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Overestimating the intensity of negative feelings in autobiographical memory: evidence from the 9/11 attack and COVID-19 pandemic

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ABSTRACT

When recalling autobiographical events, people not only retrieve event details but also the feelings they experienced. The current study examined whether people are able to consistently recall the intensity of past feelings associated with two consequential and negatively valenced events, i.e. the 9/11 attack ($N=769$) and the COVID-19 pandemic ($N=726$). By comparing experienced and recalled intensities of negative feelings, we discovered that people systematically recall a higher intensity of negative feelings than initially reported – overestimating the intensity of past negative emotional experiences. The COVID-19 dataset also revealed that individuals who experienced greater improvement in emotional well-being displayed smaller biases in recalling their feelings. Across both datasets, the intensity of remembered feelings was correlated with initial feelings and current feelings, but the impact of the current feelings was stronger in the COVID-19 dataset than in the 9/11 dataset. Our results demonstrate that when recalling negative autobiographical events, people tend to overestimate the intensity of prior negative emotional experiences with their degree of bias influenced by current feelings and well-being.

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Overestimating the intensity of negative emotion in autobiographical memory: evidence from the 9/11 attack and COVID-19 pandemic

Memories of emotional autobiographical events encompass details of what occurred and associated feelings. A common feature of these memories is that even though they are often vividly recollected, they are sometimes inaccurate or change over time (Rimmele et al., 2011; Talarico & Rubin, 2003). For example, studies of flashbulb memories – autobiographical memories for the circumstances of learning about a consequential, surprising event (Brown & Kulik, 1977) – have shown that many recollected details differ over time (Neisser & Harsch, 1992).

When investigating the consistency of flashbulb memories, past research typically examined memory for six canonical features: location/place, ongoing activity, informant, others present, own affect, and aftermath (Brown & Kulik, 1977). However, details associated with emotional and consequential events may vary in how well they are remembered (Rimmele et al., 2012), and among the canonical features associated with flashbulb memories of the 9/11 attack, memory for one's subjective feelings at the time of the attack i.e. own affect, was least consistent (Hirst et al., 2009).

In the present study, we examine factors that contribute to the remembered intensity of feelings associated with autobiographical events. Memories for feelings differ from other event details in many

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ways. In particular, feelings are internally generated and dissociable from external perceptual cues. Therefore, events that generated subjective feelings in the past may elicit feelings upon recollection which may or may not align with past experience. Moreover, unlike external event details, feelings are distinguished not only by their basic identity – how they are categorised or labelled (e.g. fear and happiness) – they also vary in intensity. Lastly, unlike most external event details, feelings associated with memories can impact individuals' current psychological health and well-being (Hamann, 2001; Safer et al., 2001). We take advantage of two consequential public events – the 9/11 terrorist attack and the COVID-19 pandemic – to explore factors that contribute to memories for feelings. Specifically, we examine (1) the consistency (9/11) or accuracy (COVID-19) of how intensely feelings are remembered, (2) how current feelings influence the remembered intensity of past feelings, and (3) the relation between the consistency or accuracy of remembered feelings and current well-being.

Existing studies examining how intensely feelings are remembered investigated memories for autobiographical, personally salient events and assessed either the consistency or accuracy of remembered feelings. Assessing the consistency or accuracy of memory for feelings both involve probing memory for feelings across multiple time points, but they differ with regard to what individuals are asked to remember. Studies of emotional memory accuracy (Levine et al., 2001, 2021) ask participants to report their *current feelings* about a consequential event, and later evaluate accuracy by comparing the remembered feelings to those reported at an earlier timepoint. In contrast to memory accuracy, the consistency of emotional memories is assessed by asking participants to report how they *felt* during a specific past consequential experience across distinct timepoints. As the initial assessment involves recollecting previous feelings, it is impossible to know if the report accurately reflects previous experience – it is only possible to determine if the memory is consistent over time. In the present study, we collected survey data during the COVID-19 pandemic to assess memory accuracy and used data from a study conducted in the wake of the 9/11 attack to assess memory consistency.

Previous studies examining memory for the intensity of specific emotional reactions have demonstrated that remembered feelings are generally accurate or consistent. One example involves a

study investigating memory for the grief associated with the death of a spouse (Safer et al., 2001). To characterise the accuracy of remembered grief, the authors administered a questionnaire 6 months after the death of participants' spouses probing their current intensity of grief and later evaluated how this initial report was remembered 4.5 years later. The authors found a lack of a statistically significant difference between the intensity of initially reported and remembered grief, which was on average only 2.1% less intense than initial ratings (Safer et al., 2001). However, accurate recollection of the intensity of past feelings did not preclude remembered feelings from being susceptible to biases. Instead, associations between recalled and current grief implicated a retrospective bias whereby current feelings are better predictors of remembered feelings than initial emotional experience. Given that the death of a spouse is a significant personal event (Frijda, 1992), retrospective biases in recollection have the potential to impact current well-being. For example, overestimating the intensity of a previous negative experience may enable individuals who have not adapted well to maintain a positive self-image. Consistent with this view, Safer et al. (2001) observed that widows who experienced relatively little improvement in well-being over time were more likely to overestimate previous grief in their recollections. However, given a lack of evidence for the causal directionality of this association, it is also possible that overestimating past stress results in diminished appraisals of current well-being. This suggests that despite the intensity of specific remembered feelings being generally accurate, directional biases in memory may be related to variations in well-being.

Another group of studies examined memories for the intensity of feelings experienced during salient political events. Notably, emotional reactions to such events can vary in valence and perceived consequentiality depending on individual beliefs (e.g. Levine, 1997; Levine et al., 2001, 2020, 2021; Schmidt et al., 2021). In one study, Schmidt and colleagues (2021) investigated two sources of bias when people recalled their feelings for past political events: current appraisals and feelings. To characterise the consistency of feelings and appraisals, the researchers had participants rate how intensely they felt 12 emotions at the moment they learned the news about the U.K. leaving the E.U., as well as how consequential Brexit was for the U.K. and themselves – two weeks and 18 months after Brexit. Similar to

Safer et al. (2001), there was a lack of statistically significant differences between the intensity of remembered and experienced negative feelings. However, closer examination reveals variability at the individual level, with 46.9% of participants overestimating emotional intensity and 42.7% underestimating it (Schmidt et al., 2021). Exploring these individual differences indicated the intensity of remembered feelings is shaped by current appraisals and current emotions: those who viewed Brexit as more consequential for the U.K., and who currently felt worse, tended to overestimate their negative feelings compared to their initial report.

The positive association between current appraisal and remembered feelings is also documented in studies looking at people's feelings during other political events (Levine et al., 2021). In this study, participants reported how intensely happy, angry, and fearful the election outcome made them feel two days, and six months following the 2016 US presidential election. When averaging each individual emotion, the authors did not observe any overall statistically significant differences between experienced and remembered emotions. However, there was considerable individual variability with 41% of participants overestimating the intensity of their past negative experience, 37% overestimating positive experience, and 22% remembering their experience consistently. Notably, the magnitude and direction of each individual's bias were strongly associated with how their feelings about the election changed over time: the more negative participants currently felt regarding the election outcome, the more they overestimated the intensity of previous negative emotions like anger and fear. However, participants whose feelings were consistent over time, and those who appraised the election outcome as more important, were more likely to remember the intensity of their feelings accurately. These results support the notion that memory biases may stem from both current emotions and appraisals during recall (Levine, 1997).

These findings demonstrate that despite the recollection of past feelings appearing accurate at a group level, directional biases in the recollection of emotional intensity can exist at an individual level. Consequently, inconsistencies among results from previous studies may reflect differences in the kinds of autobiographical emotional experiences assessed. For example, in contrast to the death of a loved one, emotional reactions to political events are likely more varied as they depend on an individual's

political views. Therefore, although the death of a loved one and election outcomes are both personally consequential, feelings associated with election outcomes are likely to be less uniform across participants. This suggests that the intensity of feelings associated with consequential events are not all remembered similarly, and differences in the accuracy or consistency of memory for the intensity of feelings may depend on one's appraisal of the emotional valence and consequentiality of the event.

Most previous research examining memories of feelings has examined the extent to which the intensity of specific feelings experienced in relation to an event is remembered over time. In contrast, Hirst et al. (2009, 2015) examined how consistently participants labelled the nature of their previous emotional experience. Specifically, participants completed a free-recall paradigm where they reported their feelings during the 9/11 attacks across four distinct time points: 1–2 weeks, 1, 3 years, and 10 years after the initial attack. If participants provided similar emotion labels (e.g. afraid/fear) at each timepoint, their memory was marked as consistent, but if a different emotional label was used (e.g. afraid/sad) their memory was considered inconsistent. Using this measure, Hirst et al. (2009) concluded memories of feelings were highly inconsistent over time – after 1 year similar emotion labels were used to describe feelings associated with the 9/11 attack only about forty percent of the time. Hirst et al. (2009) also conducted a follow-up analysis of rank-ordering retrospective ratings of the intensity of sadness, anger, fear, confusion, frustration, and shock to examine how the relative strength and order of remembered emotional reactions differed over time. This analysis additionally demonstrated that memories of past feelings were highly inconsistent over time, which is in contrast to the conclusions drawn from other aforementioned studies where people seem to be consistent in recalling their past emotions on a group level.

There are a couple of possible explanations for the discrepancy. First, the difference in current appraisal and emotion related to the 9/11 attack and political events could influence recalled emotion. Second, the different findings may be driven by how remembered feelings were probed. Hirst and colleagues asked participants to label their previous feelings by reporting the identity of the emotion they experienced. In contrast, being asked to report the remembered intensity of a list of specific emotions provides more contextual cues. This could potentially make it easier to appear to

recollect previous experiences by limiting response possibilities. Additionally, previous work has determined people are more accurate when predicting the future intensity of emotions compared to particular emotional responses – suggesting different mechanisms may underlie the two approaches for evaluating emotional memories (Levine et al., 2012; 2018). For instance, the process of labelling one's feelings could be moderated by people's emotion differentiation ability, that is, their ability to verbally characterise their emotional experience with granularity (Barrett et al., 2001). It might be difficult for people with low emotion differentiation ability to distinguish between discrete emotions of the same valence.

Our current study uses the same 9/11 dataset as Hirst et al. (2009) but examines whether people consistently recall the intensity of previous negative emotions associated with the 9/11 attack. We further use data collected during the COVID-19 pandemic to examine the accuracy of remembered stress. Specifically, we focused on participant's perceived stress during COVID-19. Perceived stress in this context can be interpreted as a negative emotion as it stems from an appraisal of an internal, negative state (Spada et al., 2008). To our knowledge, there is no previous work looking at how consistently perceived stress is remembered. In this paper, we use the term negative feelings to refer to both perceived stress and negative emotions. The COVID-19 dataset also enabled us to examine whether the intensity of remembered feelings associated with negatively valenced emotional events is susceptible to the same kind of retrospective biases observed with election outcomes.

To date, research investigating the consistency of remembered feelings for autobiographical events has emphasised punctate emotional events (Hirst et al., 2009; Levine et al., 2021; Safer et al., 2001; Schmidt et al., 2021). This differs from the COVID-19 pandemic, an ongoing, prolonged emotional event. By comparing the magnitude of memory biases across these two datasets, the current study enables us to examine how the nature of an emotional event relates to the accuracy and consistency of remembered feelings.

Methods

9/11 Study

Detailed descriptions of recruitment, data collection, and survey content associated with the 9/11 study are provided elsewhere (Hirst et al., 2009; 2015).

Participants

The 9/11 study included four surveys administered over 10 years. The first was administered shortly following the 9/11 terrorist attack (Sept 17 – Sept 21, 2001) across seven locations: Boston and Cambridge, MA; New Haven, CT; New York, NY; Washington, DC; St. Louis, MO; Palo Alto, CA; Santa Cruz, CA. Three follow-up surveys were administered approximately 1, 3 and 10 years after 9/11 (Survey 2: Aug 5 – Aug 20, 2002; Survey 3: Aug 9 – Aug 20, 2004; Survey 4: Aug 1 – Aug 15, 2011). All surveys included questions probing participants' memory about the 9/11 attack. Survey 1 was conducted on paper, and surveys 2–4 were conducted on paper or via a website. For analyses, we only included people who completed survey 1 and at least one follow-up survey, resulting in a total of 880 subjects (614 Female, 261 Male, 5 Unreported; Age $M = 38.63$, $SD = 21.48$; Race and Ethnicity: 21 Hispanic (2.4%), 664 White (75.5%), 46 Asian (5.2%), 23 Black (2.6%), 38 More than one race (4.3%), 4 Other (0.5%), 84 Unreported (9.5%)). Among them, 769 (536 Female, 230 Male, 3 Unreported; Age $M = 39.18$, $SD = 21.70$; Race and Ethnicity: 19 Hispanic (2.5%), 591 White (76.9%), 37 Asian (4.8%), 19 Black (2.5%), 30 Multiracial (3.9%), 4 Other (0.5%), 69 Unreported (8.9%)) completed survey 2. All participants provided consent and ethics approval was obtained from the Institutional Review Boards of all affiliated institutions including New York University and New School for Social Research (for details, see Hirst et al., 2009; 2015).

Questionnaires

For all surveys, participants reported the current intensity of their feelings concerning the 9/11 attack by responding to the prompt *At this moment, how strongly or intensely do you feel [sad/angry/fear/confusion/frustration/shock] about the attack?* on a scale from 1 (*low*) to 5 (*high*). In addition, for surveys 2, 3, and 4, participants reported the remembered intensity of their feelings concerning 9/11 in the two weeks following the attack by responding to the prompt: *How strongly or intensely did you feel [sad/angry/fear/confusion/frustration/shock] about the attack?* The order of the questions probing current and remembered intensity was counterbalanced between participants. For a detailed description of the survey, see Hirst et al. (2009, 2015).

COVID-19 Study

Participants

Participants were recruited from Prolific and Amazon Mechanical Turk online crowdsourcing platforms for two periods during the COVID-19 pandemic. Informed consent was obtained prior to beginning the experiment. At the first time point (T1; May 3, 2020 – Nov 16, 2020), 1810 participants (851 Female, 927 Male, 15 Other, 17 Unreported; Age $M = 32.02$, $SD = 10.80$) completed scales measuring state distress and a battery of questionnaires probing subjective stress due to COVID-related stressors. Participants were later invited to participate in a follow-up at a second-time point (T2; Aug 13, 2021 – Oct 7, 2021; interval $M = 402$, $SD = 49$ days; Supplementary Figure 1) in which they again completed all scales and questionnaires administered at T1 as well as additional questions retrospectively probing memory for COVID-related stress experienced at T1. A total of 726 participants (40.1%; 345 Female, 367 Male, 5 Other, 9 Unreported; Age $M = 34.77$, $SD = 12.1$; Race: 544 White (75%), 74 Asian (10%), 51 Black(7%), 45 Multiracial (6.3%), 12 Other (1.7%); Ethnicity: 66 Hispanic (9%)) returned. This study was approved by the Harvard University Committee on the Use of Human Subjects (IRB19-0789).

COVID-related questionnaires and psychological scales

Previous research and clinical observations suggest that people exhibited stress-related responses during the pandemic (Campo-Arias et al., 2020; Park et al., 2020; Taylor et al., 2020). To assess subjective stress associated with COVID-19, we compiled a list of 17 COVID-related stressors and asked participants to rate *How much stress are you currently experiencing?* on a Likert scale from 1 (*no stress at all*) to 5 (*a lot of stress*). Probed stressors included decreased socialisation, increased obstacles to engaging in regular daily activities, and problems obtaining basic needs such as paychecks and groceries (see Supplementary Table 10 for full list). Participants could select N/A if they were not currently experiencing specific stressors. These questions were completed at both time points.

At T2, after reporting current COVID-related stress, participants were reminded of when they completed Survey 1 (*when you first entered the study on MM/DD/YY...*). They were next instructed to recall their previously reported stress (*Please try to remember how you might have felt and responded then*). Cueing

presumably reduced the likelihood that participants would report their average COVID-related previous stress, rather than their stress at T1. They were subsequently presented with the list of stressors evaluated at T1 and rated their remembered stress using the same scale as before. Again, they could select N/A if specific stressors were considered irrelevant.

In addition to COVID-related stress, participants reported their emotional well-being by completing the 10-item Perceived Stress Scale (PSS; Cohen et al., 1983) and 21-item short-form Depression Anxiety Stress Scale (DASS-21; Henry & Crawford, 2005). These scales were administered at both time points.

Statistical analysis

Bayesian general linear models

Data were analysed using R, version 4.0.2 (version 4.3.1; R Core Team, 2023). For our analyses, we leveraged Bayesian Generalized Linear Models (BGLM). Utilising BGLM allowed us to take advantage of several Bayesian methods for evaluating the robustness of our results including posterior predictive checks for model fit, and Highest Density Intervals (HDI) for evaluating the uncertainty associated with parameter estimates. BGLM was implemented in R and interfaced with Stan via the *stan_glmer* function in the *rstanarm* R package (version 2.26.1; Goodrich, et al., 2023). See Supplementary Methods for more detailed information regarding Markov Chain Monte Carlo (MCMC) simulations.

Transparency and openness

We report how we determined our sample sizes, describe all participant exclusion criteria, manipulations and measures, and the software used for analyses. Additionally, to promote the quality and transparency of our analyses, we adhere to Bayesian Analysis Reporting Guidelines – a standardised list of criteria for producing and reporting reproducible Bayesian analyses for scientific publication (Kruschke, 2021). Analysis code is available at https://github.com/DaPsyientist/COVID911_EmoMem and data is available at <https://osf.io/kqe54/>. This study's design and analysis were not pre-registered.

Results

To accommodate the data-generating process of participants' ratings (1–5), dependent variables were transformed to lie between 0 and 1 for analysis with BGLMs using beta family distributions (Branscum et al., 2007;

Smithson & Verkuilen, 2006). Wherever participants had differing numbers of ratings due to “N/A” responses, a weighted beta regression method was utilised whereby weight corresponded to the number of responses provided by a participant. Prior evidence from simulations indicates the posterior direction (pd) statistic we report possesses a linear relationship with the frequentist p -value (Makowski et al., 2019). As such, pd can be interpreted as an index of effect existence, rather than statistical significance, which is approximately equivalent to $1 - p$ -value. Unless otherwise noted, parameter estimates are presented with median values and the highest density interval (HDI) at the 95% threshold. Similar to the frequentist confidence interval, the HDI describes a probabilistically likely range of posterior distribution values for an effect size given the observed data and explicit model assumptions.

Participants experienced decreased negative feelings at one year follow-up but overestimated the intensity of past negative emotional experiences

We leveraged the 9/11 and COVID-19 datasets to characterise the relationship between previous, current and remembered negative emotional experiences. First, we assessed how the intensity of negative emotions associated with the 9/11 attack changed over time. To enable comparisons between the COVID-19 and 9/11 datasets, we focused on ratings collected 2 weeks and 1 year following the attack, respectively. In line with previous work (Hirst et al., 2009; Schmidt et al., 2021), we characterised the overall intensity of negative feelings by averaging participants’ ratings over six negative emotions (sadness, fear, anger, confusion, frustration and shock; Cronbach’s $\alpha = 0.73$ for T1 experienced, 0.85 for T2 experienced, 0.71 for T2 remembered; McDonald’s total $\omega = 0.82$ for T1 experienced, 0.89 for T2 experienced, 0.81 for T2 remembered), and utilised a mixed-effects BGLM with time point (T1/T2) as a within-participant categorical predictor. Results from this analysis indicate the effect of time has a 100% probability [pd] of being negative providing evidence that the intensity of negative feelings experienced at T2 (2.81 ± 0.98) was lower than feelings at T1 (3.45 ± 0.82 ; $M = -0.77$, $\text{HDI}_{95\%} [-0.83, -0.70]$; Figure 1(a), Supplementary Table 1). In other words, people experienced less intense negative feelings one year after the attack.

After establishing that the level of negative feelings decreased, we evaluated the consistency of emotional

memory for the 9/11 attack. Following past work evaluating memory for the intensity of feelings (Levine et al., 2001; Levine et al., 2021), we compared remembered feelings reported at T2 with the intensity they reported at T1. Similar to our previous analysis, we used a mixed-effects BGLM with memory type (T1/Remembered) as a within-participant categorical predictor. Our results indicate the effect of remembering has a 100% probability [pd] of being positive providing evidence that people recalled experiencing more intense negative emotions (3.76 ± 0.75) than what they actually experienced (3.45 ± 0.82 ; $M = 0.40$, $\text{HDI}_{95\%} [0.33, 0.46]$; Figure 1(a). In other words, people’s memory of the intensity of negative emotions associated with the 9/11 attack was inconsistent, manifesting an overestimation in the intensity of their previous negative emotional experience (see Supplementary Results and Supplementary Figure 4 for emotion-level analyses).

Following a similar analysis procedure, we examined how stress related to the COVID-19 pandemic changed over time. COVID-related stress was characterised by averaging stress ratings across all 17 COVID stressors. The results were qualitatively similar to our 9/11 dataset: The effect of time had a 100% probability [pd] of being negative providing evidence that stress experienced at T2 (2.11 ± 0.81) was lower than stress at T1 (2.30 ± 0.84 ; $M = -0.28$, $\text{HDI}_{95\%} [-0.36, -0.21]$; Figure 1(b), Supplementary Table 2). In contrast, the effect of remembering has a 100% probability [pd] of being positive providing evidence that compared to actual stress at T1 (2.30 ± 0.84), remembered T1 stress was greater (2.40 ± 0.87 ; $M = 0.20$, $\text{HDI}_{95\%} [0.13, 0.27]$; Figure 1(b), Supplementary Figure 12). Altogether, these results suggest that the diminishing intensity of negative emotional experiences over time and the inaccuracy of memory for these experiences is not unique to the 9/11 attack, but more broadly applicable to negative emotional events including the COVID-19 pandemic (see Supplementary Results and Supplementary Figure 3 for regression analysis including demographic covariates).

Compared to COVID-related stress, memory for the intensity of negative feelings associated with the 9/11 attack was more inconsistent

After establishing a similar tendency to misremember negative emotional experiences occurring one year

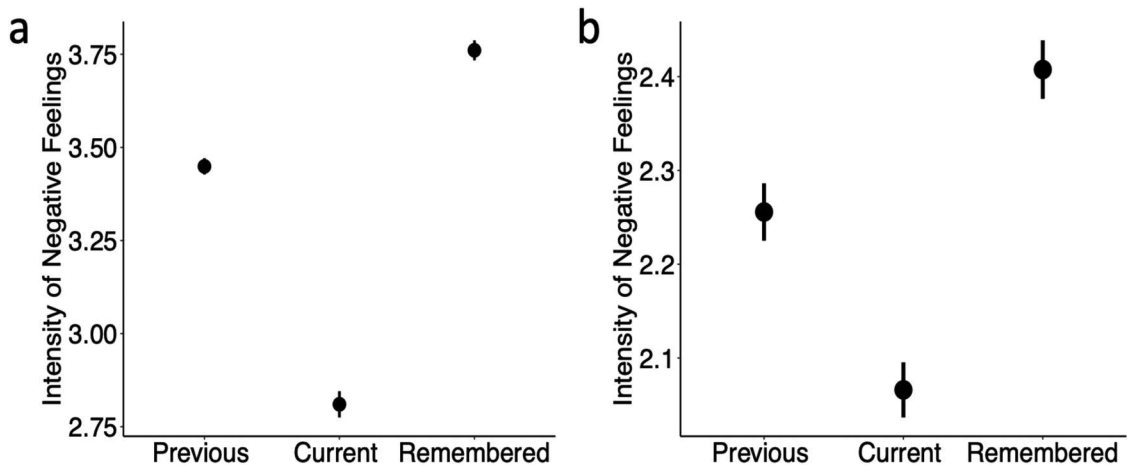


Figure 1. Relationship between previous, current, and remembered negative feelings in the (a) 9/11 and (b) COVID-19 datasets. At the 1-year follow-up survey, people reported currently experiencing less negative feelings while recalling higher levels of negative feelings than what they originally reported. Previous = T1 experienced; current = T2 experienced; remembered = T2 remembered. Points indicate mean estimate. Error bars indicate standard error. See Supplemental results for regression analysis including demographic covariates.

prior, we examined whether the magnitude of emotional memory inconsistency differs between the 9/11 and COVID-19 datasets. To this end, a memory deviation index was calculated for each participant by subtracting ratings of remembered from previously experienced feelings. A positive memory deviation indicates people recalled higher levels of stress/negative feelings than previously experienced i.e. overestimated previous stress/negative feelings. Model regressors included a categorical variable indicating the dataset (9-11/COVID-19) as well as previous ratings to control for baseline level differences. We found the effect of 9/11 has a 100% probability [pd] of being positive providing evidence that compared to COVID-related stress, memories of negative feelings elicited by 9/11 were more biased ($M = 0.21$, $HDI_{95\%} [0.17, 0.26]$, Supplementary Table 3), reflecting that participants were more likely to overestimate the intensity of experienced negative feelings for 9/11 compared to COVID-related stress.

Both previous and current emotional ratings influence remembered feelings

To further characterise sources of bias resulting in the overestimation of remembered negative feelings, we examined the relative influence of past and current negative emotional experiences and stress on memory. Specifically, we fitted Bayesian linear regressions to predict remembered feelings using

both current (T2) and previously reported feelings (T1). Separate regressions were fit for the 9/11 and COVID-19 datasets. The results indicate the effects of current and previously reported feelings have a 100% probability [pd] of being positive providing evidence that both current (9/11: $M = 0.46$, $HDI_{95\%} [0.44, 0.49]$; COVID: $M = 0.70$, $HDI_{95\%} [0.68, 0.73]$; Figure 2, Supplementary Table 4) and previous negative emotional experience/stress (9/11: $M = 0.48$, $HDI_{95\%} [0.45, 0.51]$; COVID: $M = 0.47$, $HDI_{95\%} [0.44, 0.49]$, Supplementary Table 5) are positively correlated with remembered negative emotional experience/stress. In other words, participants who reported higher negative feelings in the original questionnaire or at 1-year follow-up remembered experiencing more negative feelings initially. These results hold when controlling for measures quantifying the objective hardship (see Supplemental Results).

This analysis also enabled us to compare how people relatively weigh previous and current emotional experiences when constructing remembered emotional experiences. The 9/11 dataset results indicate that there was no difference between the predictive power of current and previous negative feelings (T1: $HDI_{95\%} [0.45, 0.51]$; T2: $HDI_{95\%} [0.44, 0.49]$; Figure 2(a,b); see Supplementary Results and Supplementary Figure 6 for the analysis conducted on each negative emotion). In contrast, the COVID-19 dataset results indicate that compared to previous stress, current stress exerts a larger

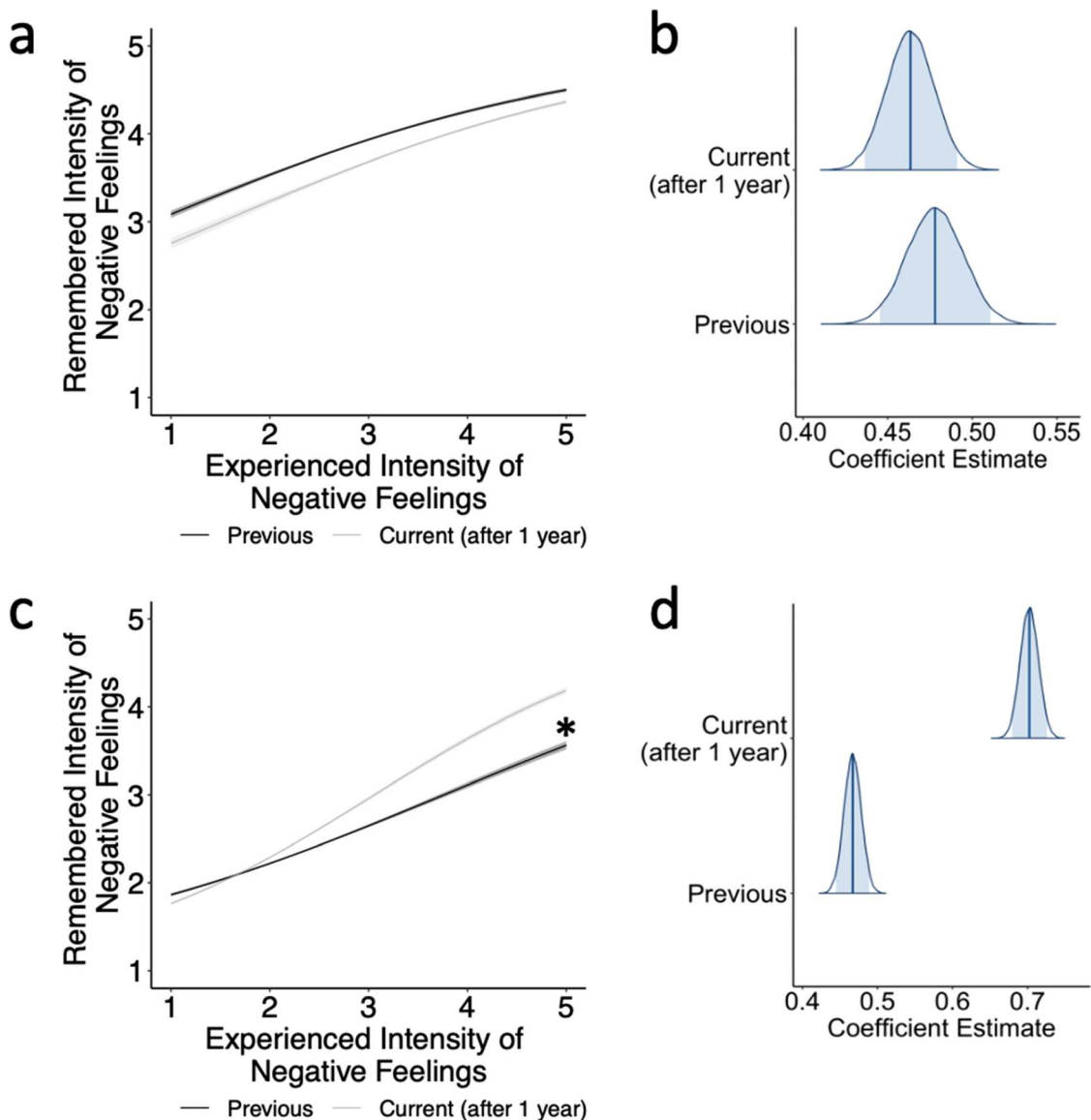


Figure 2. Influences of previous and current feelings on remembered feelings probed after 1 year. In the 9/11 (a,b) and COVID-19 (c,d) datasets, negative feelings and stress experienced at T1 and T2 (1-year follow-up) predict remembered negative feelings at T2, respectively. In the 9/11 dataset (a,b), the regression coefficients for T1 and T2 negative feelings did not differ in magnitude while in the COVID-19 dataset (c,d), the regression coefficient for T2 is larger than T1. Shaded areas indicate 95% credible interval of the model prediction (a,c) and posterior estimate of the coefficients (b,d). Previous = T1 experienced; current = T2 experienced; remembered = T2 remembered. * suggests that the 95% credible interval of the posterior estimates is non-overlapping. See Supplemental results and Supplementary Figures 5 and 7 for regression analysis including demographic covariates.

influence on the construction of remembered stress (T1: $HDI_{95\%}[0.44, 0.49]$; T2: $HDI_{95\%}[0.68, 0.73]$; Figure 2(c,d) – as indicated by non-overlapping HDI. This suggests that although COVID-19 and 9/11 were both negative and consequential events, they differ with regard to the degree of bias caused by current feelings.

Deviation of remembered from experienced negative feelings changes over time and peaks 3 years post 9/11

The previous analyses focused on data where the interval separating the memory probe and event onset was approximately 1 year. Utilising the 9/11

dataset, we examined whether the deviation between experienced and remembered negative feelings stay constant at 1-, 3-, and 10-year intervals (see Supplementary Results and Supplementary Figure 10 for the analysis conducted on each negative emotion). The results suggest that memory for negative feelings concerning the 9/11 attack deviated from the original negative feeling rating to the largest degree after 3 years (1 year vs. 3 years: $M=0.03$, $\text{HDI}_{95\%}$ [0.02, 0.04]; 10 years vs. 3 years: $M=0.03$, $\text{HDI}_{95\%}$ [0.02, 0.04]; Figure 3, Supplementary Table 6) and did not differ between 1 year or 10 years (1 year vs. 10 years: $M=0.002$, $\text{HDI}_{95\%}$ [-0.01, 0.01]).

Subjective well-being improves over time and is negatively associated with overestimating remembered COVID-related stress

The COVID-19 dataset included PSS and DASS, two psychometric scales measuring stress and depression, anxiety, and stress, respectively. To reduce the dimensionality of our data and obtain a general emotional well-being index, we performed a principal component analysis on the pooled questionnaires (N items = 31) at T1. Scores were reverse coded to ensure a higher score indicates better emotional well-being. We then used the first principal component (47.1% variance explained) as a composite

score of emotional well-being that highly correlated with the subscale scores calculated using PSS and DASS separately (all $r_s > .8$, all $p_s < .001$; Supplementary Table 11). Participants' emotional well-being at T2 was then calculated using the loading matrix obtained from T1 (Supplementary Table 12). Subsequently, we conducted a Bayesian linear regression analysis to compare emotional well-being at T1 and T2. The results of this analysis indicate that the effect of time has a 99.93% probability [pd] of being positive providing evidence that compared to initial well-being at T1 (0 ± 3.82), participants' well-being at T2 improved (0.15 ± 3.85 ; $M=0.37$, $\text{HDI}_{95\%}$ [0.14, 0.54]; Supplementary Table 7, Supplementary Figure 2). Finally, the association between changes in emotional well-being and deviations in remembered COVID-related stress was examined. Specifically, we used the difference between emotional well-being at T1 and T2 to predict deviations in memory, with previous stress being included as a covariate. This analysis indicated the effect of improved emotional well-being has a 100% probability [pd] of being negative providing evidence that increased emotional well-being was associated with decreased deviations in remembered COVID-related stress ($M=-0.03$, $\text{HDI}_{95\%}$ [-0.03, -0.02]; Figure 4, Supplementary Table 8). This partial correlation is robust, remaining positive when controlling for current stress (Supplementary Table 9) and operationalising subjective

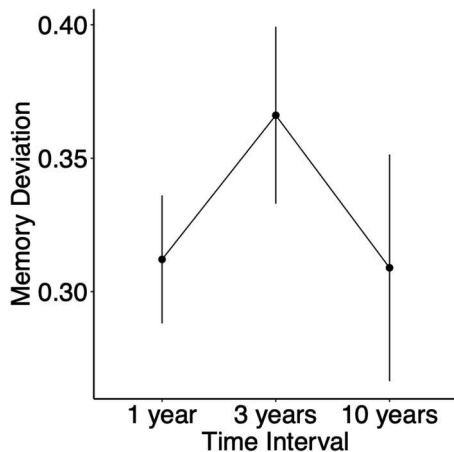


Figure 3. Deviation of remembered negative feelings from experienced negative feelings concerning the 9/11 attack after 1, 3, and 10 years. A positive memory deviation index indicates the overestimation of previous negative emotional experiences. Deviation peaked during the 3-year follow-up survey. Points indicate mean estimate. Error bars indicate standard error. See Supplemental results and Supplementary Figures 8 and 9 for regression analysis including demographic covariates.

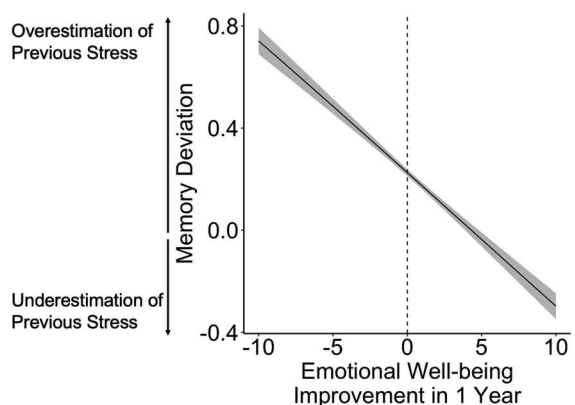


Figure 4. Association between improvements in emotional well-being and deviation in memory of COVID-19 related stress. A positive memory deviation index indicates an overestimation of previous negative emotional experiences. People with higher emotional well-being at the 1-year follow-up have smaller deviations in memory. Shaded areas indicate 95% credible interval of the model prediction. See Supplemental results and Supplementary Figure 11 for regression analysis including demographic covariates.

well-being using just the DASS score ($M = -0.77$, $HDI_{95\%} [-0.83, -0.70]$). Notably, our sample tended to overestimate prior stress (Intercept $M = 0.44$, $HDI_{95\%} [0.42, 0.47]$) – suggesting people with improved emotional well-being remain inaccurate in reporting the intensity of remembered stress, but display less overestimation.

Discussion

This study investigated the subjective components of episodic memory underlying autobiographical recall with an emphasis on auto-noetic consciousness – the explicit awareness of self (how one felt) within a particular time–space context (Tulving, 1972). Specifically, our study aimed to examine three aspects regarding the intensity of remembered feelings for the COVID-19 pandemic and the 9/11 attack: (1) how consistent (9/11) or accurate (COVID-19) the intensity of remembered feelings are, (2) how current feelings influence memories for the remembered intensity of past feelings, and (3) the association between the consistency or accuracy of remembered feelings and current well-being.

Assessing the consistency of remembered feelings for emotional experiences associated with 9/11 demonstrated that the intensity of past feelings was inconsistently recalled. Remembered feelings were also inaccurately recalled for our COVID-19 sample. Both samples were associated with a tendency to overestimate the intensity of past negative emotional experiences. On the surface, this seems to conflict with past studies where participants remembered the intensity of their past feelings accurately. However, conclusions from these studies were obtained by evaluating overall accuracy at the group level. When the accuracy of each individual's remembered feelings is considered across these studies, the results reveal individual variability with regard to how accurately the intensity of remembered feelings is recalled. For instance, Levine and colleagues (2021) found that when participants felt more negative over time about the 2016 US presidential election, they overestimated how angry and scared they initially were, and underestimated happiness. Similarly, Schmidt and colleagues (2021) found that individuals who currently felt worse, or saw Brexit as more consequential for the U.K., recalled stronger negative emotions than their initial experience. This indicates that how accurately the intensity of feelings is remembered depends on the valence of

the initial experience and individuals' current appraisals. Our results differ from these past election outcome studies in that we only examined events likely to elicit negative reactions. Consequently, the bias we observed for remembered feelings across both our samples was larger than in previous studies and directionally consistent.

Our 9/11 sample also enabled us to generalise how the consistency of remembered feelings changes over a longer time scale than one year. For the 9/11 attacks, remembered feelings were most overestimated after three years – rising after the first year, and returning to first-year levels after ten years (Figure 3). This pattern of results suggests the consistency of remembered feelings varies non-linearly over time. One potential explanation for this non-linear pattern is the *Moore effect* (Hirst et al., 2015). Previous research investigating the consistency of autobiographical memory for event details associated with 9/11 determined that the appearance of Michael Moore's film *Fahrenheit 9/11* three months prior to distribution of the 3-year follow-up survey reinvigorated attention to 9/11. This effect is particularly relevant as we utilise the same dataset in our present analyses. Hirst et al. (2015) identified this phenomenon as resulting in a marked increase in accuracy, but only for the consistency of event details (i.e. facts such as where was President Bush at the time). It is therefore possible that by reinvigorating attention to 9/11, the perceived relevance of 9/11 may have been increased – resulting in more consequential appraisals of the previous negative experience. Nonetheless, future research can determine the generality of this non-linear association with other consequential events like the COVID-19 pandemic.

In addition to characterising the consistency of memory, we evaluated whether remembered feelings were susceptible to similar biases as those observed in previous studies. In their prior investigation of the intensity of remembered grief in widows, Safer and colleagues (2001) uncovered a recency bias whereby the intensity of current grief was more predictive of remembered grief than initial grief. Schmidt and colleagues (2021) replicated and expanded these findings by demonstrating that remembered negative emotions were biased by current negative feelings in addition to appraisals regarding the consequentiality of the event. In order to determine whether remembered feelings were biased by current emotional experience, we investigated the influence of past and current feelings on the remembered intensity of

negative events across our two samples. For accurate recollection, current emotional experience should only be associated with remembered feelings insofar as current and past feelings are similar. However, results from our two samples demonstrate that both current and initial emotional experiences were involved in the constructions of remembered feelings. Furthermore, current experience predicted remembered feelings despite participants experiencing a lower intensity of negative emotional experience or stress than either their initial, or remembered, ratings. These results are consistent with those obtained in past studies on the vulnerability of remembered emotion (Levine, 1997; Safer et al., 2001) and highlight the pervasive influence of current experience on remembered feelings.

Across both the 9/11 and the COVID-19 dataset, the intensity of remembered feelings was overestimated with current emotional experience biasing remembered feelings. Beyond these similarities, there was variation in our samples with regard to the magnitude of each effect. Compared to COVID-related stress, the remembered intensity of negative feelings elicited by 9/11 was overestimated more. Furthermore, whereas the intensity of current and past emotional experience was weighted equally in memories for the intensity of feelings experienced during 9/11, current stress had a larger bias than past stress on remembered feelings in our COVID-19 sample – implicating a recency bias in recollection. There are several factors which may have led to these observed differences.

Previous studies have shown that the quality and quantity of emotional details in autobiographical memories may differ in association with how recent or remote remembered time periods are (Wardell et al., 2021). Our current study compares memory for emotional experiences across the same time period (i.e. one year), but demonstrates quantitative differences in the magnitude of overestimation across our events despite a qualitatively consistent effect of overestimation. This suggests that in addition to the duration between periods when memory is probed, the duration of an autobiographical event can influence the recollection of details associated with the event. Punctate, negative events like 9/11 are temporally acute which may facilitate stronger recollections of feelings that may deviate from the initial experience. In contrast, prolonged, intense negative events like COVID-19 may increase the difficulty of distinguishing recent experiences from

those at earlier time points – resulting in an overreliance on recent experience when constructing a memory. Of particular note, research investigating how emotional experiences influence the recollection of autobiographical memory demonstrates that lockdowns associated with the COVID-19 pandemic can compress individuals' perceptions of passing time (Rouhani et al., 2023). Therefore, the larger recency bias in the construction of remembered stress we observed for our COVID-19 sample may be the result of a compressed temporal representation of self. Alternatively, recent research indicates that the recollection of past experiences associated with COVID-19, such as the protective behaviour individuals engaged in, is motivationally biased and depends strongly on current evaluations (Sprengholz et al., 2023). These results align well with our finding that current stress factors heavily into the construction of remembered stress and suggests the effect of current stress may be greater in recollection for negative emotions experienced during COVID-19 compared to 9/11 due to the motivational salience associated with the prolonged ongoing stress of the pandemic.

In addition to the temporal duration of an autobiographical event, another potential factor influencing remembered negative feelings is how memory was evaluated. Specifically, the COVID-19 survey at T2 asked participants how they felt when they first filled out the survey at T1; in contrast, our 9/11 sample was tasked with recalling the intensity of their initial emotional experience during the attack. Memory for feelings associated with an arbitrary date when participants entered the COVID-19 study may be less rich than memories of a salient event like the 9/11 attack. Therefore, people may rely more on their recent experience when reconstructing their memories for dates that are arbitrarily imposed by the experimenter. This account is supported by Safer et al. (2001), where the participants demonstrated a recency bias in their memory of grief 6 months after the death of a spouse was probed i.e. during the extended period of grief. The higher reliance on recent experience in COVID-19 dataset may also reflect a difference in experimental design. In the COVID-19 study, participants always first reported current stress and then recalled previously experienced stress, which may make participants anchor their remembered stress on their current stress level, while the order of these two sets of questions is counterbalanced in the 9/11 dataset. Finally,

the feelings probed across the two datasets also differ. The COVID-19 survey asked participants to report their perceived stress related to 17 COVID-related stressors while the 9/11 survey asked participants to rate 6 negative emotions. Although we conceptualised both studies as examining negative feelings in the current paper, it is possible that the recall processes associated with stress and negative emotions may be distinct. Moreover, prompts used in the COVID-19 survey only asked about specific stressors using close-ended questions, whereas the 9/11 survey also used open-ended questions to assess negative emotions. Therefore, it is possible that the COVID-19 survey did not holistically capture people's overall stress experience. However, future experiments are necessary to confirm the hypotheses above.

The final aspect we investigated about the intensity of remembered feelings was whether there was an association between misremembered feelings and current well-being as measured by the DASS and PSS. As well-being was not measured in the 9/11 sample, we only examined this for our COVID-19 sample. Consistent with our finding that stress ratings decreased over time, people's well-being improved after one year. Critically, improvements in well-being were negatively associated with overestimating past COVID-related stress: individuals who improved the least in well-being tended to overestimate the intensity of their past negative experience the most. This is consistent with previous work showing that widows whose grief improved the most – signalling effective coping – tended to overestimate the intensity of past negative experiences the least, a form of retrospective reappraisal (Safer et al., 2001). This congruence suggests retrospective reappraisal is occurring in our COVID-19 sample, with improvements in well-being reflecting better coping with stress – although it is possible that other factors may also be contributing to improved well-being, such as a general alleviation of stress with time. We cannot rule out these possibilities, but they are not mutually exclusive with our arguments and notably the association between changes in well-being and memory bias remains robust even after including current stress as a covariate in our model (Supplementary Table 8).

These findings indicate both our samples were biased towards overestimating the intensity of past negative feelings. Furthermore, our regression analysis suggests that overestimating past negative

feelings may be associated with decreased current well-being. This pattern of results is consistent with research examining the relation between remembered grief and well-being (Safer et al., 2001), but inconsistent with other research investigating how the recollection of pre-exam anxiety relates to confidence in coping abilities (Keuler & Safer, 1998). These discrepancies indicate that misremembering the intensity of negative feelings is generally associated with changes to current well-being, but its effect may depend on situational context and the nature of the emotional experience. Demonstrating that inaccurate recollection can be consequential to well-being is important as we know very little about the effects of misremembered emotions on current emotional well-being. Our results only inform us about the context of recalling the intensity of previously endured stress but indicate that overestimating the intensity of negative feelings is negatively associated with current well-being.

Broadly speaking, our findings are in line with previous work investigating how people predict their future emotional experiences (i.e. affective forecasting) whereby participants show biases in estimating the magnitude of their anticipated reactions to future emotional events (Levine et al., 2018; Wilson & Gilbert, 2005). The literature on affective forecasting has offered two main explanations for the source of these biases, with one argument being that people exhibit focalism, attending too much to the event that they are currently experiencing rather than future relevant events. This argument could account for the robust correlation between current and remembered feelings. Another explanation – termed immune neglect – postulates that people fail to fully consider their ability to cope with negativity, which is similar to the concept of retrospective appraisal. Indeed, although recalling past feelings essentially focuses on the past, this process shares many commonalities with predicting future affective experiences (e.g. D'Argembeau & Van der Linden, 2004) in that both require one to simulate their feelings at a different time and space. Accordingly, people may inadvertently extrapolate from currently salient information such as current beliefs, appraisals, and feelings when forming judgments about both past and future feelings. Therefore, unrepresentative salient information has the potential to bias recollection.

Previous studies have shown that the quality and quantity of emotional details in autobiographical memories may differ from other types of details

(Wardell et al., 2021). In our current study, we utilised the same 9/11 sample as Hirst et al. (2009) and demonstrated that how memory for the emotional details of autobiographical events is probed may also lead to varying results. Therefore, our study provides unique insights into the mechanistic processes of episodic memory systems by highlighting the influence of retrieval methodologies on memory accuracy. Hirst et al. examined the consistency of remembered feelings by comparing how categorical negative emotion labels used to describe an initial 9/11 experience changed over time. However, we used an alternative measure of consistency which allows us to compare how memory for consequential, emotional events varies as a result of how remembered feelings are defined. In contrast to Hirst and colleagues, we evaluated how numerical ratings for the remembered negative intensity of the initial 9/11 experience changed over time – a continuous measure of consistency more commonly utilised in research examining the consistency of remembered feelings (Kaplan et al., 2016; Levine et al., 2001; Levine et al., 2021; Safer et al., 2001; Schmidt et al., 2021). These past studies generally demonstrate low rates of inaccuracy below 3%, but this is likely the result of individual variability in memory biases which depend on the valence of the emotional event and individual appraisals of its consequentiality. Compared to these past studies, remembered feelings in our 9/11 sample were more inaccurate with a 9% rate of overestimation. However, this is strikingly less than the 58% rate of inaccuracy obtained by Hirst and colleagues when using a categorical measure of consistency with the same sample (Hirst et al., 2009). This suggests that providing emotion labels as cues for subjects to use when retrospectively rating their emotional experience likely minimises response variability because, without these labels, participants' categorical ratings would lack knowledge of the initial rating scale. Indeed, Hirst and colleagues anticipated this confound and explicitly stated they were not interested in participant's memory for a particular score as this would require them to remember the scale they used as well as their emotional intensity.

Our findings complement past research on the consistency or accuracy of remembered feelings for emotional experiences in three important ways. First, our results clarify that in contrast to previous conclusions, remembered feelings for negatively valenced experiences are inconsistent. Although

past research suggests remembered feelings for emotional events are accurately remembered, these results were likely confounded by examining memory for emotions with differing valence, and via memory biases from individual's appraisals of the event's consequentiality. In contrast, memory in our 9/11 and COVID-19 samples was directionally biased in a consistent manner resulting in a general overestimation of the intensity of negative remembered feelings. Secondly, comparing how the intensity of past emotional experiences was remembered across our two samples indicates not all negative events are remembered the same. In particular, our research highlights the overall accuracy of memory for feelings during past events depends on several factors including the nature of the event, the way remembered feelings are probed, and the type of feeling. These findings also suggest the temporal duration of an emotional event may impact remembered feelings and highlight the necessity for further research contrasting memories for punctate and prolonged stressful events.

Lastly, leveraging different measures of consistency within the same sample suggested that the overall inaccuracy of remembered feelings depends on how memory is evaluated. When we compared the remembered intensity of emotions specified by researchers to the free recall of categorical emotion labels, we observed that the latter exhibited a higher degree of inconsistency. This suggests that prior research, which assessed the accuracy of remembered emotional intensity for cued emotions, may have inadvertently underestimated the inconsistency of remembered feelings. As a result, future studies should exercise caution when deciding how to characterise the consistency of remembered feelings. Whereas evaluating the accuracy of intensity ratings for emotions enables the characterisation of how specific emotional experiences change over time, using free-recall categorical measures may provide a more complete picture of the overall consistency of remembered feelings. Additionally, another question that remains concerns the extent to which subjective ratings of experienced feelings are consistent over time. In other words, the ratings for emotions may differ by virtue of being repeatedly probed. Admittedly our results could be influenced by this test-retest noise. That said, we would not expect the noise to be directional, i.e. showing an overall pattern of overestimation, as what our main results suggest. Indeed, previous work has found that

emotions recalled after one day do not significantly differ from the emotion experienced (Hughes et al., 2022), suggesting a test-retest reliability for self-report emotions at least on a short time scale.

Constraints on generality

This study has limitations. First, we tried to shed light on people's memory of negative autobiographical events using datasets related to the 9/11 attack and COVID-19 pandemic, but our findings may not generalise to events that are more personal and/or common in daily life, such as quarrelling with a friend. Although we examined several contextual factors that could influence people's remembered feelings, more research is needed to enable a comprehensive understanding of the relationships between event features and the remembered negative feelings. Second, selection bias may exist in our samples. For the 9/11 dataset, we included people who completed at least one follow-up study instead of people who completed all three questionnaires (1, 3, and 10 years after the attack). This data exclusion criterion was established to obtain a relatively well-powered sample size, but risks ignoring people who intentionally chose not to participate in follow-ups. Similarly, for the COVID-19 sample, some participants did not return. Furthermore, both samples were geographically located in the US which may limit how well our results generalise to populations outside of the US. When comparing the COVID-19 and 9/11 samples, we notice that there exists a difference in gender composition (9/11: 29.7% male; COVID-19: 50.5% male). Therefore, any effect of gender on memory could impact two datasets differently and thus contributing to the difference we observe between the two datasets. Third, in the second survey of COVID-19 study, current feeling is always probed before remembered feelings, which may make the results susceptible to anchor effects (for a review, see Furnham & Boo, 2011). Finally, our study suggests that the accuracy and consistency of memory are sensitive to how recollection is probed. However, we restricted our analysis to the remembered intensity of negative stressful experiences, and did not examine how arousing events of a positive valence are remembered. Although it is possible to evaluate other kinds of stressors such as the birth of a child – which is usually seen as a positive stressor – it is difficult to predict what the association between emotional memory accuracy and well-being would be

given that our paper highlights the importance of context in this relationship. Thus, the findings presented in this paper may not generalise beyond the remembered intensity of negative emotional experiences and we leave the question of whether the effect of stressful emotional events differs due to valence as a question for future research.

Our findings demonstrate a relative fallibility in memory for the intensity of emotional experiences. However, these findings deserve further elaboration. Whereas participants in both the 9/11 and COVID-19 samples were inaccurate in recalling their prior emotional intensity, they consistently recalled the negative valence of these events. This suggests that errors in memory are rather a matter of degree and that despite occasional inconsistencies or inaccuracies, memory often excels at preserving the emotional context of autobiographical experiences; a complexity our findings illustrate. These insights invite ongoing investigations into the interplay between memory and the diverse spectrum of emotional experiences, particularly with designs that assess the full valence spectrum.

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



Data availability statement

Part of this data was presented at the 14th Annual Meeting of the Social & Affective Neuroscience Society, seminars at Harvard University, and the 56th Annual Meeting of the Association of Behavioral and Cognitive Therapies. Analysis code is available at https://github.com/DaPsyientist/COVID911_EmoMem and data is available at <https://osf.io/kqe54/>.

Author contributions

JC and HF were involved in conceptualisation, investigation, data curation, formal analysis, methodology, visualisation, and writing. OTK and JS were involved in the investigation, data curation, and writing. YS, MAK, SV, JPO and HMD were involved in the investigation and writing. DCS was involved in the investigation. RM was involved in investigation, data curation, and project administration for the 9/11 dataset. WH was involved in conceptualisation, investigation, data curation, methodology, funding acquisition, project administration and supervision for the 9/11 dataset. EAP was involved in conceptualisation, investigation, data curation, methodology, funding acquisition, project administration, supervision, and writing.

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