Physiological and Affective Arousal Guide Metacognitive Reporting and Recall for Naturalistic Experiences

Joanne E. Stasiak, William J. Mitchell, Samantha S. Reisman, David F. Gregory,

Vishnu P. Murty, and Chelsea A. Helion

Department of Psychology, Temple University

Corresponding Author:

Joanne Stasiak

joanne.stasiak@temple.edu

Temple University

347.251.7788

Abstract

As individuals navigate the world, they are bound to have emotionally intense experiences. These events not only influence momentary physiological and affective responses, but also have a powerful impact on emotional recall. In this research, we used an ecologically-valid context of a haunted house to examine the association between physiological arousal and metacognitive memory of emotional experience. Participants navigated a haunted house while heart rate and explicit fear ratings were recorded, and then recalled specific events from the haunted house and the intensity of these emotional events one week later. We found that heart rate predicted both reports of negative affective intensity in the moment and during later recall of the haunted house events. However, we found that recalled emotional intensity was influenced by both affective categorization and physiological arousal, such that individuals who labelled a recalled event as fear-eliciting reported more fear upon recall than they indicated experiencing at the time (and vice-versa for events labelled as not fear-eliciting). This work suggests that our physiological and emotional experiences may meaningfully interact to inform metacognitive recall of salient experiences.

Keywords: metacognition, heart rate, emotion, affective recall

Introduction

In the film “28 Days Later”, the main character Jim awakens from a long coma in a deserted hospital (Boyle, 2003). While the audience’s intense emotional experience is informed by the frantic musical score that is playing, Jim is instead likely relying on internal cues (e.g., his increasingly racing heart) to make the same affective assessments – that he is in danger and may soon need to outrun berserk zombies in the streets of London. While perhaps not to the extremes of a zombie apocalypse, in our daily lives we often encounter physiologically arousing events that impact how we assess our emotional experiences. We posit that this arousal can meaningfully inform how these events are experienced and recalled. The aim of the present research was to examine the relationship between physiological arousal, emotional intensity, and metacognitive recall in the context of a highly evocative and emotionally-charged setting (i.e., a haunted house).

Emotionally-charged stimuli elicits strong changes in autonomic nervous system activity, both for affectively rich lab-based stimuli (Fernandez et al., 2012; Kreibig, 2010; Diemer et al., 2014; Siegel et al., 2018) and for real-life emotional experiences (Andersen et al., 2020; Brosschot & Thayer, 2003; Shapiro et al., 2001). Heart rate (HR) is one of the primary ways to track autonomic nervous system activity, and is often impacted by negative affect. For example, significant increases in HR have been observed while observing fear-inducing movies and pictures (Fernandez et al., 2012; Golland, Keissar, & Levit-Binnun, 2014; Peira et al., 2012), during simulated social stress situations (Kotlyar et al., 2008), and during negative mood states (e.g., anger, stress, anxiety) in ecological settings (Brosschot & Thayer, 2003). While some studies have demonstrated associations between *explicit* reports of emotional arousal and HR (Diemer et al., 2014; Golland et al., 2014; Brosschot & Thayer, 2003), this association is inconsistent (Diemer et al., 2016; Gross, 1998; Egloff et al., 2006; Holmes, Brewin, & Hennessy, 2004). In addition, there is a paucity of research on the association between physiological arousal and metacognitive emotional experience and recall. An individual’s physiological response to an emotion-eliciting event, coupled with the emotional “label” that they assign to it (e.g., “fear”, “excitement”) may have meaningful implications for how the affective event is integrated into memory.

Prior research on emotion and memory has found effects of both emotional and physiological arousal on memory recall (Kensinger & Schacter, 2008; Sutherland & Mather, 2018; Abercrombie et al., 2008; Talarico, LaBar, & Rubin; 2004; Vrana, Cuthbert, & Lang; 1989). Stimuli with emotional meaning tend to be remembered more often, and more accurately, than neutral stimuli (Kensinger & Schacter, 2008; Sutherland & Mather, 2018), and elevated heart rate has been linked to enhanced autobiographical memory and increased recall accuracy for emotion-eliciting stimuli (Abercrombie, et al., 2008; Talarico et al., 2004; Vrana et al., 1989). In addition, negative content is remembered to a greater extent than positive content (Reisberg & Heuer, 2004; Kensinger, 2009). However, while much of this prior work has highlighted recall effects for memories of details of the actual emotional event, it is unclear whether physiological arousal similarly influences the metacognitive recall of the emotions that participants experienced at the time of the event (i.e., “how did I *feel*?”). Given recent evidence on the reconstructive nature of memories (Kensinger & Ford, 2021), it is of critical importance to understand how we also recall our perception of the emotional intensity of prior events. In addition, prior research often only assessed single features of the emotional experience in a given study, often using laboratory-based paradigms that preclude the complexity of real-life emotional events. To our knowledge, the present research is the first to examine metacognitive emotional recall using both explicit report and real-time physiological recordings in the context of a naturalistic environment.

Prior research on metacognitive emotional memory has found inconsistent results with regard to accuracy, finding evidence that individuals both overestimate (i.e., recalling experiencing more emotional intensity than they reported at the time of the event itself; Thomas & Diener, 2003) and underestimate (Kaplan, Levine, Lench, & Safer, 2016) emotional intensity upon recall. While some sources of emotional recall bias have been identified (e.g., one’s current emotional state, appraisals of the eliciting event, and personality traits), the generally mixed results on metacognitive emotional recall suggest that there may be multiple interactive processes involved during both the encoding of affective stimuli and in emotional memory construction (Levine & Safer, 2002; Schacter, 2008). We posit that the processes that underlie metacognitive emotional recall are multifactorial, and reflect the interplay between physiological (i.e., HR) and cognitive (i.e., affect labelling) factors experienced both during the event and at the time of recollection.

The aim of the current study is to examine the association between physiological arousal and affective intensity on metacognitive emotional reporting and recall in an immersive, naturalistic environment. We collected heart rate and explicit measures of experienced fear while participants traversed a haunted house. A week later, we had participants recall their emotional experiences. We test three distinct hypotheses: 1) explicit fear reported in the haunted house will be positively associated with concurrent heart rate, 2) there will be a positive association between heart rate in the haunted house and recalled negative emotional intensity of specific events, and 3) how participants affectively label the event will predict its recalled emotional intensity.

Results

Heart rate predicts explicit fear ratings in a naturalistic context.

The haunted house was divided into six discrete sections (easternstate.org). Following each section, participants indicated how scared they were during the section on a scale from 1 (“Not at all scary”) to 5 (“Extremely scary”). We first ran preliminary analyses demonstrating that the haunted house (averaged across all sections) elicited significantly more physiological responding (i.e., higher heart rate) as compared to baseline (i.e., filling out surveys in the lab). Analyses are provided in the Supplemental Materials (Figures S1 and S2). See SM for additional models including gender and group as fixed effects (Tables S2, S3, and S4).

Next, we assessed whether participants' reports of fear during the haunted house were reflected in their momentary heart rate. To test this, we ran a multilevel model, with reported fear per section of the haunted house as a fixed effect and average heart rate during the same section as the dependent variable. As each participant made multiple affect ratings in the haunted house and in the follow-up, participant was included as a random effect. This allowed intercepts to vary for each participant, controlling for the interdependence of within-participant data. We found that greater experienced fear significantly predicted heart rate ($\beta = 0.14$, $SE = 0.03$, $t(202.55) = 4.82$, 95% CI [0.08, 0.19], $p < 0.001$) (Figure 1). A likelihood-

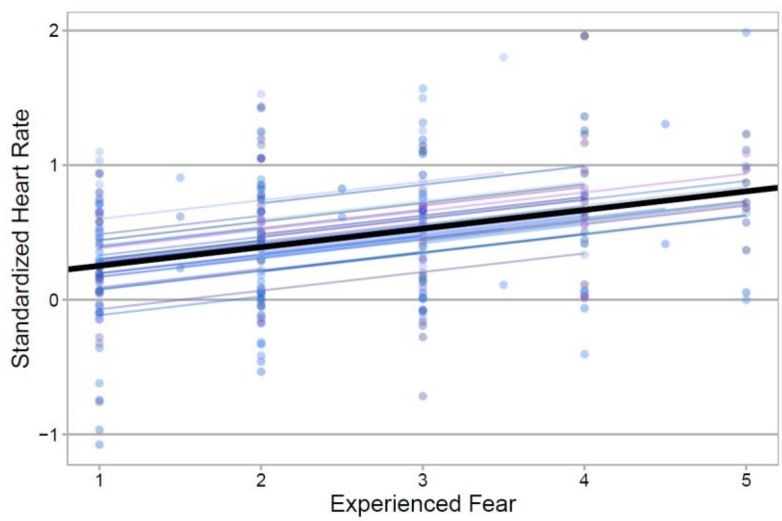

Figure 1. A multilevel model revealed that self-reported experienced fear intensity was significantly associated with heart rate; individual lines reflect individual participant scores.

---

ratio test confirmed that our model predicted significantly more variance ($\chi^2(1) = 22.39$, AIC = 344.59, BIC = 358.62, $p < 0.001$) compared to the null model (i.e., with only participant as a random effect predicting heart rate) (AIC = 364.98, BIC = 375.50).

Heart rate predicts metacognitive emotional memory recall.

A week after the haunted house, participants returned to the lab and recalled their emotional experiences. Each participant was asked to recall ten distinct memories. For each memory, participants indicated what emotions they experienced and the intensity of each indicated emotion during the event (using the PANAS; Watson, Clark, & Tellegen, 1988). For the purposes of comparison with emotional experience during the haunted house (in which participants only indicated their level of fear), we had participants indicate fear intensity for all recalled events, regardless of whether it was identified as one of the recalled emotions. We next examined how physiological responding relates to metacognitive recall for emotional experience. To do so, we examined the nature of the relationship between reported emotional intensity and heart rate during the section being recalled by the participant. Reported emotions from the follow-up survey were binned into positive and negative, following PANAS identifications (see Table S1 for PANAS categorizations). We ran a multilevel model with standardized heart rate as the dependent variable, recalled negative emotional intensity as the independent variable, and participant as a random effect. To account for elevation in heart rate that could potentially be attributed to arousing, positive emotions, we also included recalled intensity of positive emotions as a covariate. Thus, we can examine the strength of the relationship between momentary heart rate and recalled negative emotional intensity while controlling both for the potential noise of positive emotions and inter-subject variability. We found a significant effect, such that events of increased recalled negative emotional intensity were positively associated with increased heart rate during the event (β = 0.09, SE = 0.02, $t(223.72) = 4.20$, 95% CI [0.05, 0.14], $p < 0.001$). There were no significant associations found between recalled positive emotions and heart rate (p=0.80). A likelihood-ratio test was performed to further examine the effect of recalled emotional intensity against a null model (i.e., with positive emotions and participant predicting heart rate) (AIC= 432.04, BIC= 445.74), we found that our model explained significantly more variance ($\chi^2(1)$=17.23, AIC= 416.80, BIC= 433.93, p<0.001). For the purposes of transparency, the association of each recalled emotional intensity with heart rate is presented in the heatmap (though the primary analysis was performed using averaged positive and negative emotions) in the supplemental materials (Figure S3).

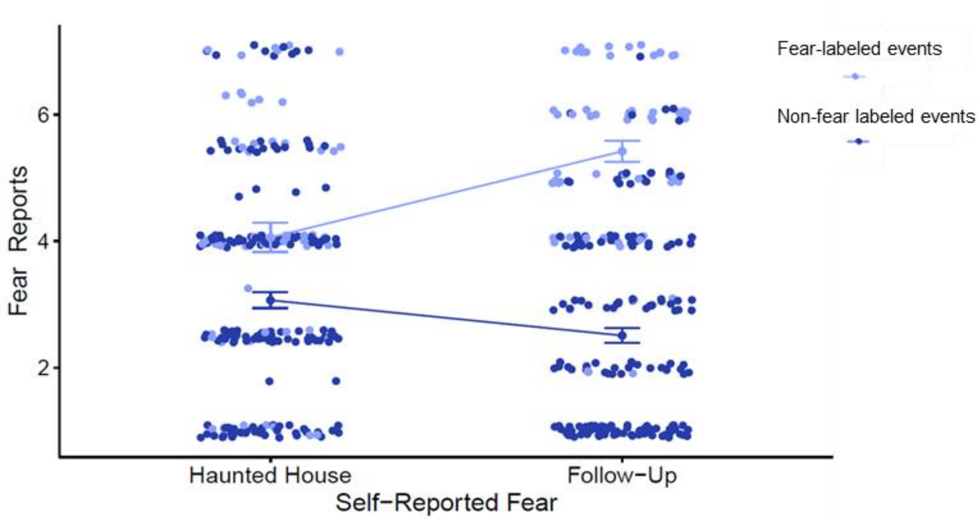

Figure 3. A 2 x 2 repeated-measures ANOVA revealed recalled fear to be significantly higher than experienced fear for fear-labeled events, while recalled fear was significantly lower than experienced fear for non-fear labeled events.

Fear labelling predicts divergence in recalled fear intensity.

Our results indicate a prominent role of physiological arousal in predicting both concurrent and recalled fear. However, prior research strongly suggests that recall is not a direct reflection of the past, and can be distorted over time. One contributor to emotional memory distortion may be how the experienced emotion is labelled or categorized (Satpute et al., 2016). To examine this, we partitioned responses into samples of events that participants labelled as fear-eliciting (i.e., events in which participants selected fear as an emotion elicited by the event during the recall session) and events that were non-fear labeled (i.e., events in which fear was not selected as an emotion elicited by the event during the recall session). All recalled events, regardless of being labelled as fear-eliciting or not, were assessed for fear intensity at the follow-up session in order to provide a comparison for the explicit fear ratings given in the haunted house.

We first compared the fear reports given during each section of the haunted house (i.e., experienced fear) to those given during the follow-up session when recalling events from the same haunted house section (i.e., recalled fear)[1]. We ran a 2 (event: fear-labeled, non-fear labeled) x 2 (memory: experienced fear, recalled fear) repeated-measures ANOVA on reported fear intensity. We found a significant interaction (F(1, 468)=32.26, p<0.001, 95% CI [-2.58,-1.25], $\eta^2 = 0.05$), such that recalled fear (M = 5.42, SD = 1.33) was significantly higher than experienced fear for fear-labelled events (M = 4.06, SD = 1.82, p < 0.001, d = 0.854) and that recalled fear (M = 2.51, SD = 1.56) was significantly lower than experienced fear for non-fear-labelled events (M = 3.07, SD = 1.68, p = 0.007, d = 0.344) (Figure 3). That is, not only were fear-labelled events associated with greater experienced fear and heightened recalled fear at a one-week delay, but the non-fear-labelled events were associated with less intense experienced fear and diminished recalled fear.

Exploratory Analyses: Examining fear divergence in relation to momentary heart rate

These results demonstrating a divergence in recalled fear intensity as a function of fear labelling motivated additional exploratory analyses. Specifically, we examined how physiological responding in the haunted house may contribute to the distortions in memory for recalled fear versus experienced fear. We ran a multilevel model with standardized heart rate as the independent variable and change in recalled fear (i.e., recalled fear – experienced fear) as the dependent variable. Values greater than zero indicated that recalled fear was greater than what was initially experienced, and values less than zero indicated that recalled fear less than what was initially experienced. We found a significant, negative relationship wherein greater heart rate in the haunted house was associated with *less* recalled fear than what was initially experienced, and lower heart rate in the haunted house was associated with *greater* recalled fear than initially experienced (β = -0.71, SE = 0.21, t(279.39) = -3.36, 95% CI [-1.12, -0.30], p< 0.001) (Figure 4). A likelihood-ratio test indicated that this model fit the data significantly better (χ^2(1) = 11.16, AIC = 1245.1, BIC = 1259.7, p < 0.001) than the null model (with only participant predicting change in

[1] Ratings of experienced fear, which were measured on a scale of 1 to 5, were rescaled to a 7-point scale for the purpose of comparison with assessments of recalled fear.

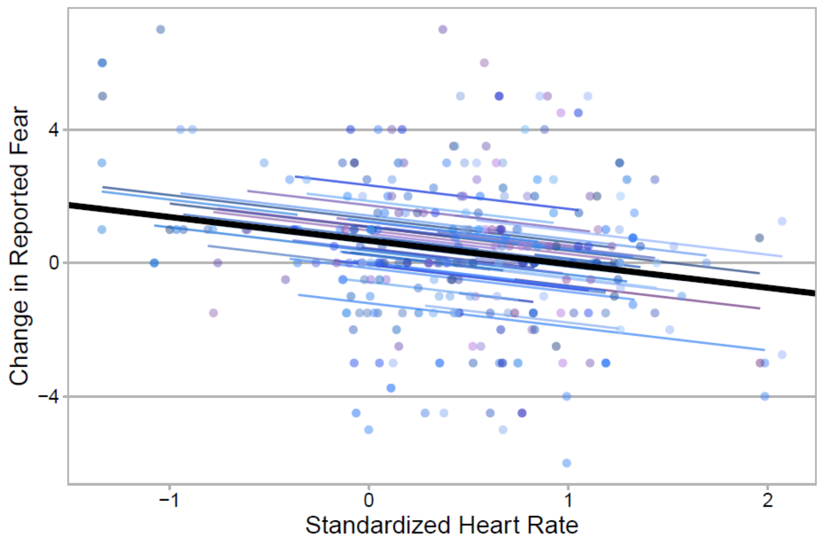

Figure 4. A multilevel model revealed that heart rate in the haunted house was significantly, negatively associated with changes in reported fear; individual lines reflect individual participant scores.

---

recalled fear) (AIC = 1254.2, BIC = 1265.2). That is, moments associated with increased heart rate in the haunted house were further associated with decreases in recalled fear intensity. These findings suggest that emotionally intense negative events elicit physiological arousal in the moment, and further that recalled fear of these events are exaggerated over time.

Discussion

Our everyday experiences are often affectively complex, and can elicit physiological responses that shape how we experience and recall our emotional states. The goal of this research was to examine the interplay between emotional experience and physiological arousal on emotional recall in a quasi-naturalistic environment. While a haunted house is an atypical context, it is arguably a closer approximation of the kinds of situations that elicit intense fear experiences as compared to the stimuli frequently used in controlled laboratory settings. Further, although the majority of lab-based paradigms often focus on a relatively narrow band of stimuli (e.g., emotional pictures, social feedback), the affective events in our daily lives are not unimodal, and rather subsume a multitude of sensory information that collectively influence emotional experience. The unique environment afforded by a haunted house provides the visual, tactile, auditory, and olfactory elements that parallel the immersion of the natural world, and afford examination of the heightened emotional and physiological responses that accompany intense emotional events.

Our findings suggest that there may be a strong link between physiological arousal and momentary emotional reporting. We found that physiological arousal significantly predicted experienced fear intensity during the haunted house, indicating that physiological responding was associated with subjects' explicit, heightened emotional distress. This finding was bolstered by the corresponding positive relationship between physiological arousal in the haunted house and recalled negative emotional intensity. Taken together, this suggests a strong association between physiological response, emotional experience, and memory recall**.** While past research has suggested that individuals may use semantic knowledge of emotions to inform their affective recollections (e.g., "what *should* I have felt?") (Robinson & Clore, 2002), our results suggest that physiological responses at the time of the event may also play a meaningful role in emotional recall. That is, rather than individuals purely employing a schematized knowledge of emotion, the observed positive relationship between physiological responding and emotional intensity suggests that individuals may integrate physiological information into recalled affective experience.

We also found a systematic distortion between momentary emotional reporting and retrospective emotional recall: events labelled as fear-eliciting were associated with greater experienced fear and heightened recalled fear, whereas events labelled as non-fear-eliciting were associated with less intense experienced fear and decreased recalled fear intensity. This is particularly surprising given prior research on the reduction of emotional intensity as a function of temporal distance (Habermas & Berger, 2011). Our findings bolster extant research on emotion recall bias, which suggests that retrospective assessments of experienced emotions tend to be inaccurate (Colombo et al., 2020), and support further investigation into the effects of affect-labeling on emotional recall. These findings support a putative adaptive function of meta-cognitive experience such that the division between fearful and neutral events becomes exaggerated over time.

Finally, an exploratory analysis revealed that these observed changes in fear intensity were significantly and negatively associated with HR in the haunted house. That is, events accompanied by higher HR in the haunted house were recalled as being *less* fear-inducing than initially reported, while events associated with lower HR in the haunted house were recalled as being *more* fear-inducing than initially reported. While past work has found arousal to be associated with increased recall of emotionally salient stimuli (Abercrombie et al., 2008; Talarico et al., 2004; Vrana et al., 1989), we did not find evidence that physiological arousal improves memory accuracy. Speculatively, these findings may point to meaningfully different mechanisms underlying unique memory systems. While the majority of prior work has highlighted memory for emotional stimuli, we are specifically examining memory for one's own emotional states. Similar distinctions in recall were observed by Reisman and colleagues (2021), who found that heightened arousal was associated with increased memory for peripheral details, but decreased episodic memory. It is possible that memory for metacognitive emotional experience (i.e., how afraid a person was) may be differentially drawing upon physiological arousal relative to recall for external emotional stimuli (i.e., the event that elicited the fear).

This research presents novel findings for the influence of naturalistic experiences on emotional recall, but a few limitations should be noted. First, our relatively small sample size limits generalizability of results to a wider population. However, the naturalistic nature of this study may speak to the potential extension of our findings, as assessing emotional experiences outside of a lab approximates the affective richness of the real world. In addition, our analyses were conducted both within-subjects and longitudinally, increasing our statistical power with a limited sample size. Another limitation of this study is our measure of experienced fear, which was operationalized by asking how scared participants felt at the end of each section of the haunted house. We recognize that there may exist a conceptual difference between attributing scariness to an environment and reporting an internal state, however, our observed physiological concordance speaks to the similarity of these affective reports. We further note that our collection of *only* fear ratings in the haunted house limited the comparisons we could make between experienced and recalled emotional intensity. We made this choice given the limited time between each section of the haunted house, in addition wanting to keep emotional demands for participants relatively low given the stressful haunted house environment. As research has detailed the emotional ambivalence of naturalistic experiences (Andersen et al., 2020; Brosschot & Thayer, 2003), we note how this collection restricts potential findings of memory distortions of affective events, and does not account for the role of emotions varying in valence. Future studies examining the metacognitive affect reporting would benefit from collecting reports of online positive affect.

Implications and Future Directions

In this research, we found a systematic divergence of recalled emotional intensity for naturalistic experiences of fear, such that both increases and decreases of recalled fear intensity were observed upon participants' affective categorizations. While such deviations have been found in prior recall bias work (Conner & Barrett, 2012; Levine, Lench, Kaplan, & Safer, 2012), our findings are the first to show this divergence occurring specifically for fear assessments, rather than between positive and negative emotions more generally. This discrepancy in fear reports was associated with differences in how participants emotionally labelled each experience. These findings may have particular implications for clinical work in subareas of anxiety, depression, post-traumatic stress disorder (PTSD), and obsessive-compulsive disorder (OCD). Past research has found overestimation of threat to be prevalent in individuals with anxiety (Peschard & Philippot, 2017; Lench & Levine, 2010), and inflated recall of negative affect has also been found in individuals with depression and PTSD (Ben-Zeev, Young, & Madsen, 2009; Slagle, 2007). Examining the relationship between emotional intensity, physiological responding, and fear labelling in high-intensity experiences like haunted houses may shed light on the processes underlying the development of potential emotional triggers.

Furthermore, our finding linking affective recall to physiological responding may potentially shed light on the processes associated with memory for emotional states. It is likely that there are individual differences that may underlie both how intensely an emotional event is experienced, and the intensity of the recalled emotional state. For example, individuals with anxiety and/or OCD may have difficulty managing recollective doubt and may engage in maladaptive strategies such as rumination to alleviate negative feelings (Tolin, Brady, & Hannan, 2008; Yook et al., 2010). Examining the factors that influence how emotions are recalled and either amplified or attenuated could provide information about the way affective experiences are differentially internalized and represented in individuals with various psychopathologies.

Whether it's portrayed in a film or experienced in a haunted house, outrunning hungry zombies may not *exactly* approximate the experiences that people encounter in their everyday lives. However, the heightened affect and physiological intensity associated with these experiences *can* approximate the effects associated with the emotionally evocative events experienced in the real-world. We found that physiological arousal predicted both experienced and recalled negative affect. Moreover, we found that the way emotional events are labelled may meaningfully impact how they are recalled. Taken together, this research suggests that living through and engaging with emotionally evocative experiences not only impacts how we feel in the moment, but also how we shape mental representations of these arousing events, and finally how we draw upon these perceptions when recalling our emotional pasts.

Materials and Methods

Participants

Fifty-four participants (M_{age} = 24.22, SD_{age} = 3.97, 26 female) were recruited from the Philadelphia area. The sample size reflects the maximum number of participants we could recruit within the limited time span that the haunted house was open (~ 1 month). Data from 10 participants were excluded from analyses: one participant was not able to complete the haunted house, one participant had been to the haunted house one week prior, and eight participants had incomplete audio and/or physiological recordings, bringing the final sample to 44 participants (M_{age} = 24.43, SD_{age} = 4.08, 19 female). Participants were paid $70.00 in Visa debit cards upon completion of the study. The study was approved by the university's Institutional Review Board. This study was run only once. We had planned to run a follow-up study in the Fall of 2020 to address study limitations, but we were unable to do so due to unavailability of the haunted house and safety concerns surrounding the COVID-19 pandemic.

Procedure

Participants were run in small groups ($M_{group\ size}$ = 4.50, $SD_{group\ size}$ = 0.79) during the first session of the study. Twelve groups were run, one at a time, over the course of the 2019 Halloween season (4 weeks). Upon arrival at the lab, participants read and signed informed consent documents. Following consent, participants were fitted with heart rate monitors, which took baseline recordings while computerized questionnaires were completed (see Supplemental Materials (SM) for the list of questionnaires collected). Participants were given audio recorders, which were used to disclose explicit affect ratings at various points in the haunted house, and then traveled with two research assistants to Terror Behind the Walls at Eastern State Penitentiary (www.easternstate.org), a fully immersive haunted house. Additional physiological recordings began upon arrival at the haunted house and ended upon conclusion. Approximately one week after their haunted house session, participants returned to the lab to complete an fMRI free-recall task[2] and a follow-up questionnaire. Participants were then debriefed and paid for their participation.

Session One

Haunted House. Terror Behind the Walls is a yearly held haunted house attraction at the historical site of Eastern State Penitentiary in Philadelphia, Pennsylvania, consisting of six sections: 1) Lock Down, 2) Blood Yard, 3) Machine Shop, 4) Infirmary, 5) Quarantine 4D, and 6) Break Out. Each section has a unique theme, setting, and cast of characters, and each visitor completes these sections in the same order. Upon arrival at Eastern State Penitentiary, participants were briefed that one research assistant would accompany the group through the haunted house and that each participant would lead the group during at least one section of the haunted house.

In an attempt to make the experience as naturalistic as possible, instructions during the haunted house were limited; participants were encouraged to act and react as naturally as possible, like they would if they were not participating in a study. Following completion of the haunted house, participants were reminded to return to the lab approximately one week later.

Audio Recordings. Audio was recorded on a handheld recorder (Sony ICD-PX470 Stereo Digital Voice Recorder), which participants carried throughout the haunted house. Although haunted houses may potentially elicit many different emotions, we were specifically interested in how the fear reported in the haunted house (i.e., experienced fear) may influence physiological responding and emotional recall. To assess dynamic experienced fear, participants were instructed to rate

[2] Participants completed an fMRI scan, wherein they freely recalled their experience of being in the lab and being in the haunted house. While this data was collected, it is not the focus of the present research and is not discussed further.

"How scary was that last section for you?" on a scale from 1 ("Not scary at all") to 5 ("Extremely scary") following each of the six sections of the haunted house. Although participants were not explicitly reporting how much fear they had experienced, in a follow-up study with a pool of online participants (n = 40), we found fear and scariness ratings to be significantly, positively correlated ($\rho(39) = 0.78$, $p < 0.001$).

Physiological Recordings

Baseline recording. In the lab, participants were fitted with Firstbeat heart rate monitors (Firstbeat Technologies Ltd., Jyväskylä, Finland). The monitors were placed on the skin below the chest muscles, above the base of the ribcage; placement was checked by a research assistant to ensure accurate readings. Firstbeat Sports software was used to record and transform the physiological data. Baseline recordings were taken from the point at which the monitors were put on, up to the time in which the subjects had completed the computerized questionnaires ($M_{duration}$ = 15.8 min).

Haunted house recording. A second collection of physiological recordings began just prior to when subjects entered the haunted house and ended when subjects exited the last section ($M_{duration}$ = 55.2 min). During the haunted house, a research assistant held a tablet with the Firstbeat software open and pressed a "Lap" button to signify the entrance/exit of a section, rooms, and hallways. These laps were used to parse the physiological data and track it to the audio recordings and later accounts of the experience.

The Firstbeat software collects raw interbeat interval (IBI) data and transforms it to heart rate (HR; beats per minute). Artefacts were removed using Firstbeat's artefact correction module, which identifies IBI's that exceed minimal and maximal duration limits and corrects artefacts by referencing neighboring intervals (Saalasti, Seppänen, & Kuusela, 2004). HR was then standardized at the beat level for each participant.

Session Two

Participants individually returned to the lab approximately one week later (time elapsed: M_{days} = 5.98, SD_{days} = 0.79) to complete computerized questionnaires assessing the participants' experience during the haunted house, in which subjects recalled and described ten discrete events from the haunted house that were clearest in their memory. For each event, participants reported the emotions they felt and the intensity of these emotions. The emotions participants could endorse were based on the PANAS (Watson et al., 1988) and were supplemented to provide an array of potentially experienced emotions. While subjects could endorse any emotions they experienced, an assessment of "Fearful/Afraid" was always given to subjects, regardless of if it was selected. This was done to parallel the fear ratings given in the haunted house.

Data Analysis

Matching physiological and recalled data. To identify the physiological data that corresponded with the events written about by participants, the researchers composed a list of 60 discrete moments that consistently occurred in the haunted house.[3] Participants' written events were then coded according to the listed moment they matched with, and finally were tracked to timestamps within the physiological data and audio recordings. Events that could reliably be tracked to a specific area of the haunted house were included for analyses, and nondescript events (e.g., "a man jumped out at me") that could not confidently be traced to a discrete moment in the haunted house were excluded from analyses.

[3] At least one researcher accompanied each group of participants through the haunted house. Each researcher's account of the experience was used to compile the list of events; events which consistently occurred were retained for the final list, which was reviewed and agreed upon by all researchers involved in data collection.

All statistical analyses were performed using R (R Core Team, 2017). Multilevel models were performed using the “lme4” package (Bates, Maechler, & Bolker, 2012).

Competing Interests

The authors have no competing interests to declare. This work was funded in part by the NARSAD Young Investigator Award by the Brain and Behavioral Research Foundation received by Vishnu P. Murty.

Open Practices Statement

This study was not formally preregistered, but a preprint of the manuscript has been made available on PsyArXiv. De-identified data and data analysis scripts can be found on Open Science Framework at https://osf.io/wh5za/

References

Abercrombie, H. C., Chambers, A. S., Greischar, L., & Monticelli, R. M. (2008). Orienting, emotion, and memory: Phasic and tonic variation in heart rate predicts memory for emotional pictures in men. Neurobiology of learning and memory, 90(4), 644-650.

Andersen, M. M., Schjoedt, U., Price, H., Rosas, F. E., Scrivner, C., & Clasen, M. (2020). Playing with fear: A field study in recreational horror. *Psychological Science*. doi:10.1177/0956797620972116.

Bates, D., Maechler, M., & Bolker, B. (2012). lme4: Linear Mixed-Effects Models Using S4 Classes (R Package Version 0.999999-0). http://cran.r-project.org/web/packages/lme4/index.html

Ben-Zeev, D., Young, M. A., & Madsen, J. W. (2009). Retrospective recall of affect in clinically depressed individuals and controls. *Cognition and Emotion*, *23*(5), 1021-1040.

Boyle, D. (Director). (2003). *28 days later* [Film]. 20th Century Fox Home Entertainment.

Brosschot, J. F., & Thayer, J. F. (2003). Heart rate response is longer after negative emotions than after positive emotions. *International journal of psychophysiology*, *50*(3), 181-187.

Colombo, D., Suso-Ribera, C., Fernández-Álvarez, J., Cipresso, P., Garcia-Palacios, A., Riva, G., & Botella, C. (2020). Affect Recall Bias: Being Resilient by Distorting Reality. *Cognitive Therapy and Research*, 1-13.

Conner, T. S., & Barrett, L. F. (2012). Trends in ambulatory self-report: The role of momentary experience in psychosomatic medicine. Psychosomatic medicine, 74(4), 327.

Diemer, J., Mühlberger, A., Pauli, P., & Zwanzger, P. (2014). Virtual reality exposure in anxiety disorders: Impact on psychophysiological reactivity. *The World Journal of Biological Psychiatry*, *15*(6), 427-442.

Diemer, J., Lohkamp, N., Mühlberger, A., & Zwanzger, P. (2016). Fear and physiological arousal during a virtual height challenge—effects in patients with acrophobia and healthy controls. *Journal of anxiety disorders*, *37*, 30-39.

Egloff, B., Schmukle, S. C., Burns, L. R., & Schwerdtfeger, A. (2006). Spontaneous emotion regulation during evaluated speaking tasks: associations with negative affect, anxiety expression, memory, and physiological responding. Emotion, 6(3), 356.

Fernández, C., Pascual, J. C., Soler, J., Elices, M., Portella, M. J., & Fernández-Abascal, E. (2012). Physiological responses induced by emotion-eliciting films. *Applied psychophysiology and biofeedback*, *37*(2), 73-79.

Firstbeat Technologies Ltd., Jyväskylä, Finland

Golland, Y., Keissar, K., & Levit-Binnun, N. (2014). Studying the dynamics of autonomic activity during emotional experience. *Psychophysiology*, 51(11), 1101-1111.

Gross, J. J. (1998). The emerging field of emotion regulation: An integrative review. Review of general psychology, 2(3), 271-299.

Habermas, T., & Berger, N. (2011). Retelling everyday emotional events: Condensation, distancing, and closure. *Cognition and Emotion*, *25*(2), 206-219.

Holmes, E. A., Brewin, C. R., & Hennessy, R. G. (2004). Trauma films, information processing, and intrusive memory development. Journal of Experimental Psychology: General, 133(1), 3.

Kaplan, R. L., Levine, L. J., Lench, H. C., & Safer, M. A. (2016). Forgetting feelings: Opposite biases in reports of the intensity of past emotion and mood. *Emotion*, *16*(3), 309.

Kensinger, E. A., & Ford, J. H. (2020). Retrieval of emotional events from memory. Annual review of psychology, 71, 251-272.

Kensinger, E. A., & Schacter, D. L. (2008). *Memory and emotion.* In M. Lewis, J. M. Haviland-Jones, & L. F. Barrett (Eds.), *Handbook of emotions* (p. 601–617). The Guilford Press.

Kotlyar, M., Donahue, C., Thuras, P., Kushner, M. G., O'Gorman, N., Smith, E. A., & Adson, D. E. (2008). Physiological response to a speech stressor presented in a virtual reality environment. *Psychophysiology*, *45*(6), 1034-1037.

Kreibig, S. D. (2010). Autonomic nervous system activity in emotion: A review. *Biological psychology*, *84*(3), 394-421.

Larsen, J. T., McGraw, A. P., & Cacioppo, J. T. (2001). Can people feel happy and sad at the same time?. Journal of personality and social psychology, 81(4), 684.

Lench, H. C., & Levine, L. J. (2010). Motivational biases in memory for emotions. *Cognition and emotion, 24*(3), 401-418.

Levine, L. J., & Safer, M. A. (2002). Sources of bias in memory for emotions. *Current directions in psychological science, 11*(5), 169-173.

Levine, L. J., Lench, H. C., Kaplan, R. L., & Safer, M. A. (2012). Accuracy and artifact: Reexamining the intensity bias in affective forecasting. Journal of personality and social psychology, 103(4), 584.

Peira, N., Golkar, A., Öhman, A., Anders, S., & Wiens, S. (2012). Emotional responses in spider fear are closely related to picture awareness. *Cognition & emotion*, *26*(2), 252-260.

Peschard, V., & Philippot, P. (2017). Overestimation of threat from neutral faces and voices in social anxiety. *Journal of Behavior Therapy and Experimental Psychiatry*, *57*, 206-211.

R Core Team (2017). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL http://www.R-project.org/

Reisman, S., Gregory, D. F., Stasiak, J., Mitchell, W. J., Helion, C., & Murty, V. P. (2021, February 8). Influence of Naturalistic, Emotional Context and Intolerance of Uncertainty on Arousal-Mediated Biases in Episodic Memory. https://doi.org/10.31234/osf.io/fy2tm

Robinson, M. D., & Clore, G. L. (2002). Episodic and semantic knowledge in emotional self-report: evidence for two judgment processes. *Journal of personality and social psychology*, *83*(1), 198.

Saalasti, S., Seppänen, M., & Kuusela, A. (2004, October). Artefact correction for heart beat interval data. Advanced methods for processing bioelectrical signals. In *Proceedings of the ProBisi. Meeting* (p. 1e10).

Satpute, A. B., Nook, E. C., Narayanan, S., Shu, J., Weber, J., & Ochsner, K. N. (2016). Emotions in “black and white” or shades of gray? How we think about emotion shapes our perception and neural representation of emotion. Psychological science, 27(11), 1428-1442.

Schacter, D. L. (2008). *Searching for memory: The brain, the mind, and the past*. Basic Books.

Shapiro, D., Jamner, L. D., Goldstein, I. B., & Delfino, R. J. (2001). Striking a chord: Moods, blood pressure, and heart rate in everyday life. *Psychophysiology*, *38*(2), 197-204.

Sheppes, G., Scheibe, S., Suri, G., & Gross, J. J. (2011). Emotion-regulation choice. Psychological science, 22(11), 1391-1396.

Siegel, E. H., Sands, M. K., Van den Noortgate, W., Condon, P., Chang, Y., Dy, J., ... & Barrett, L. F. (2018). Emotion fingerprints or emotion populations? A meta-analytic investigation of autonomic features of emotion categories. *Psychological bulletin*, *144*(4), 343.

Slagle, D. M. (2007). A critical evaluation of emotional numbing as a distinguishing feature of posttraumatic stress disorder. University of Wyoming.

Sutherland, M. R., & Mather, M. (2018). Arousal (but not valence) amplifies the impact of salience. Cognition and Emotion, 32(3), 616-622.

Talarico, J. M., LaBar, K. S., & Rubin, D. C. (2004). Emotional intensity predicts autobiographical memory experience. *Memory & cognition*, 32(7), 1118-1132.

Thomas, D. L., & Diener, E. (1990). Memory accuracy in the recall of emotions. *Journal of personality and social psychology*, *59*(2), 291.

Tolin, D. F., Brady, R. E., & Hannan, S. (2008). Obsessional beliefs and symptoms of obsessive–compulsive disorder in a clinical sample. *Journal of Psychopathology and Behavioral Assessment*, *30*(1), 31-42.

Vrana, S. R., Cuthbert, B. N., & Lang, P. J. (1989). Processing fearful and neutral sentences: Memory and heart rate change. Cognition & Emotion, 3(3), 179-195.

Watson, D., Clark, L. A., & Tellegen, A. (1988). Development and validation of brief measures of positive and negative affect: the PANAS scales. *Journal of personality and social psychology, 54(*6), 1063.

Yook, K., Kim, K. H., Suh, S. Y., & Lee, K. S. (2010). Intolerance of uncertainty, worry, and rumination in major depressive disorder and generalized anxiety disorder. *Journal of anxiety disorders*, *24*(6), 623-628.

Supplemental Materials

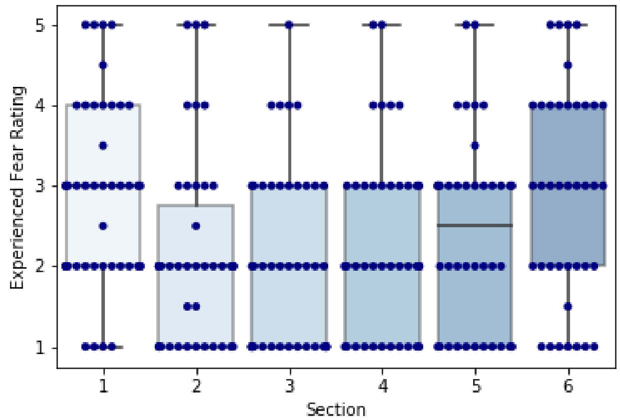

Fig. S1. We ran a one-sample *t*-test (against the rating of 1, "not scary at all") on the average explicit fear ratings participants gave in the haunted house (across sections). This analysis indicated that the haunted house successfully elicited fear responses ($M = 2.46$, $SD = 0.85$, $t(43) = 11.35$, $p < 0.001$, $d = 1.71$).

A one-way ANOVA was conducted to examine how the sections of the haunted house may have differentially elicited fear, with section predicting explicit fear ratings ($F(5, 240)=3.29$, $p=0.007$, $\eta^2=0.06$). This analysis revealed ratings from the first section of the haunted house ($M=2.88$, $SD = 1.13$, $p=0.026$) to be significantly higher than ratings in the third ($M=2.10$, $SD=1.12$) section.

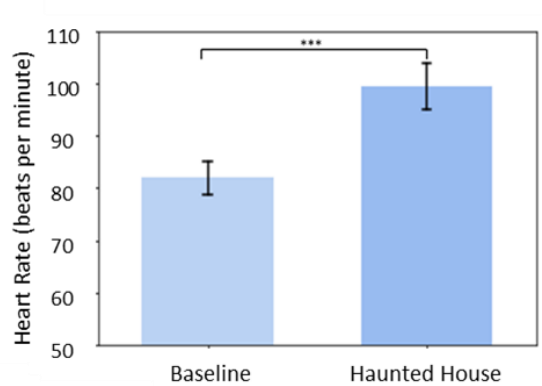

Fig. S2. A paired *t*-test revealed mean heart rate in the haunted house ($M = 100.04$, $SD = 16.43$) to be significantly higher than the baseline recording in the lab ($M = 81.87$, $SD =11.39$, $t(43) = 9.45$, $p < 0.001$, $d = 1.29$)

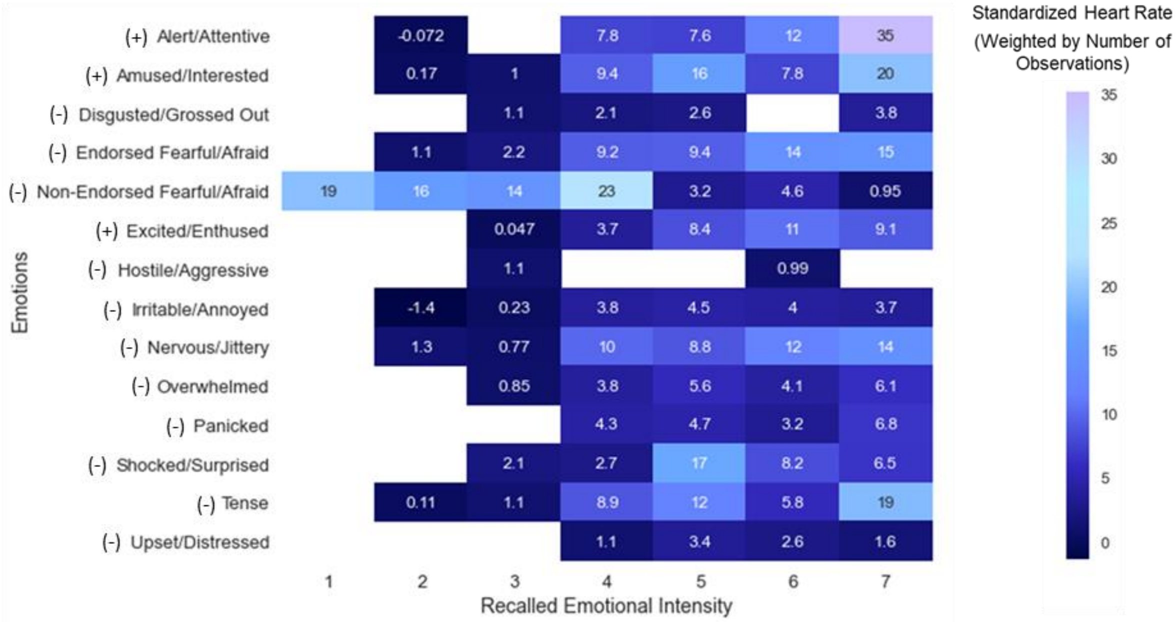

Figure S3. A heatmap was created to represent the average standardized heart rate associated with each recalled emotion, weighted by number of observations. This weighted heatmap was made by multiplying a matrix of the average standardized heart rate associated with each degree (1 – 7) of intensity for each emotion, by a matrix of the number of endorsements of each degree of intensity for each emotion. Positive PANAS categorizations are represented by (+); negative PANAS categorizations are represented by (-).

Emotion	**Valence**
Alert/Attentive	Positive*
Amused/Interested	Positive
Excited/Enthused	Positive
Hostile/Aggressive	Negative
Irritable/Annoyed	Negative
Upset/Distressed	Negative
Nervous/Jittery	Negative
Disgusted/Grossed Out	Negative
Overwhelmed	Negative
Panicked	Negative
Tense	Negative

Shocked/Surprised	Negative
Fearful/Afraid	Negative

***Table S*1.** PANAS Categorizations. *While the PANAS characterizes “Alert” and “Attentive” to be positive emotions, the connotation of being alert and/or attentive in an environment that is intended to produce fear responses may lean negative.

Due to the possible ambiguity of valence interpretation, we ran a correlation analysis of “Alert/Attentive” ratings with the averaged (within participant) negative emotion ratings, and with the averaged (within participant) positive emotion ratings.

We found that the “Alert/Attentive” ratings were significantly correlated to the positive emotion ratings (p=0.05, r=0.32), but not to the negative emotion ratings (p=0.24, r=0.19). Thus, data from “Alert/Attentive” responses were included as positive emotions in analyses that involved valence as an effect.

Random effects:

Groups	Name	Variance	Std. Deviation
PID	(Intercept)	0.03497	0.187
Residual		0.19098	0.437

Number of observations: 240, groups: PID, 43

Fixed effects:

	Estimate	Std. Error	Degrees of Freedom	t-value	p-value
(Intercept)	0.15185	0.15183	58.69727	1.000	0.321
FearRating	0.12978	0.03109	215.43019	4.174	4.34e-05***
Gender1	-0.14627	0.09907	30.65020	-1.476	0.150
Group1	0.10073	0.17140	31.45680	0.588	0.561
Group2	0.28163	0.18385	29.38966	1.532	0.136
Group4	-002272	0.19124	28.77587	-0.119	0.906
Group5	0.18600	0.24091	32.60715	0.772	0.446
Group6	0.21783	0.20703	31.89021	1.052	0.301
Group7	0.23884	0.20052	30.87708	1.191	0.243
Group8	-0.12560	0.17461	28.30886	-0.719	0.478
Group9	-0.05722	0.18704	30.74532	-0.306	0.762
Group10	0.30509	0.19547	28.32829	1.561	0.130
Group11	-0.01290	0.18727	31.28063	-0.069	0.946
Group12	-0.35473	0.22357	29.90002	-1.587	0.123

Table S2. Multilevel models of experienced fear ratings predicting concurrent heart rate for each section of the haunted house, with additional fixed effects for gender (0:Female, 1:Male) and Group (1-12). "Group" refers to the order in which participants completed the first session of the study. For example, participants in Group 1 were the first group to complete the haunted house, participants in Group 2 were the second Group to complete the haunted house, and so on.

Group 3 and Female (Gender:0) are the reference levels.

Random effects:

Groups	Name	Variance	Std. Deviation
PID Residual	(Intercept)	0.07889 0.25457	0.2809 0.5045

Number of observations: 167, groups: PID, 40

Fixed effects:

	Estimate	Std. Error	Degrees of Freedom	t-value	p-value
(Intercept)	1.471e-01	3.770e-01	9.180e+01	0.390	0.69725
NegativeEmotions	7.900e-02	2.661e-02	1.504e+02	2.968	0.00348**
PositiveEmotions	-4.334e-02	4.028e-02	1.520e+02	-1.076	0.28365
Gender1	1.547e-01	1.559e-01	23.97082	0.099	0.92170
Group1	2.021e-01	2.732e-01	2.740e+01	0.740	0.46581
Group2	5.004e-01	2.580e-01	2.371e+01	1.453	0.06441
Group3	1.861e-01	3.326e-01	3.550e+01	1.230	0.57929
Group4	-2.267e-02	3.083e-01	2.485e+01	0.720	0.94197
Group5	2.572e-01	3.615e-01	3.256e+01	1.375	0.48177
Group6	3.613e-01	3.117e-01	2.414e+01	0.787	0.25779
Group7	3.531e-01	3.013e-01	2.618e+01	0.306	0.25173
Group8	3.897e-01	3.426e-01	2.733e+01	1.137	0.26525
Group10	5.099e-01	3.3063e-01	2.888e+01	1.665	0.10676
Group11	-1.317e-04	2.810e-01	2.732e+01	0.000	0.99963
Group12	-5.880e-01	3.367e-01	2.484e+01	-1.746	0.09310

Table S3. Multilevel models of the relationship between heart rate in each section of the haunted house and recalled negative emotional intensity of specific events from those sections, with positive emotional intensity as a fixed effect, and with additional fixed effects for Gender (0:Female, 1:Male) and Group (1-12). Group 9 and Female (Gender:0) are the reference levels.

Random effects:

Groups	Name	Variance	Std. Deviation
PID	(Intercept)	0.955	0.9772
Residual		4.025	2.0061

Number of observations: 275, groups: PID, 43

Fixed effects:

	Estimate	Std. Error	Degrees of Freedom	t-value	p-value
(Intercept)	0.63678	0.73647	26.91086	0.865	0.39488
HRzScore	-0.64152	0.22750	260.99313	-2.820	0.00517***
Gender1	-0.55276	0.46669	26.55845	-1.184	0.24674
Group1	0.29893	0.84432	25.87340	0.354	0.72617
Group2	-0.40990	0.87175	25.17326	-0.470	0.64226
Group4	-0.39276	0.91461	25.15018	-0.429	0.67127
Group5	0.33570	1.12158	26.26557	0.299	0.76706
Group6	0.53628	0.91047	24.63931	0.589	0.56121
Group7	0.75361	0.94313	25.89038	0.799	0.43153
Group8	-0.70877	0.94876	35.15021	-0.747	0.46000
Group9	0.54817	0.88349	26.13019	0.620	0.54033
Group10	0.01531	0.93194	24.62369	0.016	0.98702
Group11	-0.56187	0.90966	28.70599	-0.618	0.54166
Group12	0.15584	1.12394	31.42489	0.139	0.89061

Table S4. Multilevel models of the relationship between changes in reported fear (recalled fear – experienced fear) with heart rate in the haunted house, with additional fixed effects for Gender (0:Female, 1:Male) and Group (1-12). Group 3 and Female (Gender:0) are the reference levels.

Additional Measures Collected:

Intolerance of Uncertainty Scale (IUS); Buhr, K., & Dugas, M. K. (2002). The intolerance of uncertainty scale: Psychometric properties of the English version. *Behaviour Research and Therapy*, 40, 931-945.

Beck Depression Inventory (BDI); Beck, A.T., Ward, C. H., Mendelson, M., Mock, J., & Erbaugh, J. (1961) An inventory for measuring depression. Archives of General Psychiatry, 4, 561-571.

State-Trait Anxiety Inventory (STAI); Spielberger, C. D., Gorsuch, R. L., Lushene, R., Vagg, P. R., & Jacobs, G. A. (1983). Manual for the State-Trait Anxiety Inventory. Palo Alto, CA: Consulting Psychologists Press.

Emotion Regulation Questionnaire (ERQ); Gross, J.J., & John, O.P. (2003). Individual differences in two emotion regulation processes: Implications for affect, relationships, and well-being. *Journal of Personality and Social Psychology*, 85, 348-362.

Interpersonal Regulation Questionnaire (IRQ); Williams, C., Morelli, S. A., Ong, D. C., & Zaki, J. (2018). Interpersonal Emotion Regulation: Implications for Affiliation, Perceived Support, Relationships, and Well-Being. *Journal of Personality and Social Psychology*. 115. 224-254. 10.1037/pspi0000132.