, or write about any specific sound?
22. Did you have any specific expectations about what we would do today?
23. Is there anything else that might have affected your performance on the memory test yesterday or today?

Appendix G

Participant Characteristics Reported via Post-Test Survey

Three of the 35 participants did not complete the post-test survey. The characteristics reported below were from the remaining 32 participants.

Sleep Duration

Sleep supports the consolidation of memory but preferentially benefits the consolidation of emotional aspects of memory, even for short periods of sleep (e.g., 2 hours; see Payne & Kensinger, 2018 for a review). In the post-test survey, the participants indicated how long they slept between the first and second sessions. Participants in this study slept between 6 and 10 h (M = 7.21, SD = 1.11).

Stress Ratings

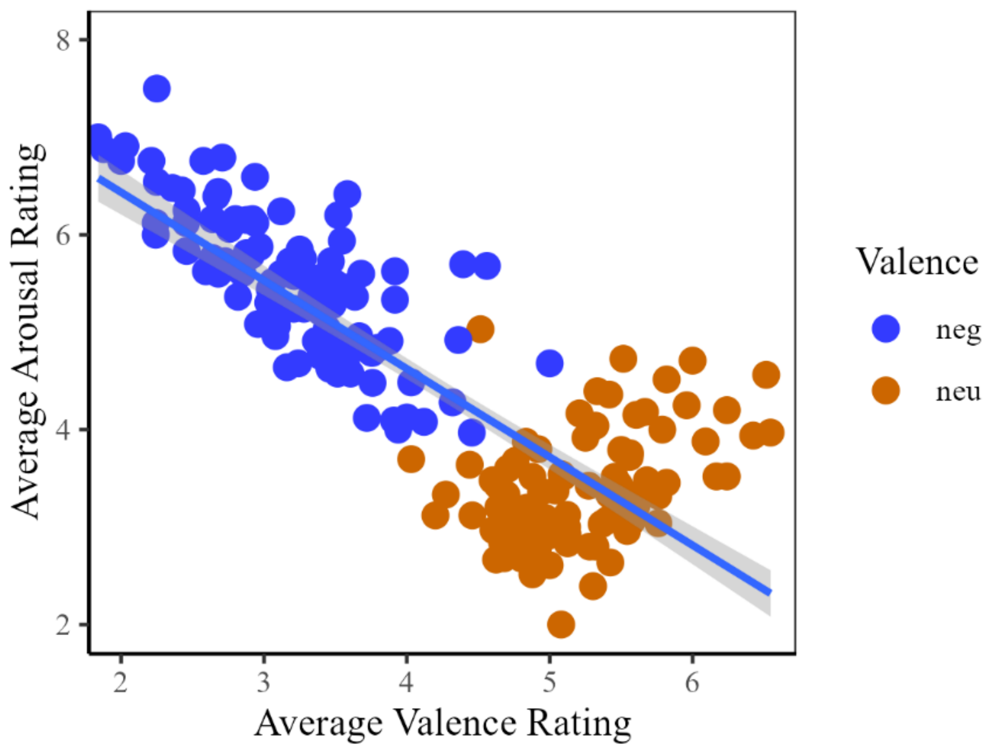
Like sleep, stress often benefits memory consolidation (see Payne & Kensinger, 2018 for a review). However, acute stress that occurs outside the physical context of the study materials tends to impair encoding and retrieval of the studied material, and these impairing effects can be larger for emotional stimuli than for neutral stimuli (Shields et al., 2017). In the post-test survey, participants indicated how stressed they were on a scale of 1 (not stressed) to 5 (Very Stressed) for each the first and second session. Across participants, the average stress level during the first session was 2.06 (SD = 0.83) and during the second session was 2.72 (SD = 1.04), indicating that participants had low to moderate levels of stress.

Participant reflection on stimuli between experimental sessions

In the post-study survey, we asked participants if they thought, talked about, or wrote about any specific sounds from the study during the 24 hours between sessions. Most participants (27 of 32) reported that they thought about or talked with friends about their experience of taking the study after the first session. Of those participants, 13 reported thinking about or talking about specific sounds: eight participants reported only negative sounds (e.g., “the multiple death type noises”), 2 reported both negative and neutral sounds (e.g., “that I liked the cutting vegetables ones and did not enjoy the sharp scraping ones”), 1 participant reported only neutral sounds (“nature and horse sounds that reminded me of my ranch”), an 2 participants did not specify the valence (e.g., “the ones that stood out to me”).

Appendix H

Relationship between Average Arousal and Valence Ratings from Participants



Note. Participant ratings (n = 35) for the 96 stimuli used in this study. Ratings for arousal and valence ranged from 1 to 9. The best fit regression line and standard error region is shown.