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Physiological arousal guides situational appraisals and metacognitive recall for naturalistic experiences

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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 may also have a powerful impact on one's memory for their emotional experience. In this research, we used the naturalistic context of a haunted house to examine how physiological arousal is associated with metacognitive emotional memory (i.e., the extent to which an individual remembers having experienced a certain emotion). Participants first navigated the haunted house while heart rate and explicit situational appraisals were recorded, and then recalled specific events from the haunted house and the intensity of these affective events approximately one week later. We found that heart rate predicted both the intensity of reported scariness in the haunted house and meta-cognitive memory of affect during recall. Critically, we found evidence for malleability in metacognitive emotional memory based on how the event was initially labeled. Individuals tended to recall events that they explicitly labeled as fear-evoking as being *more* intense than they reported at the time of the event. We found the opposite relationship for events that they labeled as not fear-evoking. Taken together, this indicates that there are strong relationships between physiological arousal and emotional experiences in naturalistic contexts, but that affective labeling can modulate the relationship between these features when reflecting on the emotionality of that experience in memory.

1. Introduction

Imagine for a moment walking down a dark alleyway late at night. You may feel your heart rate rising, an increased sense of vigilance, and a feeling of underlying dread that reaches its apex right before you emerge back onto a well-lit street. This experience is a complex one – with specific cognitive (e.g., vigilance) and affective (e.g., fear or dread) components, informed by feelings of physiological arousal, an appraisal of the situational context, and knowledge of the eventual nature of the outcome (i.e., relief that nothing bad occurred). While decades of research have examined how these factors influence episodic memory for emotional events (i.e., what happened), it remains an open question as to how these factors inform metacognitive recall, or how we recall feeling at the time of the event (i.e., how did I feel?). This question is the focus of the present research.

Increased heart rate can be one of the hallmarks of fear-inducing experiences like watching horror movies, going to a haunted house, or even public speaking. In our daily lives we are often exposed to arousing events that impact how we interpret a situation and assess our emotional experiences. This arousal can subsequently inform how these events are experienced and recalled. While the link between physiological responding and explicit emotional labeling may be tightly coupled in the moment, to what extent does this association persist in memory? Here, we examine what we term *metacognitive emotional memory*, the extent to which an individual remembers experiencing a certain emotion. To our knowledge, this research is the first to quasi-naturalistically examine how physiological arousal influences situational appraisal in the moment and potentially serves to tie explicit emotion labels to these appraisals upon recall. We examined this question in the context of a haunted house that participants traversed in small groups, as we collected real-time heart rate and explicit situational appraisals of scariness. We hypothesize that there will be a positive association between physiological arousal (as assessed via heart rate) and affective intensity at the time of the event, and that this association will persist when

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individuals recall how they felt at the time of the event (i.e., metacognitive emotional memory).

1.1. Neural and behavioral bases of metacognitive emotional experience and recall

These hypotheses are motivated by decades of previous behavioral and neural research linking physiological response and emotional experience in the context of laboratory and experience sampling studies. Emotionally-charged stimuli elicit strong changes in autonomic nervous system (ANS) activity, both for affectively rich lab-based stimuli (Fernández et al., 2012; Kreibig, 2010; Diemer et al., 2014; Siegel et al., 2018) and for real-life emotional experiences as assessed via methods like experience sampling (Andersen et al., 2020; Brosschot and Thayer, 2003; Shapiro et al., 2001). Heart rate (HR) is one of the primary ways to track ANS activity, and is often heightened during negative emotional experiences. For example, significant increases in HR have been observed while viewing fear-inducing movies and pictures (Fernández et al., 2012; Golland et al., 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 and 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 and Thayer, 2003), this association is not consistently found (Diemer et al., 2016; Gross, 1998; Egloff et al., 2006; Holmes et al., 2004). Taken together, this indicates that physiological arousal may be linked to affectively-neutral experiences, but not *necessarily* integrated into one's explicit emotional representation of the event.

Physiological arousal also plays a potentially meaningful role in affective recall, giving us insight into the underlying neurobiology of how ANS engagement influences emotional memory (Kensinger and Schacter, 2008; Sutherland and Mather, 2018; Abercrombie et al., 2008; Talarico et al., 2004; Vrana et al., 1989). Stimuli with emotional meaning tend to be remembered more often, and more accurately, than neutral stimuli (Kensinger and Schacter, 2008; Sutherland and 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). Enhanced memory for emotional events is in part attributed to interactions between the amygdala and medial temporal lobe (Dolcos et al., 2004; Ritchey et al., 2008; Murty et al., 2010; Fastenrath et al., 2014; Canli et al., 2000; Skelin et al., 2019), specifically drawing from activations of the basolateral nucleus of the amygdala (BLA) during encoding epochs (Mather et al., 2016; LeDoux, 1994). Notably, norepinephrine – a primary neurotransmitter produced during stress – is implicated in both human and animal research to have strong neuromodulatory effects on the BLA and on emotional memory (Tully and Bolshakov, 2010; Roozendaal and Hermans, 2017; McGaugh et al., 1996). High levels of norepinephrine are associated with enhanced memory for emotional stimuli, while impaired memory is observed when beta-adrenergic blockers are employed. Further, the central nucleus of the amygdala (CE) is strongly implicated in fear conditioning (Kapp et al., 1979), a process characterized by both aversive memories and physiological responding (Johansen et al., 2011; Battaglia and Thayer, 2022). Lesions to this region and the medial subdivision (CeM) are causally associated with suppressed learned fear responses and decreased cardiac reactivity (Keifer et al., 2015; Wilensky et al., 2006; Kapp et al., 1979). Taken together, this provides strong evidence for the interplay of the sympathetic nervous system, emotional experiences, and memory consolidation. While prior work on memory for affective stimuli has highlighted recall effects for encountered events stimuli (e.g., the surrounding environment, peripheral and central details), 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*?").

1.2. Situational appraisals and emotional experiences

When one assesses their emotional state in the moment, they may be taking in numerous external (e.g., how loud thunder is clapping) and internal (e.g., how fast their heart is beating) sources of information to form an impression of what they are feeling (Damasio and Damasio, 2018). These assessments can intertwine to engender perceptions of one's surroundings and characterize appraisals of the situation itself. That is, the emotional characteristics that an individual experienced in a specific context (e.g., "I feel stressed") can be attributed to an environment (e.g., "that interview was stressful") and/or the stimuli in an environment (McRae, Taitano, & Lane, 2010; Siemer and Reisenzein, 2007a; Siemer and Reisenzein, 2007b). While these emotional attributions are closely related, there is a lack of empirical evidence examining how well outwardly directed assessments of emotional content (i.e., situational appraisals) map onto internal emotional processes. Further, the mirroring of inward (i.e., emotional) and outward (i.e., situational) appraisals may not always occur. In the present research, we examine the role that physiological arousal may play in "tagging" external situations with emotional resonance, and how this association may inform subsequent emotional recall. In this study, we examined how appraisal-emotion coupling may occur in a quasi-naturalistic setting (a haunted house), and the extent to which situational appraisals (i.e., an event's "scariness") can inform how individuals recall their emotional states.

1.3. Labeling and recalling past emotional states

Research on retrospective emotional experiences provides some insight to how individuals recall their past emotional states (Wenze et al., 2012; Wilson and Gilbert, 2003). However, the findings on metacognitive emotional recall have been mixed. Some studies have found evidence for overestimation (i.e., recalling that their emotional experience was *more* intense than they reported at the time) (Thomas and Diener, 1990; Vlasenko et al., 2021) and others have instead found evidence for underestimation (i.e., recalling that their emotional experience was *less* intense than they reported at the time) (Kaplan et al., 2016). 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 retrospective re-construction of the emotional experience (Levine and Safer, 2002; Schacter, 2008). The present research tests one possible and understudied contributor to biases in emotional memory: interactions between emotional arousal and the label that individuals attach to the memory of an emotional situation.

Ascribing words to an emotional experience, termed *affect labeling*, has consistently been shown to influence how affective stimuli are perceived (see reviews by Torre and Lieberman, 2018; Lindquist et al., 2016; Barrett et al., 2007). Individuals report decreased intensity when applying discrete emotion labels to affective images relative to when the images are viewed without being labeled (Constantinou et al., 2014; Lieberman et al., 2007). These findings support affect labeling's proposed characterization as an implicit regulatory process (Torre and Lieberman, 2018). Affect labeling also recruits the ventrolateral prefrontal cortex and amygdala (Satpute et al., 2013; Lieberman et al., 2007), neural circuitry implicated in more explicit emotion regulation tasks (Ochsner et al., 2012; Banks et al., 2007; Berboth and Morawetz, 2021). Despite these findings, other studies have found conflicting evidence of the function of affect labeling, suggesting instead that prescribing a label to an event helps to *maintain* reported intensity, thus protecting against distortion biases (Mayou et al., 2000; Nook et al., 2021; Vlasenko et al., 2021). While affect labeling seems to have some influence in the early stages of information processing both verbally and neurally (Satpute et al., 2020), it remains unclear how it influences memory encoding and retrieval. Further, it remains unclear how these processes interact in the context of complex, naturalistic environments, where there are multiple sources of affective information that may not fit easily into a specific emotional label. Lastly, questions exist as to how well recalled internal emotional experiences map on to appraisals of one's situation, in that initial external affective attribution may potentially serve a regulatory role in lessening emotional intensity upon recall. As affect labeling can provide contextual information (Vine et al., 2019), processing a situation through its emotional components may be most conducive to regulation strategies aimed at external perceptions. That is, reappraisal is dependent on situational interpretations (Gross and John, 2003) and thus outwardly directed emotional assays may function as an antecedent regulatory strategy (Gross and Thompson, 2007). The present research aims to begin to close this gap of situational appraisals and metacognitive emotional memory by examining how affective labeling may inform emotional recall in the context of a naturalistic experimental paradigm.

1.4. Leveraging a naturalistic paradigm

The majority of prior research on affective labeling has only assessed single features of the emotional experience in a given study (e.g., images or sounds), tending to employ laboratory-based paradigms that lack the complexity of real-life emotional events (Wilhelm and Grossman, 2010; Sonkusare et al., 2019). The aim of the current study is to examine the association between physiological arousal and situational appraisal on metacognitive emotional recall and affect labeling for an immersive, naturalistic environment. To do this, we collected real-time heart rate and explicit measures of situational scariness while participants traversed a haunted house in small groups. A week later, we had participants recall their emotional experiences in the haunted house. We had three distinct hypotheses: 1) degree of scariness reported in the haunted house would be positively associated with concurrent heart rate, 2) there would be a positive association between heart rate in the haunted house and recalled negative emotional intensity of specific events, and 3) that individuals would recall experiencing less intense fear than their in-the-moment situational appraisal would suggest.

2. Materials and methods

2.1. 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 (1) participant was not able to complete the haunted house, one (1) participant had been to the haunted house one week prior, and six (6) participants had incomplete audio recordings, and two (2) participants were excluded due to corrupted 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.

2.2. 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 situational appraisals of scariness 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[1] and a follow-up questionnaire. Participants were then debriefed and paid for their participation.

2.2.1. 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. In 2019 it consisted of six distinct 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. Following completion of each section, participants provided verbal situational appraisals of scariness using a handheld audio recorder. 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. Verbal ratings of situational appraisal (i.e., reported scariness) were recorded on a handheld recorder (Sony ICD-PX470 Stereo Digital Voice Recorder), which participants carried throughout the haunted house. Verbal reports were used to preserve the naturalistic design, as they afforded the least disruption in the haunted house experience, relative to completing a physical or digital survey. The background noise of the haunted house, while recorded, was not analyzed due to variation in microphone placement; while some participants had wired microphones clipped to collared clothing, other participants stored the microphones in their pockets. All participants spoke clearly into the microphone when providing ratings. Although haunted houses may potentially elicit many different emotions, we were specifically interested in how fear-related affective construals of the haunted house environment (i.e., situational appraisal) may influence physiological responding and emotional recall. To assess situational appraisals of the affective environment of the haunted house, participants were instructed to verbally rate "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 (ρ (39) = 0.78, $p < 0.001$) (see SM for additional study details). While these ratings were not found to be identically mapped to each other, extant research notes a correlation coefficient greater than 0.7 to be considered strong (Moore et al., 2013).

2.2.2. 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

[1] 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.

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). Artifacts were removed using Firstbeat’s artifact correction module, which identifies IBI’s that exceed minimal and maximal duration limits and corrects artifacts by referencing neighboring intervals (Saalasti et al., 2004). HR was then standardized at the beat level for each participant.

2.2.3. 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 were provided with a list of emotions to select from and were prompted to report which emotions they felt (by clicking a checkbox) and the intensity of these emotions (on a Likert scale of 1–7). 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. The full list of emotions is as follows: Alert/Attentive, Amused Interested, Excited/Enthused, Hostile/Aggressive, Irritable/Annoyed, Upset/Distressed, Nervous/Jittery, Disgusted/Grossed Out, Overwhelmed, Panicked, Tense, Shocked/Surprised, Fearful/Afraid. While subjects could endorse any emotions they experienced, an assessment of “Fearful/Afraid” was always given to subjects, regardless of if it was selected. That is, all participants were prompted to provide an intensity rating of Fearful/Afraid for each event recalled. This was done to parallel the situational appraisals of scariness given in the haunted house.

2.3. 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.[2] 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. In total, 518 events were provided, 176 events were nondescript, and the resultant 342 (66%) events were used for analyses.

All statistical analyses were performed using R (R Core Team, 2017). Multilevel models were performed using the “lme4” package (Bates et al., 2012). Data visualization was performed using R (R Core Team, 2017) and Python (Van Rossum and Drake Jr, 1995).

[2] 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.

3. Results

3.1. Heart rate predicts intensity of situational appraisals in a naturalistic context

As a note, the haunted house was divided into six discrete sections (easternstate.org). Following each section, participants provided situational appraisals by reporting “How scary was that section for you?” 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’ situational appraisals of scariness during the haunted house were reflected in their momentary heart rate. To test this, we ran a multilevel model, with situational appraisal 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 appraisal ratings in the haunted house and emotional ratings in the follow-up, participant was included as a random effect for all models. This allowed intercepts to vary for each participant, controlling for the interdependence of within-participant data. We found that heart rate significantly predicted appraised scariness ($\beta = 0.59$, $SE = 0.12$, $t\,(229.13) = 4.82$, 95% CI [0.35, 0.84], $p < 0.001$) (Figur 1Fig. 2). A likelihood-ratio test confirmed that our model predicted significantly more variance ($\chi^2\,(1) = 22.35$, AIC = 700.92, BIC = 714.95, $p < 0.001$) compared to the null model (i.e., with only participant as a random effect predicting appraised scariness) (AIC = 721.27, BIC = 731.79).

3.2. Heart rate predicts metacognitive emotional memory recall

A week after the haunted house, participants returned to the lab and recalled their emotional experiences in the haunted house. Each participant was instructed to recall ten distinct memories. For each memory, participants indicated what emotions they experienced (using the PANAS; Watson et al., 1988), and the intensity of each indicated emotion during the event. For the purposes of comparison with emotional experience during the haunted house (in which participants only appraised scariness), 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 recalled 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 recalled negative emotional intensity as the dependent variable, standardized heart rate 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 adjusting for both 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 ($\beta = 0.09$, 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

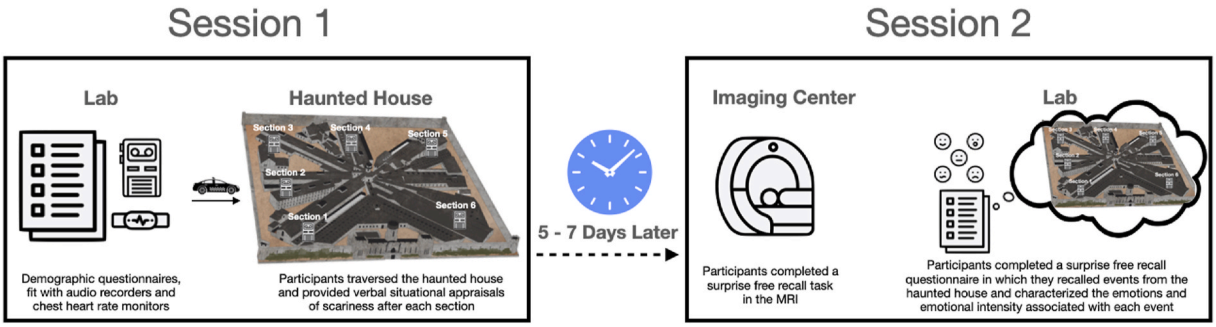

Fig. 1. Illustration of the study design. In Session 1, all participants first arrived at the lab, where they filled out demographic questionnaires and were fitted with audio recorders and heart rate monitors. Then, all participants and two research assistants traveled to the haunted house, where all participants completed each of the six sections, following which they provided explicit verbal reports of situational scariness. In Session 2, participants arrived back to the university to complete a free recall task while undergoing an fMRI scan. Participants then moved to a testing room to complete a second free recall task in which they described events from the haunted house, selected emotions that they remember experiencing during the event, and the intensity of each emotion experienced.

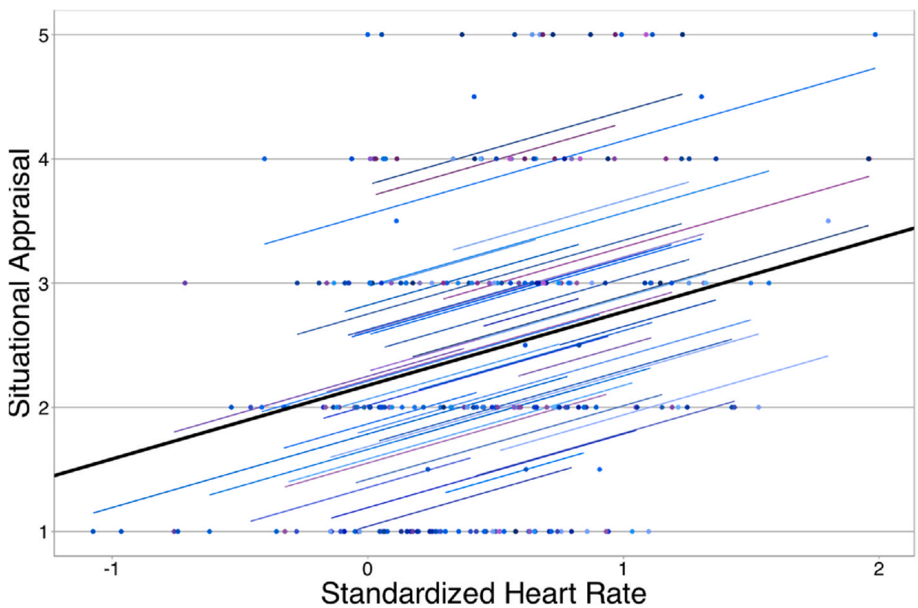

Fig. 2. A multilevel model revealed that self-reported situational appraisals of scariness were significantly associated with heart rate; individual lines reflect individual participant scores.

= 432.04, BIC = 445.74), we found that our model explained significantly more variance (χ^2 (1) = 17.23, AIC = 416.80, BIC = 433.93, $p <$ 0.001). The association of each recalled emotional intensity with heart rate is presented in a heatmap in the SM (Figure S3). See also Table S5 for a frequency table of the emotion ratings.

3.3. *Situational appraisals and emotion labeling predicts divergences in metacognitive emotional recall*

We next examined how affect representations change over time by partitioning responses into samples of events that were labeled as fear-eliciting (i.e., events in which participants selected fear as an emotion elicited by the event during the recall session, n = 62) and events that were non-fear-eliciting (i.e., events in which fear was not selected as an emotion elicited by the event during the recall session, n = 174). Participants rated fear intensity for all recalled events, regardless of whether it was explicitly labeled as fear-eliciting. This was to provide a comparison for the situational appraisals of scariness given in the haunted house.

We first compared the situational appraisals given during each section of the haunted house to those given during the follow-up session when recalling events from the same haunted house section (i.e., recalled fear).[3] We ran a multilevel model on fear endorsement predicting recalled fear intensity, controlling for situational appraisals of scariness and including participant as a random effect. We found significant main effects of fear endorsement

(β = 2.68, SE = 0.22, t (233) = 12.11, 95% CI [2.25, 3.12], p < 0.001) and situational appraisals (β = 0.23, SE = 0.06, t (233) = 4.095, 95% CI [0.12, 0.34], p < 0.001) on recalled fear, such that events identified as being fear-eliciting were recalled as more emotionally intense than events that were not (Fig. 3). That is, not only were events that participants labeled as being fear-eliciting associated with heightened

recalled fear at a one-week delay, but the labeled non-fear-eliciting events were associated with diminished recalled fear relative to what participants reported in the haunted house.

Additional analyses controlling for the number of days between sessions did not reveal a significant effect of temporal variability (Table S6).

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

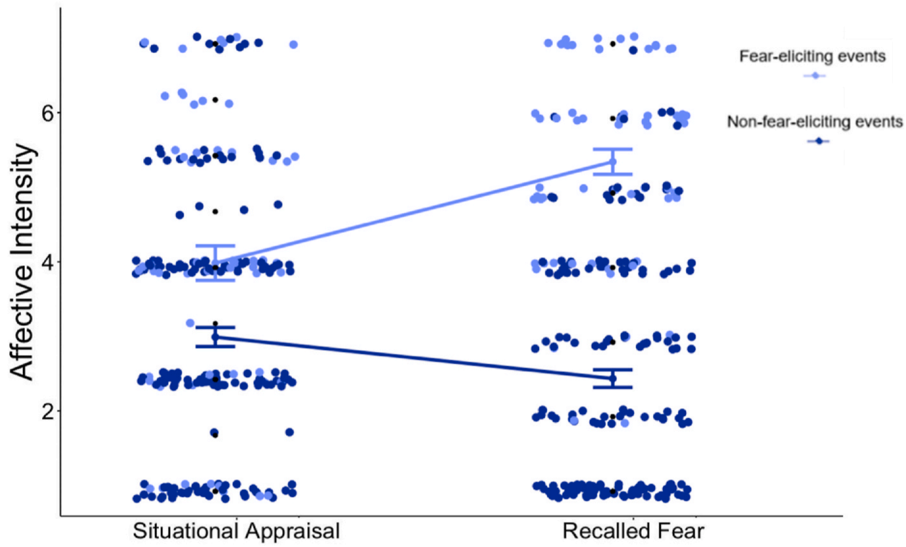

Fig. 3. A multilevel model revealed recalled fear to be significantly higher than situational appraisals for fear-eliciting events, while recalled fear was significantly lower than appraised scariness for non-fear eliciting events.

3.4. Exploratory analyses: predicting recalled fear from situational appraisals, momentary heart rate, and affect labeling

We took an exploratory approach to assess how baseline scariness, as appraised in the haunted house, may interact with momentary heart rate and labeling upon recall to generate reports of recalled fear. We ran a multilevel model with situational appraisals and heart rate as the dependent variables, fear endorsement as an interaction term, and participant as a repeated random effect, predicting recalled fear intensity. Surprisingly, we found a non-significant relationship ($p > 0.5$), in that the relationship between situational appraisals and heart rate failed to predict recalled fear intensity, even when accounting for the mediating role of affect labeling (Figure S4).

3.5. Exploratory analyses: examining fear divergence in relation to momentary heart rate

We next examined how physiological responding in the haunted house may contribute to the observed distortions in memory for recalled fear versus situational appraisals of scariness. We ran a multilevel model with standardized heart rate as the independent variable and change in recalled fear (i.e., recalled fear – appraised scariness) as the dependent variable.

Values greater than zero indicated that recalled fear was greater than what was initially appraised, and values less than zero indicated that recalled fear less than what was initially appraised. We found a significant, negative relationship wherein greater heart rate in the haunted house was associated with *less* recalled fear than what was initially appraised, and lower heart rate in the haunted house was associated with *greater* recalled fear than initially appraised ($\beta = -0.71$, $SE = 0.21$, t (279.39) = -3.36, 95% CI [−1.12, −0.30], $p < 0.001$) (Fig. 4). A

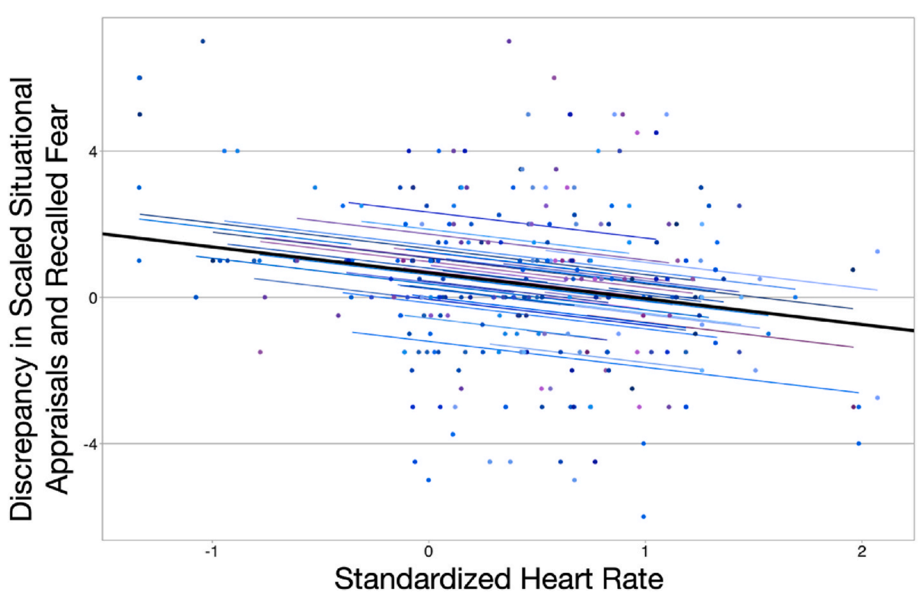

Fig. 4. A multilevel model revealed that heart rate in the haunted house was significantly, negatively associated with changes in reported fear; individual lines reflect individual participant scores.

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 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 negative events that are emotionally intense elicit physiological arousal in the moment, and further the recalled fear of these events are exaggerated over time. Additional analyses controlling for duration between sessions did not reveal a significant effect of duration variability (Table S7).

4. Discussion

The goal of this research was to examine the interplay between emotional experience and physiological arousal on emotional recall in a multi-featural, complex environment. This approach may provide a closer approximation of the kinds of situations that elicit intense fear experiences as compared to the stimuli often used in controlled laboratory settings. While the majority of lab-based paradigms focus on a narrow band of stimuli (e.g., emotional pictures, social feedback), the affective events in our daily lives contain a multitude of sensory information that collectively influence emotional experience. Our findings suggest that there may be a strong link between physiological arousal and momentary affective reporting. We found that physiological arousal significantly predicted appraised scariness during the haunted house. This indicates that physiological responding was associated with subjects' explicit affective cognition and suggests that engagement of the ANS helps to shape subjective appraisals of affective events. 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, situational appraisal, and emotional 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 and Clore, 2002), our results suggest that physiological responses at the time of the event may also play a meaningful role in emotional recall. Rather than individuals purely employing schematized emotion knowledge (e.g., "I was in a haunted house, those are scary, I must have been afraid"), the positive association between physiological responding and emotional intensity suggests that individuals may be integrating physiological information at the time of encoding. This relationship may inform the intensity of the recalled affective experience.

We also found a systematic distortion between momentary situational appraisal and retrospective emotional recall. Events that participants labeled as fear-eliciting at the time of recall were associated with heightened recalled fear relative to appraised scariness, whereas those labeled as non-fear-eliciting events were associated with decreased recalled fear intensity relative to appraised scariness. This is surprising given prior research on the reduction of emotional intensity as a function of temporal distance (Habermas and Berger, 2011). Our findings are consistent with extant research on emotion recall bias, which suggests that retrospective assessments of experienced emotions tend to be inaccurate (Colombo et al., 2020). Future research should examine the extent to which the recall bias for metacognitive emotional experience becomes more (or less) exaggerated over time via mechanisms of consolidation—which are tightly associated with ANS engagement—and its ramifications for adaptive or maladaptive emotional functioning.

Finally, our first exploratory analysis revealed a surprising non-significant relationship between situational appraisals, momentary heart rate, and fear-endorsement on recalled fear intensity. While we may have expected a predictive relationship between the coupling of arousal and appraisal with labeling and recalled fear, in that higher arousal and greater appraised scariness would be associated with greater recalled fear for fear-endorsed events, our findings may instead point to the complexity of physiological arousal in affective contexts; as autonomic specificity of emotion is widely contended (Cannon, 1927; Schachter and Singer, 1962; Barrett, 2006), assessing arousal in naturalistic settings may further reveal how physiological profiles of emotion may be less unique that proposed. An additional exploratory analysis further demonstrated how the relationship between emotion, recall, and physiology is not clear-cut. Our analysis relating the discrepancy in appraised scariness and recalled fear with momentary heart rate revealed that these observed changes were significantly and negatively associated with HR in the haunted house. Events accompanied by higher HR in the haunted house were recalled as being *less* fear-inducing than initial appraisals of scariness would suggest, while events associated with lower HR in the haunted house were recalled as being *more* fear-inducing. While past work has found arousal is 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 meta-cognitive emotional memory accuracy. Speculatively, these findings may point to meaningfully different mechanisms that recruit distinct memory systems. For example, similar distinctions in recall were observed by Reisman et al. (2021), who found that heightened arousal at the time of an event was associated with increased memory for peripheral details, but decreased event/action details. 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 of external emotional stimuli (i.e., the event that elicited the fear). Further, given the importance of affective labeling during the emotional event in these biases, this opens possibilities that neural systems focused on affective labeling and semantics may interact with more traditional emotional memory systems (i.e., the medial temporal lobe) during periods intervening encoding and subsequent meta-cognitive recall.

This work expands current affect labeling literature, as we demonstrate how individuals can reliably tie labeling during recall to situational appraisals made in the moment. This is significant in multiple ways: first, it builds on work suggesting that there is a distinction between explicitly labeling one's affect and labeling the properties of stimuli that engender affect (McRae et al., 2010) and that these labels recruit distinct prefrontal networks (Lee and Siegle, 2012). While we argue that appraisals of scariness and self-reported fear are tightly coupled conceptually, we acknowledge that it is not a mirrored mapping of affective assays. However, whereas McRae and colleagues (2010) find evidence for an implicit physiological down-regulatory effect of labeling stimuli features relative to explicit emotion, we find physiological arousal to track strongly with situational appraisals, suggesting that the distinction may be lessened in a naturalistic setting where atmospheric emotional intensity may inform both external and internal affect perceptions. Second, this work serves to provide evidence for implicit processes that infer internal emotion states from external situations, in that our participants are able to recall specific events from the haunted house that were initially appraised for scariness, and subsequently label an internal emotional experience that occurred during that event.

This research presents novel findings for the influence of naturalistic experiences on emotional recall, but a few limitations should be noted. We note that our collection of *only* appraised scariness 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 to 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 and Thayer, 2003), we acknowledge 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 metacognitive affect reporting would benefit from collecting reports of online positive affect, as there has been recent evidence for the up-regulation of positive emotions through affect labeling (Vlasenko et al., 2021). Such work would shed light on how emotions dynamically change with respect to each other when observed and recalled. Additionally, we acknowledge that although our follow-up study examining the conceptualizations of scariness and fear revealed a relatively strong correlation coefficient of 0.7, this is not as tightly coupled as we expected, and thus limits comparisons of the two measures. Acquiring momentary assays of explicit fear, as well as numerous other emotions would further strengthen this work to provide a nuanced look at the variation in coupling between metacognition, physiology, and recall for different emotions. For example, in our assessment mapping momentary heart rate onto reported emotional intensity upon recall (Figure S3), we observed a strong association between recall of anger-related emotions (Hostile/Aggressive) and heart rate. While the number of these occurrences were low and therefore limits our ability to make inferences, it would be a fruitful avenue to explore how approach-oriented emotions, like anger, may potentially demonstrate a stronger association with sympathetic activity in the moment. Additional work could examine how assessing emotions on a valence-arousal continuum, relative to discrete categories, may better reflect individual-level perceptions of affective experience (Barker et al., 2020) and influence how emotions are recognized and selected during recall (Nook et al., 2015). To better understand the dynamics of emotional experience and recall as it relates to physiological arousal, it would be valuable to acquire baseline ratings of affect to subsequently make comparisons from and to rule out the potential effect of regression to the mean. In our exploratory analysis (Fig. 4), we examined how momentary heart rate was tied to changes in appraised scariness and recalled fear; while our interpretations are limited due to the lack of baseline ratings, this could be an interesting line of research for future studies to explore predictive qualities of arousal and vulnerability to memory distortion.

This research offers significant contributions to the field of metacognition and emotional memory through the use of a somewhat more naturalistic environment. While lab-based studies offer numerous strengths, including limiting between-subject variability and minimizing extraneous noise (Fernández-Dols and Crivelli, 2013), our daily experiences do not occur in such sterile isolation. Examining how emotional processing occurs with respect to concurrent attentional distractions and multidimensional stimulation provides a greater approximation of how cognitive and affective mechanisms play out over time. The complexity that is inherent to naturalistic stimuli affords a greater understanding of the complexity of real-world emotional experience. That is, our findings that fear representations update as a function of affect labeling represent that there are unique conditions under which emotions may be recalled differentially, and that it is not as clearly predictable as some previous research suggests (Kaplan et al., 2016; Thomas and Diener, 1990). Furthermore, our examination of situational appraisal may closely mimic how individuals use various sources in their environment to construct perceptions and understanding of one's current state (Parkinson and Manstead, 1992). Leveraging naturalistic designs to assess how emotional contexts are integrated into one's emotional memory may account for more emotional complexity than what can be imbued in lab-based paradigms.

4.1. Implications and future directions

In this research, we found that while physiological arousal and emotionally-relevant experience are closely coupled at the time of the event, they diverge during recall based on how the event is emotionally labeled. These results may have novel implications for the field of cognitive neuroscience. Prominent psychophysiological research has demonstrated the modulatory effects of cardiac timing on stimuli processing, finding that fearful stimuli are encoded as being even more intense at systole (the phase of heart contraction in which arterial baroreceptors are sent to the brain) relative to diastole (Garfinkel and Critchley, 2016; Garfinkel et al., 2021). This highlights the selective enhancement of emotionally salient stimuli as a function of bodily arousal. Notably however, such effects are disrupted by interoceptive ability, such that individuals who demonstrate greater physiological awareness are less susceptible to systolic enhancement (Garfinkel et al., 2013). This suggests that future work should examine the role that individual differences in interoception may play in metacognitive emotional recall.

In terms of neural circuitry, given the insula's role in integrating interoceptive information and in awareness writ large (Berntson et al., 2011; Craig, 2009), it has been proposed that insular activity promotes metacognitive accuracy, especially when functionally coupled with the dlPFC (Fleming and Dolan, 2012; Vaccaro and Fleming, 2018). Future research should examine the role that this functional coupling may play in facilitating or hampering metacognitive memory for emotional or highly arousing events. Paradigms testing memory for emotional experience as a function of physiological arousal may highlight unique medial temporal lobe-amygdala connections, in which recall may be modulated by insula activity.

These findings may also 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 and Philippot, 2017; Lench and Levine, 2010), and inflated recall of negative affect has also been found in individuals with depression and PTSD (Ben-Zeev et al., 2009; Slagle, 2007). Examining the relationship between emotional intensity, physiological responding, and fear labeling in high-intensity experiences may shed light on the processes underlying the development of potential emotional triggers and may further provide information about the way affective experiences are differentially internalized and represented in individuals with various psychopathologies.

Most individuals don't walk down dark alleyways or navigate haunted houses in their daily life. However, the heightened affect and physiological intensity associated with these experiences *can* approximate the effects associated with the emotionally evocative events frequently 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 labeled 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.

Credit author statement

The listed authors contributed as follows: Joanne Stasiak: Data Curation, Formal Analysis, Investigation, Methodology, Software, Visualization, Writing (original draft preparation), Writing (review and editing). Billy Mitchell: Data curation, Investigation, Project administration, Writing (review and editing). Samantha Reisman: Investigation, Project administration, Writing (review and editing). David Gregory: Investigation, Project administration, Writing (review and editing). Vishnu Murty: Conceptualization, Funding acquisition, Project administration, Supervision, Writing (review and editing). Chelsea Helion: Conceptualization, Supervision, Writing (review and editing).

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/

Declaration of competing interest

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.

Data availability

Link to data/code is available at: https://osf.io/wh5za/

Appendix A. Supplementary data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.neuropsychologia.2023.108467.

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