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Can neutral episodic memories become emotional? Evidence from facial expressions and subjective feelings

Sascha B. Duken[a,b,*], Franziska Neumayer[c], Nadza Dzinalija[d], Merel Kindt[a], Vanessa A. van Ast[a,1,**], Renée M. Visser[a,1,***]

[a] Department of Clinical Psychology, University of Amsterdam, Amsterdam, the Netherlands
[b] Department of Clinical Psychology, Utrecht University, Utrecht, the Netherlands
[c] Department of Child and Adolescent Psychiatry, Center for Psychosocial Medicine, University Hospital Heidelberg, Heidelberg, Germany
[d] Department of Medical Humanities, Amsterdam University Medical Center, Vrije Universiteit Amsterdam, Amsterdam, the Netherlands

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ABSTRACT

Maladaptive emotional memories are a transdiagnostic feature of mental health problems. Therefore, understanding whether and how emotional memories can change might help to prevent and treat mental disorders. We tested whether neutral memories of naturalistic events can retroactively acquire positive or negative affect, in a preregistered three-day Modification of Valence in Episodes (MOVIE) paradigm. On Day 1, participants ($N = 41$) encoded memories of neutral movie scenes, representing lifelike naturalistic experiences. On Day 2, they retrieved each episode before viewing a happy, sad, or neutral scene from the same movie (yielding a within-subjects design with a neutral-negative, neutral-positive, and neutral-neutral condition). On Day 3, participants again retrieved each memory from Day 1. We assessed the affective tone of episodes through facial expressions of positive and negative affect (using facial electromyography, fEMG) and through self-reported feelings. Positive updating of neutral episodes led to increased expressions of positive affect, whereas negative updating led to increased self-reported negative feelings. These results suggest that complex neutral episodic memories can retroactively acquire an affective tone, but the effects were modest and inconsistent across affect readouts. Future research should investigate alternative approaches to updating emotional memories that produce more profound changes in the valence of memories.

1. Introduction

Maladaptive emotional memories are increasingly recognized as a transdiagnostic feature of mental health problems, including mood and anxiety disorders (Barry et al., 2021; Brewin, 2011; Dalgleish & Hitchcock, 2023; Kindt, 2014). For example, people with depressive symptoms have difficulties retrieving positive episodes from their past (Everaert et al., 2022; Matt et al., 1992) and they do not experience positive emotions when remembering happy events (Joormann et al., 2007; Joormann & Siemer, 2004). Since such memory distortions might play a causal role in the onset and maintenance of mental disorders (Dalgleish & Hitchcock, 2023; Hallford et al., 2021, 2022), changing the affective impact of episodic memories is a central ingredient in several treatments of mental disorders (Arditte Hall et al., 2018; Arntz, 2012; Holmes & Mathews, 2010; Leer et al., 2014). However, it remains elusive whether the affective tone of memories can indeed change and whether such change might underly the reduction of symptoms in therapeutic settings. In the current study, we tested whether neutral episodic memories can retroactively acquire positive or negative emotionality.

Evidence from fear conditioning studies suggests that emotional memories are not permanent but can be modified or even erased. When a threat memory is reactivated through a reminder (e.g., the presentation of a conditioned stimulus or context), it may enter a labile state during which the memory can be disrupted through pharmacological or behavioral interventions (Haubrich et al., 2015; Kindt et al., 2009;

* Corresponding author.
** Corresponding author.
*** Corresponding author.
E-mail addresses: s.b.duken@uu.nl (S.B. Duken), v.a.vanAst@uva.nl (V.A. van Ast), r.m.visser@uva.nl (R.M. Visser).
[1] Vanessa A. van Ast and Renée M. Visser contributed equally to this manuscript.

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Monti et al., 2016; Nader et al., 2000; but there are also failed replications, e.g., Schroyens et al., 2017, 2019). In mice, it is even possible to reverse the valence of a conditioned fear response by reactivating a contextual threat memory and re-associating the context with a new appetitive stimulus (Grella et al., 2022; Redondo et al., 2014). After such memory updating, mice show preference for the initially feared context instead of avoiding it or freezing. While these studies help to understand and treat simple associative fear memories that are relevant for some anxiety disorders such as specific phobias (Soeter & Kindt, 2015), it is unclear whether their findings translate to more complex episodic memories that are relevant in different mental disorders and involve other emotions than threat and fear (Everaert et al., 2022; Holmes et al., 2016).

In depression, episodic memories of sad and happy events are more relevant than fear memories (Everaert et al., 2022; Joormann & Siemer, 2004; Millgram et al., 2019). These episodic memories involve other emotional, cognitive, and psychobiological processes than fear memories. For instance, sadness and happiness are elicited by different events (Gilman et al., 2017; Rottenberg et al., 2007), have different effects on behavior and cognition (Lench et al., 2011), and are characterized by different peripheral and central psychobiological processes (Kreibig, 2010; Kreibig et al., 2007, 2011; Saarimäki et al., 2016). Given these dissimilarities between conditioned fear and episodic memories, it remains elusive whether the affective tone of episodic memories can change. However, if the affective tone of episodic memories could change, this might provide insights into the etiology and treatment of memory distortions in psychopathology. If initially benign episodic memories could become more negative, this might cause excessively negative memories in some individuals (Dalgleish & Werner-Seidler, 2014). If memories can become more positive, this might help to treat diminished positive memories in depression (Dalgleish & Werner-Seidler, 2014).

So far, there is suggestive evidence that manipulating an episodic memory with new information (for example, a mood induction or unrelated story) can lead to changes in declarative memory components such as remembered episodic details (Kredlow & Otto, 2015; Liu & McNally, 2017; Piñeyro et al., 2018; Schwabe & Wolf, 2009). However, evidence for memory updating was often only found in some participants but not others (Piñeyro et al., 2018), or in one of multiple outcome variables (Liu & McNally, 2017). Another study found that reading a negative, but not a positive or neutral story, upon negative autobiographical memory retrieval changed the remembered details of the autobiographical memory (Kredlow & Otto, 2015). Importantly, most studies investigated the updating of declarative memory components rather than the affective impact of memories (Kredlow & Otto, 2015; Schwabe & Wolf, 2009). From a clinical point of view, interventions should target particularly those aspects of a memory that may give rise to symptoms, such as the affective responses that a memory evokes rather than the factual recollection of events (Visser et al., 2018).

We investigated the affective tone of memories before and after emotional memory updating through subjective feelings as well as through facial expressions of positive and negative affect using facial electromyography (fEMG; Larsen et al., 2003). Subjective feelings and facial expressions are crucial components of affective processes, but they rely on partially independent mechanisms with self-reported feelings capturing the conscious and subjective experience of emotions, and facial expressions reflect more automatic responses (Scherer, 2009). By investigating both components, it is possible to gain insights into what emotional components might be particularly susceptible to affective memory updates. Also, given that facial expressions are relatively automatic, they might be less prone to experimental biases such as demand effects, particularly in studies with obvious manipulations that are easily identified by participants (Ray et al., 2010; Sharpe & Whelton, 2016).

In a preregistered experiment, we tested whether consolidated memories of neutral events can be updated with positive or negative valence. We conducted the experiment across three days to investigate updating processes of consolidated long-term memories, rather than short-term memory processes or the integration of information into not yet consolidated memories (Diekelmann & Born, 2010; Elsey et al., 2018). On Day 1, participants encoded memories of neutral movie scenes, representing lifelike naturalistic experiences. On Day 2, they retrieved each neutral episode before viewing a positive or negative scene from the same movie, resulting in a neutral-positive and a neutral-negative updating condition. The memory retrieval before viewing the updating emotional scene represented a reactivation of the original memory, allowing the new information to be linked to the original episode (Elsey et al., 2018; Gisquet-Verrier & Riccio, 2018). It also served as a baseline assessment of the affective tone of each memory before updating. We included a control condition in which neutral information was provided on Day 2 (neutral-neutral) to investigate whether any changes in affective tone were specific for reactivated memories that were followed by new emotional information (neutral-positive and neutral-negative). On Day 3, we instructed participants to retrieve the original Day 1 memory, and we tested whether the emotional information on Day 2 changed participants' affective responses when thinking back to the original Day 1 scene. Importantly, participants viewed memory cues that were related to the neutral Day 1 memories, but not to the emotional scene on Day 2. Therefore, affective responses on Day 3 could solely result from memory updating of the Day 1 memory by the emotional Day 2 information.

We expected an increase in positive affect from Day 2 to Day 3 in the neutral-positive condition (measured with zygomaticus responses and subjective valence), and that this increase would be larger than in the neutral-neutral condition. Additionally, we expected an increase in negative affect in the neutral-negative condition (measured with corrugator responses and subjective valence) and that this increase would be larger than in the neutral-neutral condition.

2. Methods

2.1. Participants

Participants were recruited through advertisements on the campus and through an online portal for volunteers of the University of Amsterdam. Interested participants completed a brief online screening questionnaire. Based on this screening, people were not invited to the lab when: a) they reported that they knew more than three movies from our stimulus set or more than one movie clip within one condition, b) they had already participated in a similar study from our lab, c) they did not have at least an advanced English proficiency level (verified during first contact per phone), or d) they met any other exclusion criterion (color blindness, current mental disorder or a diagnosis within the last year, current or past neurological problem, excessively frequent recreational drug or alcohol use). These exclusion criteria were assessed again on site to verify the responses in the online screening.

A previous study that measured fEMG responses to negative, positive, and neutral memories but did not manipulate the emotional tone of memories (Experiment 1 in Duken et al., 2022) yielded significant effects of emotion with 48 participants. We expected that manipulated memories in the current study (in the neutral-positive and neutral-negative condition) would be less strong than originally positive or negative memories. Therefore, we aimed to test a slightly larger sample of $N = 60$ participants (not counting participants that had to be excluded based on preregistered criteria). Eighty participants attended the first lab session and provided informed consent to participate in the study. We excluded a total of twelve participants for several reasons: excessive drug use ($n = 2$), experimenter error ($n = 6$), previous participation in a similar study ($n = 1$), technical error ($n = 1$), excessive alcohol use ($n = 1$), or treatment for a psychiatric disorder ($n = 1$), which resulted in a sample size of $N = 68$ ($M_{age} = 20.3$, $SD_{age} = 2.8$, 54 self-reported females, 14 self-reported males). Based on preregistered criteria, we also excluded 27 participants because they did not have valid data for an entire condition, or because they had invalid data for more than three movie clips. Data was considered invalid if participants knew a movie before the study, if they did not recall a movie clip from Day 1, or if they confused a movie clip with an incorrect clip. Our final sample after applying all preregistered exclusion criteria consisted of N = 41 participants (M_{age} = 19.8, SD_{age} = 2.0, 31 self-reported females, 10 self-reported males). The final sample is smaller than specified in the preregistration (N = 60) because the covid-19 pandemic rendered further data collection impossible. After the covid-19 situation improved, several movie clips used in this study were made available in the Netherlands via Netflix. Therefore, potential participants became too familiar with the stimuli used in this study and it was not possible to resume data collection (the number of participants that was excluded because they knew too many movies was already high before data collection was stopped). The ethics committee of the University of Amsterdam approved the study protocol (2019-CP-10057). The study design and analyses were preregistered on OSF (https://doi.org/10.17605/OSF.IO/DARYV). Data from control conditions concerning memories that were not updated with new emotional clips on Day 2 were also used in an earlier manuscript on the reliving of emotional episodic memories (Duken et al., 2022).

2.2. Materials

2.2.1. Experimental task: the Modification of Valence in Episodes (MOVIE) paradigm

2.2.1.1. MOVIE: day 1 – encoding of neutral memories. In order to investigate the encoding, updating, and retrieval of naturalistic episodic memories, we developed the three-day Modification Of Valence In Episodes (MOVIE) paradigm (Fig. 1, Visser et al 2023). On Day 1, participants viewed neutral and emotional move clips. On Day 2, they recalled the episodes, some of which were followed by a new movie clip that varied in emotional content. On Day 3, participants retrieved the Day 1 memories once more to evaluate the effect of the Day 2 manipulation.

In the present study, participants viewed eight neutral, two negative, and two positive movie clips on Day 1. They were instructed to imagine themselves in each scene as one of the depicted persons or as a bystander. After each clip, they rated how the clip made them feel in terms of valence and arousal on visual analogue scales (VAS) from 'negative' (0) to 'positive' (100) and from 'calm' (0) to 'excited' (100), respectively. The valence scale included an additional tick mark in the middle that indicated 'neutral' (50). Participants also indicated how well they could imagine themselves in each scene on a VAS from 'not at all' (0) to 'very well' (100). For all ratings, participants had a maximum

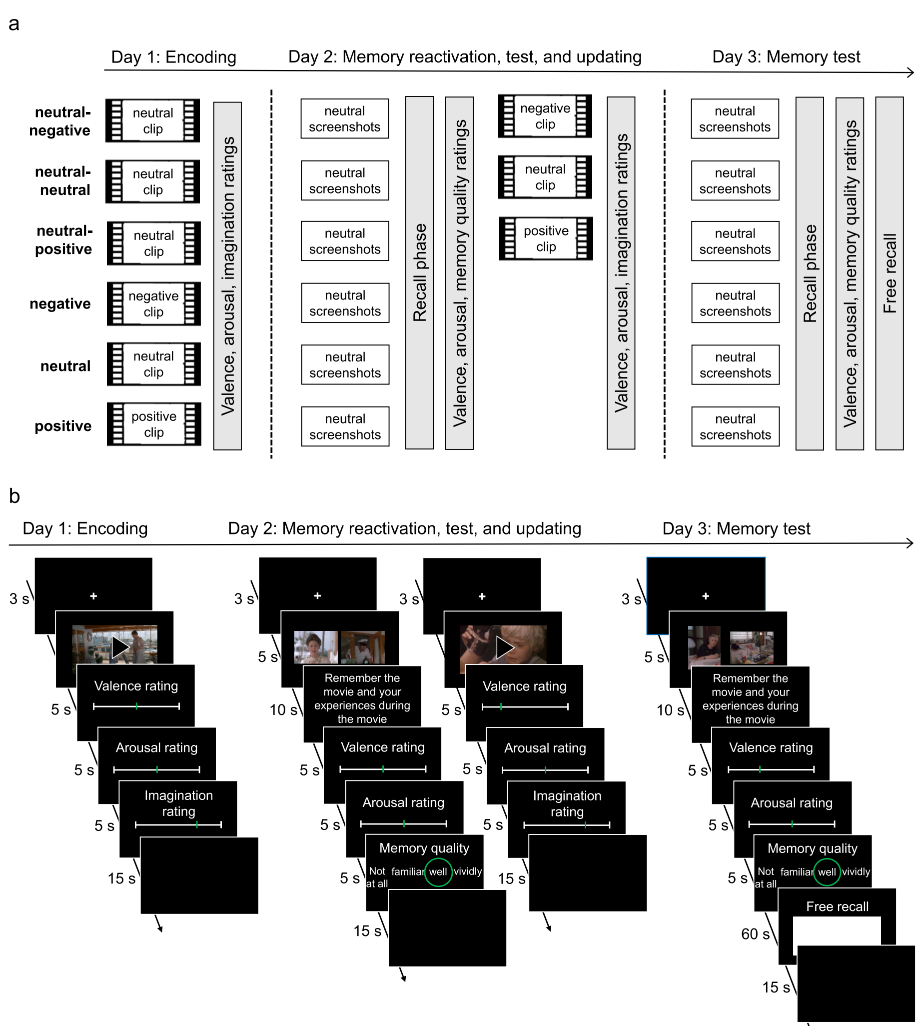

Fig. 1. Schematic overview of conditions (a) and trials (b) in the three-day Modification Of Valence In Episodes (MOVIE) task. On Day 1, participants encoded memories of neutral, negative, and positive movie clips. On Day 2, participants retrieved the Day 1 episodes with the help of two screenshots of each clip. Memories of several neutral clips were followed by the presentation of a new negative, positive, or neutral clip from the same movie. On Day 3, participants again retrieved each movie clip from Day 1 to test whether the affective tone of neutral memories had changed depending on the emotional movie clips on Day 2.

of 5 s to respond with a mouse click before the VAS disappeared from the screen, to prevent large differences due to post-encoding processes. If a participant did not confirm their rating with a mouse click within 5 s, the last mouse position on the VAS was recorded as a separate variable. For analyses of subjective reports, we combined these variables, using the confirmed response or the last mouse position if the participant did not confirm within 5 s. The order of the clips was semi-randomized in a way that no more than two emotional clips (negative or positive) were presented consecutively. Before commencing the main task, participants completed one practice trial with a short neutral clip.

2.2.1.2. MOVIE: day 2 – memory reactivation & updating. On Day 2, participants retrieved each episode from the previous day before they received new emotional information for half of the memories (neutral-positive, neutral-negative, neutral-neutral). Half of the memories were retrieved but not followed by new information and served as control conditions (positive, negative, neutral). Thereby, each memory was reactivated, and it was possible to assess the affective tone of each memory before participants received updating information. More specifically, participants viewed two screenshots from each Day 1 movie clip and were instructed to relive the respective scene as vividly as possible. The cues disappeared after 5 s but participants continued to think back for another 10 s. Following, participants rated how the memory made them feel in terms of valence and arousal, using the same VAS scales as on Day 1. Finally, participants rated how vividly they remembered the clip on a 4-point ordinal scale ('not at all', 'familiar', 'well', 'vividly').

Memory trials in the updating conditions were followed by a new negative, positive, or neutral clip from the same movie (neutral-negative, neutral-positive, neutral-neutral). Therefore, the emotional information of the Day 2 movie clips was linked to specific Day 1 memories through prior reactivation and through overlap in content (e.g., similar protagonists in a new interaction). We did not explicitly instruct participants that the new Day 2 clips were from the same movies as the Day 1 clips. Instead we explained that they will be asked to remember clips from Day 1 and that they will also see new movie clips. However, it was easy for participants to infer that each updating clip was from the same movie as the original clip, because it included the same protagonists and because the updating clip was always presented immediately after the original clip was presented. Each movie clip was followed by the same valence, arousal, and imagery ratings as the clips on Day 1. Memory trials in the control conditions (positive, negative, neutral) were not followed by an updating movie clip. Data from these control trials were formerly published as a replication of a previously conducted experiment in a manuscript showing that episodic recollection of emotional memories elicits facial expressions that can be measured with fEMG (Duken et al., 2022). Like on Day 1, participants had a maximum of 5 s to confirm each rating (both when rating their responses to memories and when rating their responses to new clips). Before starting the task, participants completed one practice trial with a reminder cue for the short practice clip from Day 1.

2.2.1.3. MOVIE: day 3 – memory test. On Day 3, participants again retrieved each episode from Day 1 to evaluate whether the updating information from Day 2 changed the affective tone of the memories. Like on Day 2, participants viewed two screenshots from each Day 1 movie clip and were instructed to relive the respective scene (but these screenshots were not the same as on Day 2; see 2.2.1. Stimuli). They again rated the memories in terms of valence, arousal, and memory vividness. At the end of each trial, participants wrote a free recall response with the keyboard, with the instruction to list everything that came to their mind when remembering the Day 1 clip. They were allowed to use bullet-points and instructed that there were no correct responses but that they should just be as honest as possible about what they thought of during the memory retrieval. This was to ensure that participants tried to relive each clip as vividly as possible, while not feeling pressured to give a correct response. They had 60 s for the written response after which the text box disappeared automatically. They were instructed to wait until the 60 s were over if they did not remember any more details.

2.2.2. Stimuli

Movie clips were selected to represent naturalistic events that elicit neutral, negative, or positive affect (particularly sadness and happiness, respectively). All movie clips were commercially available, show interactions of at least two people, and include at least a basic narrative such as a conversation. We selected clips that did not vary too much in duration and that were not too recent (to prevent that a large proportion of participants knew the clips before participating in the study). The negative clips were scenes from the movies "The Champ", "Signs", "Secret in Their Eyes", and "Basketball Diaries". The positive clips were from "About Time", "Untouchable", "Marley And Me", and "Péle: Birth Of A Legend". The neutral movie clips were from "Meet Joe Black", "The Founder", "Dead Poet Society", and "Big Night". To avoid that one or two clips would drive any potential pattern of results, we created two task versions (counterbalanced across participants) with twelve clip pairs: four neutral-positive pairs, four neutral-negative pairs and four neutral-neutral pairs. In one version, half of these pairs formed the updating conditions (neutral-negative, neutral-neutral, neutral-positive), and in the other version the other half formed the updating conditions. If the pair was not part of an updating condition, only the second part of a pair was shown on Day 1 (positive, neutral and negative), and no additional part was shown on Day 2. The negative and positive Day 1 clips served as an anchor to avoid that neutral clips would be rated as positive or negative. That is, if neutral clips could not be contrasted with emotional clips, participants might be inclined to use the whole scale to rate the neutral clips, including the ends that indicate strong emotions. The positive and negative Day 1 clips also allowed to investigate whether memories of originally emotional episodes elicited affective responses and therefore allowed to assess whether the outcome variables successfully quantified memory emotionality (independent of whether memories can be updated with emotional information or not).

Screenshots of the Day 1 clips that were presented as reminders on Day 2 and Day 3 were selected such that they contained only information from Day 1 but not Day 2 (e.g., the screenshots included objects or people that appeared in the Day 1 clip but not in the Day 2 clip). The screenshots were neutral (i.e., they did not depict emotional information) and did not include faces that were directed at the viewer or with clear facial expressions to avoid facial mimicry (Hess & Blairy, 2001). All screenshots in all conditions on Day 2 and Day 3 were selected to clearly relate to a specific Day 1 clip, so that participants would not have difficulties remembering the respective clip. We created two task versions to counterbalance which screenshots were presented on Day 2 and Day 3 across participants.

In total, there were four task versions: two versions counterbalanced which clips were shown on Day 1, and two versions counterbalanced which screenshots were presented as reminder cues on Day 2 and Day 3. The four task versions were approximately counterbalanced across participants (version 1: nine participants, version 2: thirteen participants, version 3: ten participants, version 4: nine participants).

2.2.3. Facial EMG data acquisition

We collected fEMG data from the left zygomaticus major that contracts to produce smiling indicative of positive affect, and from the left corrugator supercilii that contracts to produce frowning indicative of negative affect (Larsen et al., 2003). Two Ag/AgCl mini-electrodes were placed on the left cheek in approximately 1 cm distance and two were placed near the left eyebrow to measure zygomaticus major and corrugator supercilii activity, respectively. A ground electrode was placed on the forehead. The electrodes were connected to a bipolar EMG amplifier (built by the Technical Support Group Psychology of the University of

Amsterdam) with an input resistance of 1GΩ and a bandwidth of 5–1000 Hz (6dB/oct). The raw data was sampled at 1000 S/s. The data was rectified and integrated offline using a digital contour follower with a time constant of 25 ms using the in-house software VSRRP98 (Version 10.5; 2017, developed by the Technical Support Group Psychology). Finally, data were reduced to 250 ms segments.

2.3. Procedure

Participants attended three lab sessions of approximately 1 h each. On all days, participants were sat alone in a small, dimly lit, sound attenuated, and electrically shielded room. The experimenter was seated in an adjacent room and only entered the participant room to attach the psychophysiological sensors or to give instructions. Participants and experimenter could communicate via an intercom over the entire duration of each session. On Day 1, participants were informed about the experimental procedures, screened for exclusion criteria, and provided informed consent. Participants were not informed that the study investigated their memories but were told that it concerned their imagination. This was done to prevent the use of memory strategies that could influence encoding or consolidation and to mimic the incidental encoding of episodic memories in real life. The experimenter attached the fEMG electrodes and checked the signal quality before participants completed the Positive And Negative Affect Schedule (PANAS; Crawford & Henry, 2004) and answered several questions about their sleep and activities on the previous evening. Following, participants completed the Day 1 part of the MOVIE task. At the end of the session, participants completed the PANAS again. The procedure on Day 2 and Day 3 was like Day 1, with the difference that participants completed the Day 2 and Day 3 parts of the MOVIE task. At the end of Day 3, participants indicated which movies they knew before the study on a pen and paper questionnaire that included the title and film poster of each movie. They also completed a series of questionnaires that were not analyzed for this study: Beck's Depression Inventory (Beck et al., 1996), the trait subscale of the State-Trait Anxiety Inventory (Spielberger et al., 1970), the Plymouth Sensory Imagery Questionnaire (PSI-Q; Andrade et al., 2014), and the Perceived Awareness of the Research Hypothesis Scale (PARH; Rubin, 2016). Finally, participants were debriefed.

2.4. Data analysis

2.4.1. Facial EMG data preprocessing

All analysis steps were conducted in R unless stated otherwise (R Foundation for Statistical Computing, 2019; RStudio Team, 2018). First, we applied an automated artefact rejection that replaced outliers in the time-series data that differed more than 3 standard deviations (SD) from the mean of the time-series with missing values. Such an automated artefact rejection is reproducible, well-suited for preregistered research, and avoids arbitrary experimenter decisions about whether a high value is caused by an emotional expression or by an artefact. This artefact rejection was applied within muscle (zygomaticus major, corrugator supercilii), within day (Day 1, Day 2, Day 3), and within condition (negative, positive, neutral). Artefacts in baseline-data was rejected separately (2 s prior to stimulus presentation), within participants but across conditions, because outliers that may be valid values during an emotional response can represent an invalid outlier in baseline-data. Following, data was baseline-corrected by subtracting the mean of the baseline (2 s prior to the stimulus onset) from the response while watching and remembering movie clips. For movie trials, we averaged the fEMG response over the entire duration of a movie clip. For memory trials, we averaged across the first 10 s of memory retrieval (5 s retrieval cue presentation and 5 s silent retrieval after the cues disappeared).

2.4.2. Preregistered analyses of expressed affect and subjective feelings after memory updating

All confirmatory analyses were preregistered. Small adjustments from the preregistration are listed in the Appendix. In line with the preregistration, we excluded trials that were not retrieved successfully on Day 2 or Day 3 (participants responded 'not at all' to the memory quality question), trials in which participants confused the movie clip associated with presented screenshots with a clip from a different movie (based on their free recall responses on Day 3, assessed by two independent raters), and trials that included movie clips that participants had seen before participating in our study (assessed with a questionnaire at the end of Day 3), resulting in a total of 17.42% excluded trials across participants.

We conducted repeated measures ANOVAs and planned comparisons for all preregistered manipulation checks and hypothesis tests. For this purpose, data was averaged within participants and conditions. Prior to each analysis, outliers (more than 3 SD below or above the mean of a specific condition) were replaced by calculating the sample mean for that condition without the outliers and adding or subtracting 3 SD, thus replacing extreme values by less extreme values. In all analyses, there was a maximum of two outliers per condition. In some trials, participants did not confirm their valence rating of a movie clip or memory before the scale disappeared from the screen. In these cases, the last mouse position on the scale before it disappeared was defined as the response. We did not further transform the data because a visual inspection of histograms suggested that they were approximately normally distributed. ANOVAs were conducted with the 'ez' package for R (Lawrence, 2016). Greenhouse-Geisser corrected p-values (p_{GG}) are reported in cases where Mauchly's test indicated that the assumption of sphericity was violated. For planned comparisons, one-tailed p-values are reported. Cohen's d for pairwise comparisons were calculated with the 'effectsize' package (Ben-Shachar et al., 2018).

2.4.3. Exploratory Bayesian analyses

We conducted exploratory Bayesian analyses in addition to all preregistered p-value tests. A Bayes Factor (BF) represents evidence for one hypothesis compared to another (Hoijtink et al., 2019). For example, a $BF_{H0} = 4$ would indicate that observed data are four times more likely under the alternative hypothesis (H) than under the null hypothesis (0). In other words, the support in the observed data for the alternative hypothesis would be four times larger than for the null hypothesis. Since Bayes Factors provide information on the relative strength of evidence for two hypotheses and allow to find evidence for the null hypothesis, they provide additional information on the strength of evidence for or against the predicted effects. In case of more relative evidence for the alternative hypothesis, we report $BF_{H0.}$ In case of more evidence for the null hypothesis, we also report BF_{0H}.

3. Results

We investigated whether neutral episodic memories could retroactively acquire a positive or negative affective tone when participants were confronted with new emotional information upon reactivation of the memory. Zygomaticus (smiling) and corrugator (frowning) responses as well as subjective feelings during memory encoding, updating, and retrieval are presented in Fig. 2. Affective responses to memories in the control conditions that were not updated with new information are presented in Fig. 3 (negative, positive, neutral). The change of affective responses from Day 2 (before updating) to Day 3 (after updating) in the updating conditions is presented in Fig. 4 (neutral-negative, neutral-positive, neutral-neutral).

3.1. Manipulation checks

3.1.1. Manipulation checks: emotionality of encoded episodes on day 1

We investigated whether the neutral, positive, and negative movie clips that participants viewed to encode new memories elicited the intended emotions, measured as zygomaticus activity, corrugator activity, and self-reported valence. First, we tested whether viewing

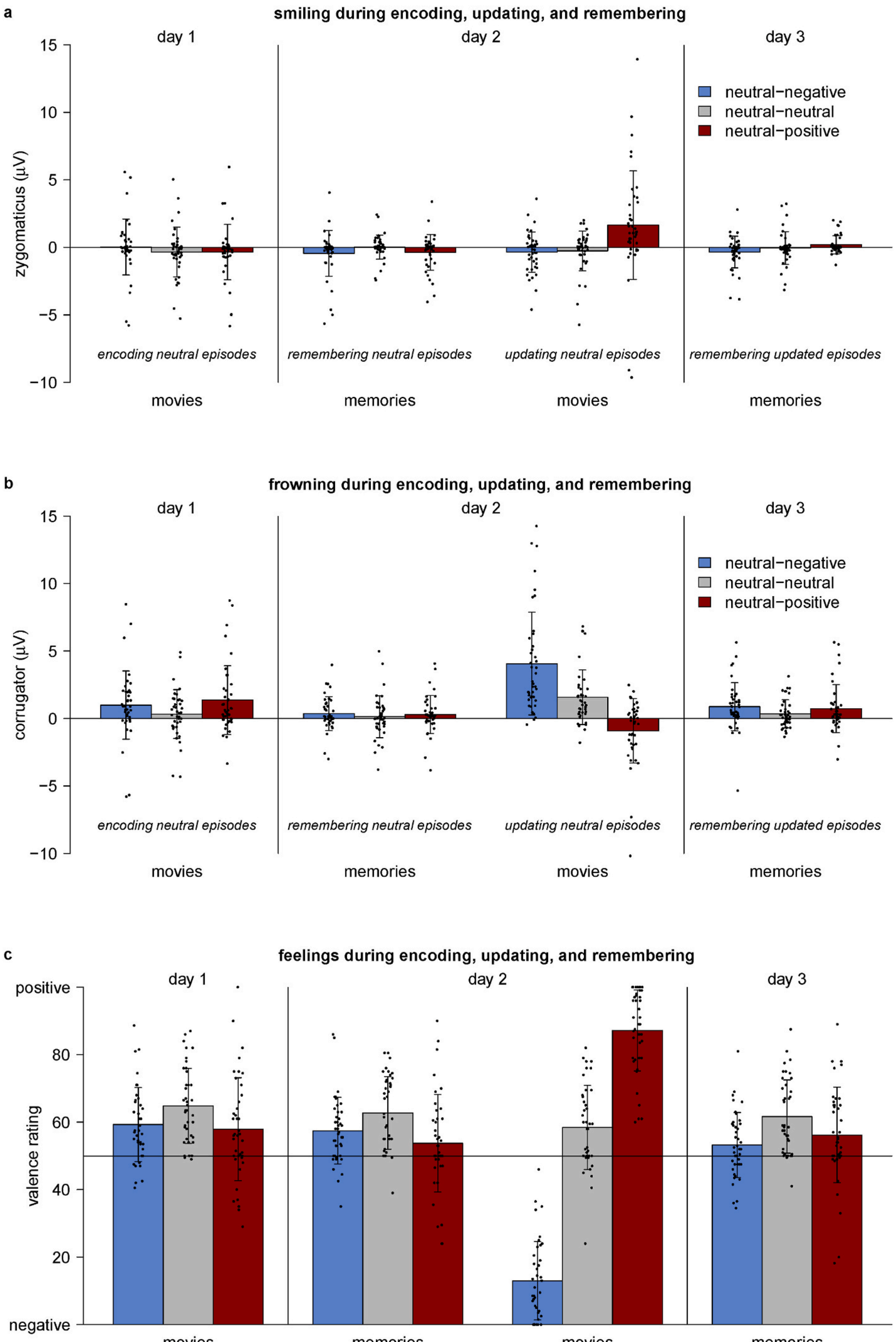

Fig. 2. Affective responses during the encoding (Day 1), updating (Day 2), and retrieval (Day 3) of episodic memories. Affective responses were measured with fEMG of the zygomaticus (**a**), and of the corrugator (**b**), as well as with self-reported valence (**c**). On Day 1, participants viewed neutral movie clips. On Day 2, participants remembered these clips before viewing a positive, neutral, or negative clip form the same movie. On Day 3, participants again remembered the Day 1 movie clips to assess whether the neutral memories acquired an affective tone. The horizontal line in **c** represents neutral. Data was averaged within participants and conditions before averaging across participants. Error bars represent ±1 SD from the mean.

positive movie clips on Day 1 elicited more zygomaticus activity than watching neutral or negative movie clips. Specifically, we conducted a one-factorial repeated measures ANOVA on Day 1 data across the six conditions (neutral-negative, neutral-neutral, neutral-positive, unaltered negative, unaltered neutral, unaltered positive). As expected, zygomaticus activity differed significantly across conditions ($F(5,200) = 10.00$, $p_{GG} < 0.001$, generalized $\eta^2 = 0.14$, $BF_{H0} = 122.63*10^4$). Participant smiled more when watching positive clips than when watching neutral clips (mean difference $\Delta M = 2.73$, standard error of the mean difference $\Delta SE = 0.41$, $t(200) = 6.68$, $p < 0.001$, 95% CI [1.92, 3.53], $d = 0.63$, $BF_{H0} = 212.20*10^6$) or when watching negative clips ($\Delta M = 2.92$, $\Delta SE = 0.52$ $t(200) = 5.65$, $p < 0.001$, 95% CI [1.90, 3.93], $d = 0.68$, $BF_{H0} = 494.48$). The finding that neutral clips elicited less zygomaticus activity than positive clips indicates that they were indeed perceived as neutral and that there was the potential for positive memory updating to increase zygomaticus responses to these episodes.

Second, we tested whether viewing negative movie clips elicited more corrugator activity than watching neutral or positive clips in a one-factorial repeated measures ANOVA with six conditions ($F(5,200) = 10.05$, $p_{GG} < 0.001$, $\eta^2 = 0.16$, $BF_{H0} = 224.07*10^4$). Participants

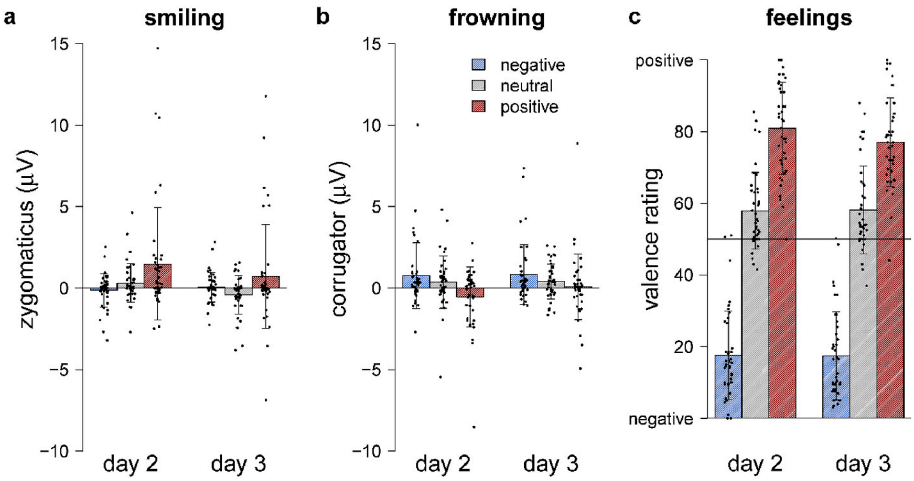

Fig. 3. Affective responses while remembering negative, positive, and neutral episodes that were not updated with new emotional information (control conditions: negative, neutral, positive), measured with zygomaticus responses (**a**), corrugator responses (**b**), and subjective valence (**c**). Data was averaged within participants and conditions before averaging across participants. Error bars represent ±1 SD from the mean. The Day 2 data from these control conditions, but not Day 3 data or data from the updating conditions, are also presented in Duken et al. (2022).

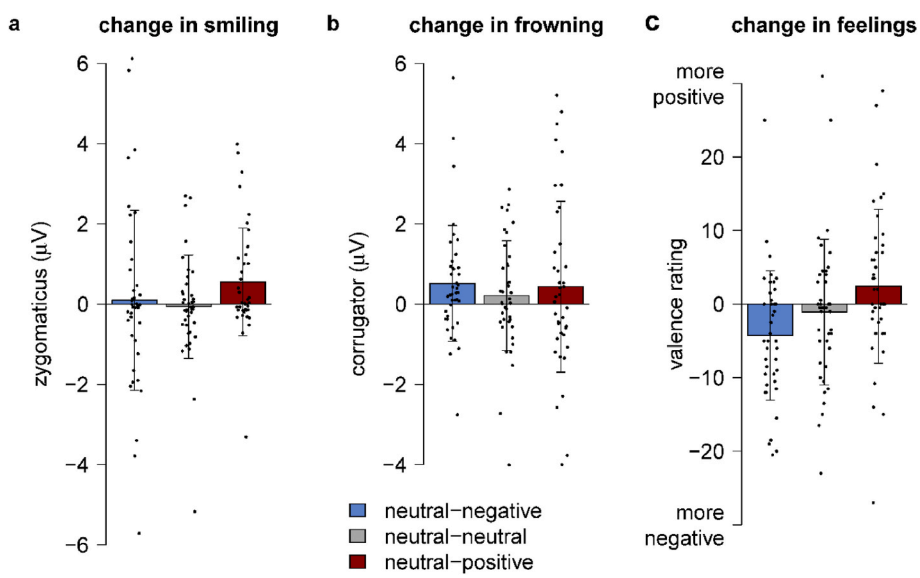

Fig. 4. Differences in affective responses between Day 2 (before updating) and Day 3 (after updating), measured with zygomaticus activity (**a**), corrugator activity (**b**), and subjective valence (**c**). The difference was calculated by subtracting the Day 2 response from the Day 3 response. Data was averaged within participants and conditions before averaging across participants. Error bars represent ±1 SD from the mean.

frowned more when watching negative clips than when watching neutral ($\Delta M = 2.38$, $\Delta SE = 0.53$, $t\ (200) = 4.47$, $p < 0.001$, 95% CI [1.33, 3.42], $d = 0.43$, $BF_{H0} = 371.77{*}10^2$) or positive clips ($\Delta M = 4.48$, $\Delta SE = 0.67$, $t\ (200) = 6.66$, $p < 0.001$, 95% CI [3.15, 5.80], $d = 0.84$, $BF_{H0} = 9719.70$). The finding that neutral clips elicited less corrugator activity than negative clips indicates that they were indeed perceived as neutral and that there was the potential for negative memory updating to increase corrugator responses to these episodes.

Finally, we investigated whether viewing positive, negative, and neutral clips led to different subjective levels of valence. Not surprisingly, a one-factorial repeated measures ANOVA across six conditions showed that participants indeed report different feelings when watching different move clips ($F\ (5,200) = 173.37$, $p_{GG} < 0.001$, $\eta^2 = 0.77$, $BF_{H0} = 814.3{*}10^{72}$). Participants reported feeling more positively after watching positive clips than after watching neutral ($\Delta M = 24.6$, $\Delta SE = 1.98$, $t\ (200) = 12.43$, $p < 0.001$, 95% CI [20.7, 28.5], $d = 1.81$, $BF_{H0} = 462.2{*}10^{13}$) or negative clips ($\Delta M = 71.0$, $\Delta SE = 2.50$, $t\ (200) = 28.37$, $p < 0.001$, 95% CI [66.1, 75.9], $d = 4.19$, $BF_{H0} = 441.3\ {*}10^{49}$). Additionally, participants felt more negative after watching negative clips compared to neutral clips ($\Delta M = 46.4$, $\Delta SE = 1.98$, $t\ (200) = 23.47$, $p < 0.001$, 95% CI [42.5, 50.3], $d = 4.45$, $BF_{H0} = 149.5\ {*}10^{23}$). The finding that neutral clips were rated less positively and less negatively than positive and negative clips, respectively, again indicates that the clips were perceived as neutral and that there was potential to increase subjective positive or negative feelings in response to these episodes.

In sum, the manipulation checks of the Day 1 data indicate that the clips in each condition elicited the intended emotions. Importantly, neutral clips (including the neutral clips in the updating conditions) elicited less positive affect and less negative affect than positive and negative clips, respectively, both in terms of psychophysiological responses and self-reported feelings.

3.1.2. Manipulation checks: emotionality of updating episodes on day 2

We investigated whether the positive, negative, and neutral movie clips that were presented on Day 2 elicited the intended emotions measured as zygomaticus activity, corrugator activity, and self-reported valence.

Zygomaticus activity while viewing movie clips differed between the neutral-positive, neutral-neutral, and neutral-negative condition (F (2,80) = 9.04, $p_{GG} < 0.001$, $\eta^2 = 0.11$, $BF_{H0} = 169.92$). Participants smiled more when watching positive clips on Day 2, compared to neutral (ΔM = 1.91, ΔSE = 0.53, t (80) = 3.59, p < 0.001, 95% CI [0.85, 2.97], d = 0.47, $BF_{H0} = 16.96$) or negative clips (ΔM = 2.00, ΔSE = 0.53, t (80) = 3.77, p < 0.001, 95% CI [0.95, 3.06], d = 0.53, $BF_{H0} = 40.030$).

Corrugator activity while viewing movie clips also differed between conditions (F (2,80) = 28.77, $p_{GG} < 0.001$, $\eta^2 = 0.34$, $BF_{H0} = 458.86*10^7$). Participants frowned more when watching negative movie clips than when watching neutral (ΔM = 2.49, ΔSE = 0.66, t (80) = 3.80, p < 0.001, 95% CI [1.19, 3.80], d = 0.72, $BF_{H0} = 120.11*10$) or positive clips (ΔM = 4.97, ΔSE = 0.66, t (80) = 7.59, p < 0.001, 95% CI [3.67, 6.28], d = 0.94, $BF_{H0} = 735.57*10^2$).

Also participants' self-reported valence differed between conditions (F (2,80) = 405.54, p < 0.001, $\eta^2 = 0.87$, $BF_{H0} = 239.82*10^{50}$). Participants reported feeling more positive after watching positive clips than after watching neutral (ΔM = 28.8, ΔSE = 2.63, t (80) = 10.98, p < 0.001, 95% CI [23.6, 34.1], d = 1.69, $BF_{H0} = 819.31*10^8$) or negative clips (ΔM = 74.2, ΔSE = 2.63, t (80) = 28.25, p < 0.001, 95% CI [69.0, 79.4], d = 3.90, $BF_{H0} = 112.6*10^{21}$). Additionally, participants also felt more negative after watching negative clips compared to neutral clips (ΔM = 45.3, ΔSE = 2.63, t (80) = 17.27, p < 0.001, 95% CI [40.1, 50.76], d = 3.25, $BF_{H0} = 164.38*10^{18}$). To conclude, the clips that represented emotional information to update neutral episodic memories elicited the intended affective psychophysiological responses and self-reported feelings.

3.1.3. *Manipulation checks: pure emotional episodic memories without updating*

Our manipulation checks above showed that movie clips reliably elicited emotional responses measured with fEMG and self-reported valence. However, if emotional movie clips are supposed to update neutral episodic memories, they should also be powerful enough to lead to emotional memories themselves. Therefore, we tested whether unaltered memories of emotional movie clips (negative, neutral, and positive in Fig. 1a) elicited emotional responses – a precondition for such clips to be able to update previously neutral memories to the extent that these memories elicit emotional responses. Fig. 2 presents the psychophysiological expression of positive and negative affect during the reliving of emotional episodic memories. The Day 2 but not the Day 3 data from these manipulation checks were also analyzed in a manuscript on the reliving of emotional episodic memories (Duken et al., 2022).

First, we tested whether remembering positive movie clips that were not updated with new information elicited more zygomaticus activity on Day 2 and Day 3 than remembering neutral or negative movie clips (Fig. 3a). Specifically, we conducted a 3 (condition: unaltered negative, unaltered neutral, unaltered positive) X 2 (test day: Day 2, Day 3) repeated-measures ANOVA. As expected, zygomaticus activity differed significantly across conditions (F (2,80) = 6.39, $p_{GG} = 0.011$, $\eta^2 = 0.06$). There was no significant effect of test day (F (1,40) = 3.92, p = 0.055, $\eta^2 = 0.01$) and no significant interaction (F (2,870) = 2.46, $p_{GG} = 0.109$ $\eta^2 = 0.01$). Bayesian analyses also indicated that a model that differentiates between conditions, but does not include test day or an interaction, best fits the data ($BF_{H0} = 173.405$). Participants smiled more when remembering positive clips compared to neutral (ΔM = 1.14, ΔSE = 0.37, t (80) = 3.12, p = 0.004, 95% CI [0.27, 2.02], d = 0.34, $BF_{H0} = 18.28$) or negative clips (ΔM = 1.13, ΔSE = 0.37, t (80) = 3.08, p = 0.004, 95% CI [0.25, 2.01], d = 0.35, $BF_{H0} = 22.19$).

Second, we tested whether remembering negative movie clips elicited more corrugator activity than remembering positive or neutral clips in a 3 (condition: unaltered negative, unaltered neutral, unaltered positive) X 2 (test day: Day 2, Day 3) repeated-measures ANOVA (Fig. 3b). We found a significant effect of condition (F (2,80) = 8.61, p < 0.001, $\eta^2 = 0.07$), but no significant effects of test day (F (1,40) = 0.91, p = 0.347, $\eta^2 < 0.01$) and no significant interaction (F (2,80) = 0.75, p = 0.474, $\eta^2 = 0.004$). Bayesian analyses also indicated that a model that differentiates between conditions, but does not include test day or an interaction, best fits the data ($BF_{H0} = 503.12$). Participants frowned more when remembering negative compared to positive clips (ΔM = 0.91, ΔSE = 0.23, t (80) = 4.02, p < 0.001, 95% CI [0.37, 1.44], d = 0.46, $BF_{H0} = 443.03$), but not compared to neutral clips (ΔM = 0.25, ΔSE = 0.28, t (80) = 1.12, p = 0.254, 95% CI [0.12, 1.19], d = 0.15, $BF_{H0} = 0.54$, $BF_{0H} = 1.85$).

Finally, we tested whether remembering positive, negative, and neutral clips elicited respective subjective feelings in a 3 (condition: unaltered negative, unaltered neutral, unaltered positive) X 2 (test day: Day 2, Day 3) repeated-measures ANOVA (Fig. 3c). There was a significant effect of condition (F (2,80) = 304.59, $p_{GG} < 0.001$, $\eta^2 = 0.82$), but no significant effect of test day (F (1,40) = 1.93, p = 0.172, $\eta^2 < 0.01$) and no significant interaction (F (2,80) = 2.71, p = 0.072, $\eta^2 = 0.01$). Bayesian analyses also indicated that a model that differentiates between conditions, but does not include test day or an interaction, best fits the data ($BF_{H0} = 882.14*10^{89}$). Participants indicated that memories of positive clips elicited more positive feelings than memories of neutral clips (ΔM = 21.0, ΔSE = 2.53, t (80) = 8.29, p < 0.001, 95% CI [14.9, 27.1], d = 1.31, $BF_{H0} = 413.17*10^{14}$) and memories of negative clips (ΔM = 61.5, ΔSE = 2.53, t (80) = 24.28, p < 0.001, 95% CI [55.5, 67.6], d = 2.96, $BF_{H0} = 850.495*10^{36}$). Negative clips elicited more negative feelings than memories of neutral clips (ΔM = 40.5, ΔSE = 2.68, t (80) = 15.99, p < 0.001, 95% CI [34.5, 46.6], d = 2.79, $BF_{H0} = 104.40*10^{35}$).

In sum, remembering unaltered positive movie clips elicited positive emotions that could be measured through zygomaticus responses and self-reported feelings. Remembering unaltered negative movie clips only elicited subjective negative feelings but not more frowning compared to the neutral condition. Therefore, corrugator activity was not well suited to investigate affective responses after neutral-negative memory updating and must be interpreted with caution in this study.

3.2. *Confirmatory analyses*

3.2.1. *Zygomaticus responses during memory retrieval after the updating of neutral episodes with emotional information*

We tested whether neutral episodic memories could be updated with positive information to the effect that they subsequently elicit positive facial expressions (Fig. 4a). Against our expectations, a 3 (condition: neutral-positive, neutral-neutral, neutral-negative) X 2 (test day: Day 2, Day 3) repeated-measures ANOVA with zygomaticus response as dependent variable yielded no significant effect of condition (F (2,80) = 2.42, p = 0.095, $\eta^2 = 0.02$), no significant effect of day (F (1,40) = 1.34, p = 0.255, $\eta^2 = 0.01$), and no significant interaction (F (2,80) = 1.66, p = 0.197, $\eta^2 = 0.01$). Bayesian analyses revealed evidence against the interaction model ($BF_{H0} = 0.04$, $BF_{0H} = 27.67$). However, the preregistered planned comparisons revealed the expected significant increase of smiling in the neutral-positive update condition (ΔM = 0.55, ΔSE = 0.26, t (117) = 2.10, p = 0.019, 95% CI [0.03, 1.07], d = 0.41, $BF_{H0} = 6.71$), and not in the neutral-neutral update condition (ΔM = −0.06, ΔSE = 0.26, t (117) = −0.24, p = 0.809, 95% CI [−0.58, 0.46], d = −0.05, $BF_{H0} = 0.13$, $BF_{0H} = 7.69$). The increase in smiling was significantly larger in the neutral-positive condition than in the neutral-neutral condition (ΔM = 0.61, ΔSE = 0.35, t (80) = 1.75, p = 0.042, 95% CI [-0.08, 1.31], d = 0.33, $BF_{H0} = 2.53$). An exploratory comparison of the change in zygomaticus activity between the neutral-positive and the neutral-negative condition was not significant (ΔM = 0.45, ΔSE = 0.35, t (80) = 1.30, p = 0.197, 95% CI [-0.24, 1.52], d = 0.19, $BF_{H0} = 0.33$, $BF_{0H} = 3.00$), possibly due to a slight non-significant increase of zygomaticus activity in the neutral-negative condition (exploratory analysis: ΔM = 0.09, ΔSE = 0.26, t (80) = 0.36, p = 0.72, 95% CI [-0.43, 0.62], d

$= 0.04$, $BF_{H0} = 0.17$, $BF_{0H} = 5.73$; see also Fig. 4a). The absence of a significant interaction even though the planned comparisons yielded the expected significant effects could be explained by the inclusion of the neutral-negative condition in the ANOVA. Specifically, we expected zygomaticus responses to increase only after positive updating, but not after neutral or negative updating. The expected absence of change in two out of three conditions (neutral-neutral and neutral-negative) might have obscured the predicted change in the positive updating condition. Accordingly, an exploratory 2 (condition: neutral-positive, neutral-neutral) X 2 (test: Day 2, Day 3) repeated-measures ANOVA that did not include the neutral-negative condition yielded a significant interaction ($F (2,80) = 4.56$, $p = 0.039$, $\eta^2 = 0.02$). In sum, planned comparisons were consistent with the prediction that neutral episodic memories can be updated with positive information and subsequently elicit smiling during memory retrieval. However, these results need to be interpreted with caution because the preregistered frequentist and a Bayesian omnibus-test yielded no evidence for the expected interaction of updating condition and test day when all three updating conditions were included in the analysis.

3.2.2. *Corrugator responses during memory retrieval after the updating of neutral episodes with emotional information*

We investigated whether neutral episodic memories could be updated with negative information to the effect that they subsequently elicit negative facial expressions (Fig. 4b). Similar to the analyses of zygomaticus responses, a 3 (condition: neutral-positive, neutral-neutral, neutral-negative) X 2 (test day: Day 2, Day 3) repeated-measures ANOVA with corrugator response as dependent variable yielded no significant effect of condition ($F (2,80) = 1.36$, $p_{GG} = 0.262$, $\eta^2 = 0.01$) and no significant interaction ($F (1,80) = 0.45$, $p = 0.638$, $\eta^2 < 0.01$), but a significant effect of test day ($F (1,40) = 4.59$, $p = 0.038$, $\eta^2 = 0.02$). Bayesian analyses revealed evidence against the interaction model ($BF_{H0} = 0.03$, $BF_{0H} = 29.41$). According to planned comparisons, there was a significant increase of frowning in the neutral-negative condition ($\Delta M = 0.51$, $\Delta SE = 0.26$, $t (110) = 1.96$, $p = 0.026$, 95% CI [−0.01, 1.04], $d = 0.36$, $BF_{H0} = 3.37$). However, the increase in frowning was not significantly larger in the neutral-negative condition than in the neutral-neutral condition ($\Delta M = 0.30$, $\Delta SE = 0.33$, $t (80) = 0.92$, $p = 0.459$, 95% CI [−0.35, 0.96], $d = 0.17$, $BF_{H0} = 0.51$, $BF_{0H} = 1.96$). In sum, the analyses of frowning responses did not yield evidence that neutral memories were updated with negative information. This is not surprising given that pure negative memories (that were not updated with new information) also did not elicit stronger frowning responses than pure neutral memories (see **3.1.3. Manipulation checks**). Instead, frowning may have increased from Day 2 to Day 3 across conditions.

3.2.3. *Subjective feelings during memory retrieval after the updating of neutral episodes with emotional information*

Finally, we tested whether providing positive or negative information after memory reactivation would lead to a change in subjective positive or negative feelings when reliving the memory one day later (Fig. 4c). We conducted a 3 (condition: neutral-positive, neutral-neutral, neutral-negative) X 2 (test day: Day 2, Day 3) repeated-measures ANOVA with self-reported valence as dependent variable. There was a significant effect of condition ($F (2,80) = 6.79$, $p_{GG} = 0.002$, $\eta^2 = 0.08$) and a significant interaction of condition and test day ($F (2,80) = 4.96$, $p = 0.009$, $\eta^2 = 0.01$). There was no significant effect of test day ($F (1,40) = 1.20$, $p = 0.280$, $\eta^2 < 0.01$). Bayesian analyses also revealed evidence for the interaction model compared to a null model ($BF_{H0} = 214.86$), but a model including only a main effect of condition received even more evidence ($BF_{H0} = 2481.15$). Planned comparisons showed that the neutral-negative update condition led to the predicted increase in self-reported negative affect (i.e., a decrease of valence on the scale from negative [0] to positive [100]; $\Delta M = -4.28$, $\Delta SE = 1.52$, $t (120) = -2.81$, $p = 0.003$, 95% CI [−7.29, −1.27], $d = -0.49$, $BF_{H0} = 20.72$). This increase in negative effect was numerically but not significantly larger than in the neutral-neutral condition ($\Delta M = -3.20$, $\Delta SE = 2.13$, $t (80) = -1.50$, $p = 0.069$, 95% CI [−7.43, 1.04], $d = -0.22$, $BF_{H0} = 0.79$, $BF_{0H} = 1.27$). The neutral-positive condition led to a numerical but not significant increase in positive affect ($\Delta M = 2.42$, $\Delta SE = 1.52$, $t (120) = 1.59$, $p = 0.057$, 95% CI [−0.59, 5.43], $d = 0.23$, $BF_{H0} = 0.85$, $BF_{0H} = 1.18$). The non-significant increase in the neutral-positive condition was numerically larger than in the neutral-neutral condition, but again not significantly ($\Delta M = 3.50$, $\Delta SE = 2.13$, $t (80) = 1.65$, $p = 0.052$, 95% CI [−0.73, 7.74], $d = 0.27$, $BF_{H0} = 1.26$). In sum, the analyses of subjective feelings provide tentative evidence that neutral memories were updated with negative information, leading to more negative feelings when remembering the episode. Results regarding the updating of neutral memories with positive information were inconclusive.

4. Discussion

We investigated whether consolidated neutral episodic memories could retroactively acquire an affective tone through memory updating when people are confronted with emotional information upon memory reactivation. To quantify the affective tone of memories, we measured psychophysiological expressions of positive and negative affect with zygomaticus (smiling) and corrugator (frowning) activity, as well as self-reported feelings. Our results suggest that neutral memories can retroactively acquire a positive tone. Participants smiled more in response to neutral memories after they were updated with positive information, and this increase in smiling was specific to positive updating (i.e., it did not occur when retrieved memories were followed by neutral information). However, evidence whether positive memory updating also led to increased subjective positive feelings was inconclusive. Additionally, our results indicate that neutral memories can retroactively acquire a negative tone, but only in terms of subjective feelings and not in terms of psychophysiological responses. While we found an increase in frowning from before to after memory updating, this increase was not specific for negative updating (i.e., it also occurred when memories were updated with neutral information). This is not surprising given that our manipulation checks showed that purely negative memories (memories that were originally negative and not updated with new information) also did not elicit stronger frowning responses than neutral memories. In sum, we found some support for the notion that neutral memories can be updated with emotional information and subsequently elicit psychophysiological expressions of affect and subjective feelings.

While our results generally suggest that the affective tone of complex memories can change due to memory updating, they are not unequivocal. Changes in affect after updating were not consistent across psychophysiological measures and self-reported feelings, with positive updates being more pronounced for expressed affect and negative updates being more pronounced for self-reported affect. There was also some inconsistency in the test statistics with predicted significant interactions in omnibus tests but not in the corresponding planned comparisons and vice versa. Furthermore, emotional memory updating only led to small changes in the affective tone, especially compared to the pronounced affective responses that were elicited by inherently emotional episodes (Figs. 2 and 3). The absence of strong concordant evidence for affective updating across analyses, variables, and updating conditions is consistent with other recent studies that only found tentative evidence for affective memory updating under specific conditions or in a subset of participants or outcome variables (Kredlow & Otto, 2015; Liu & McNally, 2017; Piñeyro et al., 2018). Consequently, updating complex memories with new emotional information appears relatively hard to achieve or to only result in subtle changes of the original memories.

The finding that the affective tone of episodic memories does not change profoundly after memory updating challenges the clinical utility of therapeutics that aim at altering sad or happy episodic memories (Elsey & Kindt, 2016, 2017). The observed changes of episodic memory emotionality are also small in comparison to some of the drastic changes observed in conditioning studies (e.g., Kindt et al., 2009) and reconsolidation interventions for phobic fear memories (e.g., Soeter & Kindt, 2015). However, the magnitude of changes in affect may depend critically on the operationalization of the updating manipulation. Inspired by animal studies on memory updating (particularly on memory reconsolidation), we assumed that memory updates are relatively automatic processes that can lead to the incorporation of new emotional information into existing memory traces – possible even without intention or awareness of the person. Therefore, the emotional updating information in our study was only weakly linked to the original memory, with some overlap in content because the clips were from the same movie with the same actors. It is possible that a clearer narrative link between an existing and a new episode would make it easier to integrate the affective tone of the new experience into an existing memory. This prediction seemingly contrasts with other studies on human memory updating that even provided new information that was completely unrelated in content to the original memory (Kredlow & Otto, 2015; Liu & McNally, 2017; Piñeyro et al., 2018; Wang et al., 2021). However, these studies also found only limited evidence for memory updating. It is possible that if there is only a weak or no narrative link between an existing and a new episode, some people might mentally create or strengthen the link between the original memory and the new episode, while others might separate them as two distinct episodes. Consequently, memory manipulations that are only weakly related to an original episode would only yield small and inconsistent updating effects. Relatedly, research on declarative memory components and on fear memories indicates that the degree of overlap between what has previously been learned (the original memory) and new information, determines whether information is integrated into existing memories or whether a new memory is formed (Cox et al., 2021; Krawczyk et al., 2017; Kumaran & Maguire, 2007; Schlichting & Preston, 2016; Sevenster et al., 2014; Sinclair & Barense, 2018). In our study, it is unclear how the narrative and overlap in content of the old and new episodes enables changes of affect. Future research should carefully delineate the optimal link between old and new information to achieve strong updating effects, for example by systematically comparing effects of updating information that has a large, a small, or no narrative link in content with the original memory (Visser et al., 2023).

An alternative approach to updating the emotionality of episodic memories with new information might be to change the meaning of the original memory. One way to achieve this might be imagery rescripting, which involves vividly reliving a past event and then imagining a different course of events (usually more positive or benign; Arntz, 2012; Morina et al., 2017). Alternatively, it might be possible to reappraise emotional experiences, for example by finding positive meaning or by focusing on positive aspects in a past negative event (Samide & Ritchey, 2021; Speer et al., 2021). In contrast to the approach tested in the current study, imagery rescripting and reappraisal both involve elaborate processing of new emotional information while reliving the original memory. This intense, explicit, and interwoven processing of new and old information may increase the relevance of the new information for the original information and consequently support more pronounced and reliable changes in the affective impact of past emotional episodes.

Even though it might be challenging to achieve strong and reliable memory updating in the short term with a single intervention, slower long-term memory updating processes might produce pronounced changes in the affective tone of episodic memories. For example, newly learned emotional information might only be linked weakly to existing information and initially people can distinguish the two sources of information well (Johnson & Johnson, 1997; Schmolck et al., 2000). However, through repeated (and possibly preferential) retrieval of the new information, the link or overlap between the two memories might be strengthened with the passage of time. At the same time, information of the original memory may decay through active forgetting processes (Hardt et al., 2013) and the original and the new information may become less distinguishable (Schmolck et al., 2000). That way, newly learned information may become increasingly accessible when an updated memory is retrieved whereas a part of the original information may decay to such an extent that it is hard or impossible to retrieve. Such processes could lead to profound memory updating over time, causing for example initially benign memories to be tainted increasingly somber during the development of a depressive episode when the original information is repeatedly combined with negative information. However, these memory updating processes remain hypothetical and to be investigated in the future. They may also bear less potential for quick efficient memory therapeutics than rapid updating processes or interventions that change the meaning of a memory, because they per definition rely on slow long-term processes.

We investigated whether neutral memories could become more negative through emotional updating, which might explain how memories can become excessively negative in mental disorders such as depression. Conversely, we also tested whether neutral memories might become more positive. There may be therapeutic value in increasing the positivity of relatively neutral memories, given that diminished positive memories play a role in mental disorders such as depression (Dalgleish & Werner-Seidler, 2014; Hitchcock et al., 2017; Holmes et al., 2016). For instance, an inability to vividly relive specific positive memories can predict the onset and course of depression (Askelund et al., 2019). Emerging memory therapeutics that are recently being developed therefore aim at improving the retrieval and reliving of positive memories in depression (Arditte Hall et al., 2018; Dalgleish & Werner-Seidler, 2014; Hitchcock et al., 2017). However, neutral experiences as investigated in this study might not be representative for memories that patients and therapists often aim to change, because negative memories (while clearly not always maladaptive) are more likely to represent a burden for the individual. Future studies should therefore investigate whether it is also possible to change the emotionality of negative memories. Recent work from our lab indeed suggests negative memories can be updated with positive emotions, at least in terms of self-reported feelings (Visser et al., 2023).

Our study on emotional memory updating has several strengths. It employed a preregistered naturalistic paradigm that may support the translation to real-world memory updating and clinical practice. Moreover, it carefully considered experimental criteria that must be met to draw conclusions on memory updating and to rule out alternative explanations. For instance, the study assessed the original memory before and after memory updating. It also probed the original but not the updating episode when assessing memory emotionality, which means that any affective responses after updating must go via the updated original memory. Finally, we investigated affective responses to updated memories through psychophysiological expressions of affect and self-reported feelings. This combination of complementary measures allowed us to overcome limitations of single measures (e.g., demand effects in self-report data and potentially limited clinical relevance of psychophysiological data) and provides more holistic insights into emotional memory processes. Regardless of its strengths, the current study also has several limitations that must be considered when interpreting the results. First, the sample size is smaller than suggested in the preregistration because it was not possible to continue data collection. However, we provide a range of descriptive and inference statistics including confidence intervals, effect sizes, and Bayesian analyses to allow nuanced and informed decisions that readers and future studies can rely on when addressing the question whether memories can be updated with emotional information. Moreover, the self-report findings have recently been replicated in a study that found negative and positive updating effects (Visser et al., 2023). Second, while our study employs a naturalistic paradigm and represents a step towards more self-relevant and ecologically valid memories, it relies on generic movie scenes that are not equally relevant or lifelike to all participants. This is a limitation that affects most studies on emotional memory that aim at a high level of experimental control to allow for causal claims on human memory updating. It is therefore important that rigorously controlled studies on emotional episodic memory updating are complemented with autobiographical memory paradigms that might not achieve the same level of experimental control but have increased external validity and facilitate translation of basic science to clinical practice (e.g., Kredlow & Otto, 2015; Maguire, 2022). Finally, our study does not allow for conclusions regarding the cognitive and biological processes that underly changes of memory emotionality. We designed the study in such a way that the memory test on Day 3 explicitly probed the Day 1 memory but not the Day 2 memory. Any emotional reaction to the memory cues on Day 3 must therefore result from some integration of the emotional Day 2 information into the neutral Day 1 memory. However, such integration may have occurred through associative processes, memory reconsolidation, or other mechanisms (Elsey et al., 2018; Gisquet-Verrier & Riccio, 2018). To elucidate the underlying processes of memory updates, it might be necessary to draw on a wide array of translational studies with animals and humans that cumulatively rule out alternative explanations. However, in terms of clinical relevance, it might not be important whether and how an underlying memory representation changes, as long as the emotions change that are elicited by the retrieved memory.

Our study indicates that it is possible to update neutral episodic memories with emotional information, even to the extent that the memories elicit psychophysiological expressions of affect. However, the results are not unequivocal and suggest that it might be relatively difficult to produce reliable and strong changes of the affective tone of episodic memories through a single intervention with weakly linked emotional information. Future research should explore other avenues towards updating emotional memories that might produce stronger effects, such as changing the emotional meaning of the original information. Emerging therapeutics that aim at altering emotional episodic memories bear great promise to alleviate the burden of mental disorders (Arditte Hall et al., 2018; Hitchcock et al., 2017). However, the efficacy of these memory therapeutics will ultimately depend on a profound understanding of the mechanisms that lead to the rise and fall of emotional memory distortions.

Data and code availability

All data, materials, and code regarding this manuscript are available on the Open Science Framework (https://doi.org/10.17605/OSF.IO/5V9GJ), with some exceptions: We did not share sensitive data such as highly specific or potentially identifying demographic information and did not share materials that are subject to copyright by third parties such as movie clips. For materials that cannot be shared, we provide detailed descriptions that allow to reproduce them. All analysis code for R is publicly available. Only the conversion from raw data to processible data is conducted with the custom in-house program VSRRP (developed by the Technical Support Group Psychology at the University of Amsterdam). The (C/C++) source code of VSRRP that executes this conversion is available upon request from the Technical Support Group Psychology at the University of Amsterdam (https://lab-fmg.uva.nl/contact/contact.html) because it is not property of the authors of this manuscript.

CRediT authorship contribution statement

Sascha B. Duken: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Validation, Visualization, Writing – original draft, Writing – review & editing. **Franziska Neumayer:** Methodology, Resources, Writing – review & editing. **Nadza Dzinalija:** Methodology, Resources, Writing – review & editing. **Merel Kindt:** Conceptualization, Methodology, Resources, Writing – review & editing. **Vanessa A. van Ast:** Conceptualization, Funding acquisition, Methodology, Resources, Supervision, Writing – review & editing. **Renée M. Visser:** Conceptualization, Methodology, Supervision, Writing – review & editing.

Declaration of competing interest

None.

Data availability

The data regarding this manuscript are publicly available on the Open Science Framework: https://doi.org/10.17605/OSF.IO/5V9GJ.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.brat.2024.104528.

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