Reliving emotional memories:
Episodic recollection elicits affective psychophysiological responses

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Abstract

Memories of emotional events can guide behavior in the present. One way to fulfill this adaptive function might be through psychophysiological responses that signal desirable and undesirable outcomes. However, it remains unknown whether remembering emotional episodes indeed re-elicits corresponding affective psychophysiological responses. We addressed this question in two experiments (N1 = 48, N2 = 59). Young adults watched positive, negative, and neutral movie clips and remembered these episodes one day later. To index the psychophysiological expression of positive and negative affect, we measured smiling (zygomaticus major) and frowning (corrugator supercilii), respectively. Participants smiled more when remembering positive compared to neutral and negative episodes. Moreover, they frowned more when remembering negative compared to positive but not neutral episodes. We also explored whether the expressed intensity of affect during remembering was proportional to the affective intensity of the corresponding original experience, but results were mixed. Our findings underscore that remembering emotional episodes actively reinstates affective psychophysiological responses. However, whether the exact expressed intensity during retrieval maps onto the original experience remains an open question. Future studies into emotional episodic memories would benefit from incorporating affective psychophysiological indices because they may represent essential motivational components that inform future behavior.

Key words:

Episodic memory, emotional memory, recollection, facial electromyography, affect

1. Introduction

Episodic recollection allows people to vividly re-experience past events, such as an enchanting first date or a devastating breakup (Tulving, 2002). It is generally assumed that episodic recollection serves an adaptive function by generating insights into causes and consequences of events and actions, which can then guide future behavior (Moulton & Kosslyn, 2009; Pillemer, 2003; Schacter, Addis, & Buckner, 2007). Especially *emotional* episodic memories might constitute an invaluable source of information in guiding behavior because positive affect associated with past events (e.g. joy) may signal desired outcomes and motivate approach behavior, whereas negative affect (e.g. sadness) may signal undesired outcomes and motivate avoidance behavior (Elliot, Eder, & Harmon-Jones, 2013; Lang & Bradley, 2010). Indeed, it is generally assumed that psychophysiological responses to emotional stimuli are not only indicative of these motivational states but they are also important for preparing behavior (Elliot et al., 2013; Lang & Bradley, 2010; Pace-Schott et al., 2019). For example, heart rate changes facilitate quick responses in potentially threatening situations (Löw, Lang, Smith, & Bradley, 2008) and pupil dilations can reflect attention allocation (van der Wel & van Steenbergen, 2018). However, it is unknown whether remembering emotional experiences such as sad or happy events can re-elicite corresponding affective psychophysiological expressions.

In line with the notion that psychophysiological responses play a crucial role in emotional memories, the retrieval of highly arousing or trauma-related memories can elicit strong peripheral reactions, for instance changes in heart rate and skin conductance (Pole, 2007). These physiological reactions to trauma-related memories are thought to represent relative automatic stimulus-response associations that are often retrieved involuntarily (Brewin & Holmes, 2003). In contrast to such automatic physiological responses to fear-inducing stimuli, psychophysiological responses to episodic memories may result from higher-order cognitive processes such as mental imagery (Moulton & Kosslyn, 2009; Pearson, Naselaris, Holmes, & Kosslyn, 2015). Accordingly, recent advances in memory research recognize episodic recollection as a constructive process that relies on imagery – a mental simulation of past or future events that leads to the experience of sensory information in the absence of external sensory input (Madore, Jing, & Schacter, 2019; Moulton & Kosslyn, 2009; Pearson et al., 2015; Schacter et al., 2007). Affective psychophysiological reactions have been suggested to be a crucial component of the simulative process during imagery because they signal desirable (positive valence) or undesirable (negative valence) outcomes of events and actions (Lang & Bradley, 2010; Moulton & Kosslyn, 2009). Imagery can indeed elicit

psychophysiological responses such as facial expressions (Schwartz, Fair, Salt, Mandel, & Klerman, 1976), heart rate changes (McNally et al., 2004; Prkachin, Williams-Avery, Zwaal, & Mills, 1999), and pupil dilations (Henderson, Bradley, & Lang, 2018). Also studies on episodic recollection suggest that episodic memories can elicit affective responses that impact behavior and well-being, but affect was usually measured with self-reports, not with psychophysiological indices (Holmes, Blackwell, Burnett Heyes, Renner, & Raes, 2016; Jing, Madore, & Schacter, 2016). Neuroimaging studies provide further indirect evidence that recollection might re-instate affective states. Specifically, remembering emotional events elicits brain activation patterns that include emotion processing regions such as the amygdala and the striatum (Danker & Anderson, 2010; Schwarze, Bingel, & Sommer, 2012; Speer, Bhanji, & Delgado, 2014; van Schie, Chiu, Rombouts, Heiser, & Elzinga, 2019). In conclusion, studies on mental imagery as well as on episodic recollection suggest that remembering emotional episodes should elicit affective psychophysiological responses.

Across two studies, we assessed facial electromyography (fEMG) during the encoding and subsequent remembering of episodic memories. We employed fEMG as an index of affective psychophysiological responses because we were primarily interested in the reminiscence of happy and sad episodes. Facial EMG responses reflect evaluations of affective valence and intensity and can distinguish between positive and negative states (Dimberg, Thunberg, & Grunedal, 2002; Larsen, Norris, & Cacioppo, 2003; Scherer, 2009), unlike other indices such as heart rate or pupil dilation that are mediated by the autonomic nervous system and are therefore most susceptible to affective arousal (Henderson et al., 2018; Löw et al., 2008). Moreover, facial expressions may be linked to the concomitant action tendencies of emotional experiences and may thus provide insight into motivational drives (Adams, Ambady, Macrae, & Kleck, 2006; Frijda & Tcherkassof, 1997; Kroczeck, Lingnau, Schwind, Wolff, & Mühlberger, 2021).

During encoding, participants watched neutral, negative, and positive movie clips. The next day, they vividly relived what they experienced, felt, and thought when watching the movie clips, in response to neutral reminder cues. We hypothesized that remembering positive events would elicit zygomaticus major responses that indicate smiling and positive affect, while remembering negative events would elicit corrugator supercilii responses that indicate frowning and negative affect. Further, although the classic view of episodic recollection (Tulving, 2002) emphasizes the re-enactment of past encoding processes, a notion that has been corroborated by neuroimaging studies (e.g., Ritchey, Wing, LaBar, & Cabeza, 2013), contemporary theories take a more constructive stance (Madore et al., 2019; Schacter et al.,

2007). This idea is for example based on the observation that brain activation patterns during retrieval differ considerably from the patterns during encoding of the memory (Xiao et al., 2017). In the context of our study, this raises the question to what extent the affective psychophysiological reactions during remembering mirror those from encoding. Therefore, we not only tested whether retrieval of emotional episodes elicited concomitant facial expressions, but we also explored whether the intensity of affective psychophysiological responses during encoding of an event predicted the intensity of responses during subsequent retrieval.

2. Experiment 1

2.1 Methods

2.1.1 Participants

Fifty-two healthy students between the age of 18 and 32 of the University of Amsterdam provided informed consent to participate in the study. They were recruited through online and on-campus advertisement and received course credit or a small financial compensation. We excluded participants with color blindness, with a current mental disorder or a diagnosis within the last year, with a current or past neurological problem, as well as participants who reported excessively frequent recreational drug or alcohol use. Four participants had to be excluded because of technical problems ($n = 3$) or because they did not come to the lab for the second day ($n = 1$), resulting in a total sample of $N = 48$ participants ($M_{\text{age}} = 21.67$, $SD_{\text{age}} = 2.78$, 36 self-reported females, 18 self-reported males). Zygomaticus and corrugator responses to affect-inducing stimuli such as movie clips can be detected with relatively small samples (e.g., $N = 24$, Hubert & de Jong-Meyer, 1990). We aimed for a larger sample size of $N = 48$ because we expected that responses to memories would be weaker than responses to the original emotional movie clips. The study was approved by the ethics committee of the University of Amsterdam (2018-CP-8672).

2.1.2 Materials

2.1.2.1 Experimental task: Day 1 – Encoding of emotional episodes

Participants came to the lab on two consecutive days to complete a computer task in which they encoded and remembered episodic memories of movies and pictures. On Day 1, participants viewed three negative, three positive, and three neutral movie clips in a block design (**Figure 1a**). The order of the three mood blocks (positive, negative, and neutral) was

counterbalanced across participants. The order of the movies within each block was fixed. Between the movie clips of each block, participants viewed 20 neutral pictures (40 per block; this design was inspired by a design of Qin, Hermans, van Marle, & Fernandez, 2012). The pictures were inserted for exploratory purposes and their analyses are not presented in this report (for more detail, see **Supplemental Material S4**). For movie clips and pictures, participants were instructed to imagine themselves in the scenes that were depicted on the screen as vividly as possible. They could achieve this by imagining that they were one of the depicted persons or that they were present in the same location observing the scene as a spectator. After each stimulus (movie clip or picture), they rated how well they managed to imagine themselves in the depicted scene on a visual analogue scale (VAS) ranging from ‘not at all’ (0) to ‘very well’ (100). These instructions and measurements were designed to ensure strong encoding and processing while avoiding mentioning that the study aimed to investigate memories. During each block, participants indicated three times how they felt in terms of valence and arousal on a Self-Assessment Manikin Scale (SAM; Bradley & Lang, 1994) ranging from positive (1) to negative (9) and from excited (1) to calm (9), respectively. The SAM was shown after the first and second movie clip and before the last movie clip of each block. After each movie clip, participants saw a black screen for 3 s. Picture trials were separated by inter trial intervals (ITIs) with a black screen that lasted 1, 2, or 3 s. The duration of the picture ITIs was semi-random such that three consecutive ITIs always lasted an average of 2 s.

After each block, there was a 7.5-minute break. In the beginning of the break, participants completed the Profile of Mood States (POMS; Grove & Prapavessis, 1992) and the Positive And Negative Affect Schedule (PANAS; Peeters, Ponds, & Vermeeren, 1996). During the break, they drew a mandala to help the mood to wear off before the next mood block began. 30 s before the next mood block started, participants saw a 30 s countdown on the screen which directed their attention back to the computer task.

2.1.2.2 Experimental task: Day 2 – Recollection of emotional episodes

Participants were asked to remember the movie clips that they had seen on Day 1. They were instructed to relive what they experienced, felt, and thought the day before while watching the specific movie clip, as consciously and as vividly as possible. **Figure 1b** provides a schematic overview of a memory trial. Following a fixation cross (1 s), participants viewed two retrieval cues that unambiguously referred to one of the movie clips from Day 1 but did not depict an emotional scene themselves (3 s, *reminder phase*). After the retrieval cues disappeared, there was a black screen for 0.5 s. Following, the instruction “Remember the

movie and your experiences during the movie” appeared on the screen for 10 s (*recall phase*). Next, participants were asked to type down everything in a text box that came to their mind during recollection. This procedure was implemented to ensure that participants tried to remember each movie clip and were engaged in the task. After one minute, the text box disappeared automatically. Participants rated how the memory of the movie clip made them feel in terms of valence and arousal, using SAM scales. They were specifically instructed that this was not an assessment of how they felt while watching the movie clip, but of how they felt while remembering. Participants further indicated their subjective memory vividness by answering the question “Thinking back to the movie, how well could you remember?” on a VAS ranging from ‘not at all’ (0) to ‘very well’ (100). Finally, participants indicated whether they had seen each movie before the study or not. Trials were separated with a black screen that lasted 3 s. The memory cues were presented in the same order as the movies on Day 1.

2.1.2.3 Stimuli

The movie clips on Day 1 aimed at creating emotional episodes consisting of negative, positive, and neutral affect. All nine movie clips are commercially available and depict interactions of multiple people. The six emotional clips appeared to be the most effective and reliable for inducing induced self-reported positive or negative emotions in previous studies (Gilman et al., 2017; Schaefer, Nils, Philippot, & Sanchez, 2010). We did not use neutral clips from previous studies because they often did not include human interactions or were too short to be comparable to the emotional videos (Gilman et al., 2017). Instead, we selected neutral clips that resembled the emotional clips as much as possible (e.g., video length, human interactions). The negative movie clips were excerpts from the movies “The Champ”, “My Girl”, and “City of Angels” (see **S1, Table S1** for descriptions of the scenes). The positive movie clips were excerpts from “There Is Something About Mary”, “A Fish Called Wanda”, and from an episode of “The Office” (Gilman et al., 2017). The neutral movie clips were excerpts from the movies “Meet Joe Black”, “JFK”, and “Lincoln”. On Day 2, two cropped screenshots of each movie served as retrieval cues for the respective clip (see **S2** for descriptions of the cues). We presented two cues to ensure that every participant could remember the respective video clip. The retrieval cues were emotionally neutral and taken from the movies or from advertisements for the movies, but not from the scenes that were shown on Day 1. Therefore, the retrieval cues unambiguously referred to one of the Day 1 clips, but they were not part of the originally encoded experience to prevent direct emotional responses to the stimulus that might not be caused by mnemonic memory.

The pictures were 240 neutral scenes depicting one or more persons. All pictures were selected from an online database of freely available photographs (<https://unsplash.com>). We selected pictures in which no facial expressions were particularly salient or oriented directly at the viewer to avoid facial mimicry (Hess & Blairy, 2001). Specifically, we used photographs that depicted people from behind, semi-profile, or that showed multiple persons that did not directly relate to the viewer.

a)

b)

Figure 1. Schematic overview of the study design in Experiment 1. Overview of the encoding task on Day 1 (a) and of a memory trial on Day 2, approximately 24 hours later (b).

2.1.3 Procedure

Participants came to the lab on two consecutive days. On Day 1, participants were informed about the experimental procedures, completed a screening form that addressed the exclusion criteria, and provided written informed consent. Participants were not informed about the memory purpose of the study to prevent the use of cognitive strategies that might influence memory encoding or consolidation and would limit the ecological validity of the experiment. Following a medical screening and informed consent, the experimenter attached the psychophysiological sensors, i.e., fEMG mini-electrodes and ECG electrodes. The ECG data were collected for exploratory purposes and were not analyzed further. After the signal quality was checked by the experimenter, the participants completed several questionnaires about individual traits before starting the computer task (see **S3**; questionnaire data was collected for exploratory purposes and not analyzed for this report): Beck Depression Inventory (BDI; Aaron T. Beck; Nederlandse versie door A. J. Willem van der Does, 2002), Plymouth Sensory Imagery Questionnaire (PSI-Q; Andrade, May, Deeprose, Baugh, & Ganis, 2014), Spontaneous Use of Imagery Scale (SUIS; Nelis, Holmes, Griffith, & Raes, 2014), Involuntary Autobiographical Memory Inventory (IAMI; Berntsen, Rubin, & Salgado, 2015), State-Trait Anxiety-Inventory (STAI-T & STAI-S; van der Ploeg, 1982). Finally, the participants completed the first part of the computerized episodic memory retrieval task, in which they viewed movie clips and pictures. After each block, participants completed the POMS and the PANAS.

On Day 2, the experimenter first attached the psychophysiological sensors. Following, participants performed the episodic memory recollection task in which they remembered the movie clips of Day 1. Lastly, participants performed a recognition task for the pictures presented on Day 1 (see **S4**). Upon completion of the study, participants were debriefed. On both days, participants were seated alone in a small, dimly lit, sound attenuated, and electrically shielded room in front of a computer screen for the entire duration of tasks. The experimenter only entered the room to attach the psychophysiological sensors, to give instructions before each task, and during the breaks on Day 1 to hand over the questionnaires. The remaining time, the experimenter was seated in an adjacent room. The experimenter and the participant could communicate via an intercom.

2.1.4 Data analysis

2.1.4.1 Facial EMG data acquisition

We collected fEMG data from the left zygomaticus major and the left corrugator supercilii (Larsen et al., 2003). The zygomaticus major contracts when people smile and is an indicator of positive emotional experience. The corrugator supercilii contracts when people frown and is an indicator for negative emotional experience. Two Ag/AgCl mini-electrodes were placed near the left eyebrow and on the left cheek in approximately 1 cm distance to measure corrugator supercilii and zygomaticus major activity, respectively. A reference electrode was placed on the forehead. The electrodes were connected to a custom-made bipolar EMG amplifier with an input resistance of $1\text{G}\Omega$ and a bandwidth of 5-1000 Hz (6dB/oct). The raw data was sampled at 1000 S/s. The fEMG data was rectified and integrated using a digital contour follower with a time constant of 25 ms using the in-house software VSRRP98 developed by the Technical Support Group Psychology of the University of Amsterdam (Version 10.5; 2017).

2.1.4.2 Facial EMG data analysis

Data for the movies on Day 1 were reduced offline to 250 ms segments (the total number ranging from 422 to 1070 segments depending on movie length). For the memory task on Day 2, fEMG data were reduced to eight 250 ms pre-stimulus segments (2 s baseline), twelve 250 ms segments during reminder presentation (3 s reminder phase), and forty 250 ms segments during the recall phase (10 s recall phase). The following analysis steps were conducted in R (R Foundation for Statistical Computing, 2019; RStudio Team, 2018). EMG data typically includes artefacts due to movement, eye blinks, etc. We applied automated artefact rejection to avoid arbitrary experimenter decisions about whether signal was due to emotional expressions or due to artefacts. Specifically, each data point that deviated 3 or more standard deviations from the mean of all time points were rejected as an artefact and replaced with a missing value. This artefact rejection was applied within muscle (zygomaticus major, corrugator supercilii), within day (Day 1, Day 2), and within condition (negative, positive, neutral). After artefact rejection, the data were averaged per trial (combining the 3 s reminder phase and the 10 s recall phase). We did not apply a baseline-correction on a trial-by-trial base because of the block design in Experiment 1. Affective psychophysiological responses were likely to persist throughout each mood block and correcting for baseline within each block would have obscured affect-driven psychophysiological responses. We excluded trials with a memory vividness rating below 5 (on a scale from 0 to 100). We chose a threshold slightly above the

minimum 0 to account for the possibility that participants may have intended to move the cursor to 0 but clicked slightly off the mark. A rating below 5 would indicate a very rudimentary memory that is not likely to elicit affective responses. We also excluded trials in which the participant confused the movie clip with another clip (based on the written responses on Day 2).

In confirmatory analyses, we compared the zygomaticus and the corrugator activity between conditions separately for the movie clips on Day 1 and the memories on Day 2. Specifically, we conducted one-way repeated-measures ANOVAs with three levels (positive, negative, neutral) with zygomaticus and corrugator activity as dependent variables, respectively. For this purpose, data was averaged within participants and conditions. We log-transformed prior to data analysis because a visual inspection of histograms indicated that the data was skewed. ANOVAs were conducted with the ‘ez’ package for R (Lawrence, 2016). For planned contrasts, one-tailed p-values are reported. Cohen’s d for pairwise comparisons were calculated with the ‘effectsize’ package (Ben-Shachar, Lüdtke, & Makowski, 2018).

We conducted exploratory multilevel analyses (Bates, Mächler, Bolker, & Walker, 2015) to investigate predictors of psychophysiological responses during the recollection of emotional events. The primary aim of these analyses was to explore whether the expressed intensity of affect during remembering was proportional to affective intensity of the corresponding original experience. We calculated the mean per condition for each subject (between person predictor) and we calculated the condition-mean centered fEMG response for each memory (within person predictor). Given that our main interest was the within-subject relationship, this cluster mean centering approach should give the most reliable estimates (Hamaker & Grasman, 2014). We estimated multilevel models in which the fEMG response on Day 2 was predicted by condition (positive, negative, neutral), condition-mean centered fEMG response on Day 1, subject-mean fEMG response per condition on Day 1, memory vividness rating on Day 2 (to account for variance in fEMG responses on day 2 that are driven by memory vividness), whether participants knew a movie before they participated in the study, and an interaction of condition and condition-mean centered fEMG response on Day 1. We always included a random intercept per subject to account for the within-subjects design. In a model selection procedure, we tested whether model fit improved when adding a random slope for condition-mean centered response on Day 1, when adding a random slope for condition, and when adding a random intercept for movie clips (evaluated with AIC, BIC, and a χ^2 -test, see **Table S8 & S9**). We excluded outliers from the final model with Cook’s d > 1 before evaluating our hypotheses. If the interaction between condition and condition-mean centered fEMG response

on Day 1 added significantly to the model, we investigated the slope of condition-mean centered fEMG response on Day 1 separately for each condition (Lenth, 2022). If the interaction was not significant, we calculated a slope across conditions.

Finally, we explored whether memories that elicited stronger psychophysiological reactions also resulted in stronger subjective feelings. Accounting for the within subjects design with a random effect for subject, we calculated multilevel correlations between valence ratings and fEMG responses (zygomaticus and corrugator) within the positive and negative condition, respectively (Makowski et al., 2022).

2.1.4.3 Subjective memory experience

We investigated differences between negative, positive, and neutral memories in terms of self-reported valence, arousal, and vividness ratings of the memories on Day 2 in three one-way repeated-measures ANOVAs with three levels (negative, neutral, positive).

2.2 Results

2.2.1 Affective psychophysiological responses during the encoding of emotional episodes

Zygomaticus and corrugator activity while experiencing emotional episodes (i.e., watching movie clips) are depicted in **Figure 2** (left and right panel). The log-transformed zygomaticus activity differed when experiencing positive, negative, and neutral episodes ($F(2,94) = 30.131, p_{GG} < .001$, generalized $\eta^2 = 0.184$). Participants smiled most when experiencing positive clips as compared to neutral ($t(94) = 6.496, p < .001$, mean difference $MD = 0.402, SE = .062$, 95% CI [0.279, 0.525], $d = 0.78$) and negative clips ($t(94) = 6.928, p < .001$, $MD = 0.429, SE = .062$, 95% CI [0.306, 0.551], $d = 0.91$). There was no evidence that zygomaticus activity differed between negative and neutral clips ($t(94) = 0.432, p = .667, MD = 0.027, SE = .062$, 95% CI [-0.096, 0.150], $d = 0.11$). Like the zygomaticus, log-transformed corrugator activity also differed when experiencing positive, negative, and neutral episodes ($F(2,94) = 19.596, p < .001, g\eta^2 = 0.082$). The corrugator was more active when viewing negative clips compared to neutral clips ($t(94) = 5.419, p < .001, MD = 0.304, SE = .056$, 95% CI [0.192, 0.415], $d = 0.89$) and compared to positive clips ($t(94) = 5.429, p < .001, MD = 0.305, SE = .056$, 95% CI [0.193, 0.416], $d = 0.83$), but there was no evidence that corrugator activity differed for the neutral versus the positive clips ($t(94) = 0.015, p = .988, MD = 0.001, SE = .056$, 95% CI [-1.111, 0.112], $d = 0.00$). These results underscore that

watching movie clips elicited positive and negative emotions that were expressed through clear psychophysiological responses.

2.2.2 Affective psychophysiological responses during the recollection of emotional episodes

We investigated whether episodic recollection led to psychophysiological responses that express the valence of the original event. Zygomaticus and corrugator activity while remembering emotional episodes are depicted in **Figure 2** (middle and right panel). A one-way repeated measures ANOVA showed that log-transformed zygomaticus activity differed when remembering positive, negative, and neutral movie clips ($F(2,94) = 7.973, p = .001, g\eta^2 = 0.064$). The zygomaticus was more active when remembering positive movie clips compared to neutral movie clips ($t(94) = 3.238, p = .001, MD = 0.221, SE = 0.068, 95\% CI [0.085, 0.356], d = 0.41$) and negative movie clips ($t(94) = 3.643, p < .001, MD = 0.248, SE = 0.068, 95\% CI [0.113, 0.384], d = 0.53$). Zygomaticus activity did not differ significantly when remembering neutral compared to negative movie clips ($t(94) = 0.406, p = .686, MD = 0.027, SE = 0.068, 95\% CI [-0.108, -.163], d = 0.07$).

A one-way repeated measures ANOVA showed that log-transformed corrugator activity differed when remembering positive, negative, and neutral movie clips ($F(2,94) = 17.958, p < .001, g\eta^2 = 0.033$). Corrugator activity was significantly higher when remembering negative movie clips compared to positive ($t(94) = 5.661, p < .001, MD = 0.224, SE = 0.040, 95\% CI [0.145, 0.302], d = 0.80$) but not compared to neutral movie clips ($t(94) = 1.128, p = .131, MD = 0.045, SE = 0.040, 95\% CI [-0.034, 0.123], d = 0.17$). Corrugator activity was significantly higher when remembering neutral compared to positive movie clips ($t(94) = 4.533, p < .001, MD = 0.179, SE = 0.040, 95\% CI [0.101, 0.257], d = 0.65$). These results indicate that remembering positive episodes elicited corresponding affective psychophysiological responses. Remembering negative episodes might have also elicited psychophysiological responses, but these did not differ from the retrieval of neutral episodes.

2.2.3 Relationship between affective responses during encoding and remembering

We investigated predictors of psychophysiological responses during the recollection of emotional events in multilevel models. The main goal of these analyses was to test whether the expressed intensity of affect during remembering was proportional to affective intensity of the corresponding original experience. First, we investigated zygomaticus activity while

remembering emotional events. Following our inclusion criteria, we included 420 observations of 48 participants. A type III Wald χ^2 test yielded a significant fixed effect of condition ($\chi^2(2) = 12.258, p = .002$) and a significant effect of the subject-mean zygomaticus response on day 1 ($\chi^2(1) = 36.154, p < .001$), and a significant interaction between condition and condition-mean centered zygomaticus response on Day 1 ($\chi^2(2) = 29.902, p < .001$). Fixed effects of the condition-mean centered response on Day 1, of memory vividness and of whether participants knew a movie before the study were not significant (condition-mean centered response on Day 1: $\chi^2(1) = 0.014, p = .905$; memory vividness: $\chi^2(1) = 0.845, p = .358$; movie knowledge: $\chi^2(1) = 0.240, p = .624$). Following up on the interaction, we unexpectedly found that higher zygomaticus activity while encoding a movie clip on Day 1 was associated with higher zygomaticus activity when remembering the clip on Day 2 in the neutral but not in the positive or negative condition (neutral: $\beta = 0.611, SE = .167, t(75.0) = 3.665, p < .001$; positive: $\beta = 0.017, SE = .146, t(39.5) = 0.117, p = .907$; negative: $\beta = 0.094, SE = .177, t(868) = 0.533, p = .596$). Following up on the effect of condition, participants' zygomaticus was more active when they remembered positive compared to neutral and negative memories, but the comparison of positive and neutral memories did not reach significance (positive – neutral: $t(390) = 1.701, p = .090, MD = 0.408, SE = 0.240, 95\% CI [-0.064, 0.881]$; positive – negative: $t(364) = 3.508, p = .001, MD = 0.721, SE = 0.206, 95\% CI [0.317, 1.125]$). There was no significant difference of zygomaticus activity when remembering neutral compared to negative events ($t(389) = 1.370, p = .171, MD = 0.313, SE = 0.228, 95\% CI [-0.136, 0.761]$).

Second, we investigated corrugator activity while remembering emotional events. We included 48 participants with 420 observations in 144 conditions. A type III Wald χ^2 test yielded a significant fixed effect of condition ($\chi^2(2) = 10.303, p = .006$) and of the subject-mean corrugator response on day 1 ($\chi^2(1) = 33.914, p < .001$). No other fixed effects were significant, including the interaction between condition and condition-mean centered corrugator response on Day 1 (condition-mean centered response on Day 1: $\chi^2(1) = 1.692, p = .193$; memory vividness: $\chi^2(1) = 0.375, p = .540$; movie knowledge: $\chi^2(1) = 0.797, p = .372$; condition by condition-mean centered corrugator response on day 1 interaction: $\chi^2(2) = 0.993, p = .609$). Following up on the effect of condition, participants' corrugator was more active when they remembered negative or neutral compared to positive events (negative – positive: $t(16.6) = 2.803, p = .012, MD = 1.122, SE = 0.400, 95\% CI [0.276, 1.97]$; neutral – positive: $t(22.8) = 2.650, p = .014, MD = 1.152, SE = 0.435, 95\% CI [0.252, 2.05]$). However, corrugator activity was not significantly higher when remembering negative to neutral events ($t(22.9) = -0.069, p = .945, MD = -0.030, SE = 0.435, 95\% CI [-0.930, 0.87]$).

2.2.4 Subjective experience of episodic recollection

To test whether the retrieval of emotional episodic memories leads to subjective positive, negative, or neutral feelings, we conducted a one-factorial repeated-measures ANOVA with self-reported memory valence as dependent variable ($F(2,94) = 104.067$, $p_{GG} < .001$, $g\eta^2 = 0.418$, see **Table 1**). Participants reported more positive feelings when remembering positive movie clips compared to remembering neutral ($t(94) = 6.007$, $p < .001$, $MD = 1.23$, $SE = 0.204$, 95% CI [0.821, 1.63], $d = 0.91$) and negative movie clips ($t(94) = 14.363$, $p < .001$, $MD = 2.93$, $SE = 0.204$, 95% CI [2.525], $d = 1.51$). Moreover, participants reported more negative feelings when remembering negative compared to neutral movie clips ($t(94) = 8.356$, $p < .001$, $MD = 1.70$, $SE = 0.204$, 95% CI [1.300, 2.11], $d = 1.68$).

We conducted a repeated measures ANOVA to compare subjective feelings of arousal when remembering positive, negative, and neutral movie clips ($F(2,94) = 31.527$, $p < .001$, $g\eta^2 = 0.166$, see **Table 1**). Post hoc contrasts showed that positive memories were experienced as more arousing than negative and neutral memories (positive versus neutral: $t(94) = 7.936$, $p < .001$, $MD = 1.535$, $SE = 0.193$, 95% CI [1.063, 2.01], $d = 1.06$; positive versus negative: $t(94) = 3.735$, $p = .001$, $MD = 0.722$, $SE = 0.193$, 95% CI [0.251, 1.19], $d = 0.55$). Negative memories were experienced as more arousing than neutral memories ($t(94) = 4.201$, $p < .001$, $MD = 0.812$, $SE = 0.194$, 95% CI [0.341, 1.28], $d = 0.64$).

We also conducted a repeated measures ANOVA to compare the subjective memory vividness for positive, negative and neutral movie clips ($F(2,94) = 66.983$, $p_{GG} < .001$, $g\eta^2 = 0.322$, see **Table 1**). Post hoc contrasts revealed that the participants rated the vividness of positive and negative memories higher than the vividness of neutral memories (positive versus neutral: $t(94) = 10.406$, $p < .001$, $MD = 27.90$, $SE = 2.68$, 95% CI [21.36, 34.43], $d = 1.26$; negative versus neutral: $t(94) = 9.592$, $p < .001$, $MD = 25.72$, $SE = 2.68$, 95% CI [19.18, 32.25], $d = 1.22$). Memory vividness did not differ significantly between positive and negative memories ($t(94) = 0.813$, $p > .999$, $MD = 2.18$, $SE = 2.68$, 95% CI [-4.35, 8.72], $d = 0.21$). Descriptive statistics per movie clip are presented in the **S5 (Table S5)**.

Finally, we explored whether memories that elicited stronger psychophysiological reactions also resulted in stronger subjective feelings. There was no significant multilevel correlation between zygomaticus activity and subjective valence ratings when remembering positive memories ($r = .05$, 95% CI [-0.11, 0.21], $t(142) = 0.59$, $p = .553$), nor between the corrugator activity and valence ratings when remembering negative memories ($r = -.14$, 95% CI [-0.29, 0.03], $t(142) = -1.66$, $p = .099$). These results indicate that there was no or only a

weak relationship between subjective feelings and affective psychophysiological responses while remembering emotional events.

Table 1.

Encoding and retrieval of episodes in Experiment 1.

		positive	negative	neutral
Movies	Zygomaticus (log)	1.380 (0.580)	0.952 (0.308)	0.979 (0.301)
	Corrugator (log)	1.784 (0.532)	2.088 (0.463)	1.785 (0.453)
	Vividness rating	58.13 (18.32)	63.86 (17.45)	50.79 (21.42)
Memories	Zygomaticus (log)	1.304 (0.546)	1.056 (0.371)	1.083 (0.347)
	Corrugator (log)	1.521 (0.533)	1.744 (0.526)	1.700 (0.538)
	Valence rating	3.250 (1.246)	6.181 (1.644)	4.476 (1.378)
	Arousal rating	6.403 (1.726)	7.125 (1.412)	7.938 (1.042)
	Vividness rating	83.60 (12.36)	81.42 (12.93)	55.71 (26.77)

Note. Presented are means and standard deviations in parentheses. Data was averaged within participants before calculating means and standard deviations.

Figure 2. Zygomaticus and corrugator activity while experiencing and remembering emotional episodes in Experiment 1. The upper and lower panel present zygomaticus and corrugator activity, respectively. The left panel presents muscle activity over time while viewing positive, negative, and neutral movie clips on Day 1. Since the movie clips varied in duration, data points towards the end of the x-axes only represent data for one movie. The colored ticks on the x axis indicate the end of specific movie clips. The middle panel shows muscle activity over time while remembering the movie clips on Day 2. The first vertical line indicates the onset of the memory cues (0 s), the second vertical line indicates the offset of the memory cues (3 s). After stimulus offset, participants kept silently reliving the memory for 10 s. The error bands represent the standard error of the mean. The data was averaged across memories within each subject before calculating the average and standard error for each time point across subjects. The right panel shows the average of the log-transformed zygomaticus and corrugator responses during the entire recall phase (13 s). The error bars represent the mean plus/minus one standard deviation.

2.3 Experiment 1: discussion

The results from experiment 1 provide evidence that participants express psychophysiological affective responses when remembering emotional events that align with the valence of those events. Participants showed higher zygomaticus activity when experiencing and when remembering positive events compared to neutral and negative events, which indicates smiling and positive affect. Participants showed higher corrugator responses when experiencing negative events compared to neutral and positive events, which indicates frowning and negative affect. However, when remembering negative events, corrugator activity was only higher compared to positive but not neutral events. These results underscore that psychophysiological responses during remembering reflect the original valence of the event. Beyond this overall effect, however, we did not find convincing evidence for a more fine-grained relationship (i.e., within each valence condition) between affect intensity of the original experience and expressed intensity during later recollection of that experience. However, participants who on average displayed stronger responses to emotional events, also displayed stronger responses to memories of events, hinting towards individual differences in the propensity to express affective responses.

Even though Experiment 1 provided initial evidence for affective psychophysiological responses during episodic recollection, there were some limitations that call for a follow-up experiment. Most importantly, the study employed a block-design in which all clips of one condition were played consecutively before participants saw clips from another condition. Therefore, participants could anticipate the valence of an ensuing clip and psychophysiological responses may represent a general mood change due to a negative or positive block, rather than responses to specific episodic memories. Another issue was that several participants reported in informal debriefings that the movie clips did not elicit strong emotions, even though these had been validated in previous research. We therefore conducted a second experiment to conceptually replicate and complement our findings.

3. Experiment 2

3.1 Methods

In Experiment 2, we aimed to conceptually replicate the observation that the recollection of emotional episodes elicits concomitant affective responses assessed through fEMG, particularly of the zygomaticus. The study design of Experiment 2 included several adjustments to allow for stronger conclusions. Specifically, we employed an event-related

design that allowed us to baseline-correct fEMG data, and consequently, to preclude the interpretation that affective responses in Experiment 1 were only driven by overall mood changes rather than by specific responses to movies and memories. Additionally, stimuli were counterbalanced across participants in different task versions which decreases the likelihood that results are driven by a specific movie clip, rather than by all movie clips in a condition. Experiment 2 was part of a larger three-day paradigm. In contrast to Experiment 1, we did not choose movie clips that were validated in previous studies but instead searched for movie clips that we expected to elicit strong emotions. The experimental design, stimuli, hypotheses, and analysis plan were preregistered on the Open Science Framework (OSF, 2019 <https://doi.org/10.17605/OSF.IO/DARYV>). Deviations from the preregistration are listed in the S9.

3.1.1 Participants

Participants were recruited through online and on-campus advertisement and received course credit or a small financial compensation. Based on self-reports in an online screening questionnaire, we excluded participants with color blindness, with a current mental disorder or a diagnosis within the last year, with a current or past neurological problem, as well as participants who reported excessively frequent recreational drug or alcohol use. Moreover, we excluded participants who had participated in a similar study from our lab, who did not have at least an advanced English proficiency level (verified during first contact per phone), and participants who knew more than three movies from our stimulus set, or more than one movie clip within one condition (verified based on self-report in the online screening questionnaire).

Eighty healthy participants between the age of 17 and 35 of the University of Amsterdam provided informed consent to participate in the study. We excluded twelve participants because of excessive drug use ($n = 2$), because of an experimenter error ($n = 6$), because they participated in a similar study before ($n = 1$), because of a technical error ($n = 1$), because of excessive alcohol use ($n = 1$), or because they were in treatment for a psychiatric disorder ($n = 1$), which resulted in a sample size of $N = 68$ ($M_{\text{age}} = 20.31$, $SD_{\text{age}} = 2.80$, 54 self-reported females, 14 self-reported males). Moreover, we excluded data from 9 participants that completed the experiment because they did not have valid data for an entire condition or because they had invalid data for more than three movie clips (invalid data meaning that the participant did not remember a movie clip from Day 1 or confused a movie clip with a different one). Therefore, our final sample for preregistered analyses consisted of $N = 59$ participants ($M_{\text{age}} = 20.12$, $SD_{\text{age}} = 2.77$, 47 self-reported females, 12 self-reported males). For analyses that

were not preregistered, we included data from all $N = 68$ participants that completed the experiment. The study was approved by the ethics committee of the University of Amsterdam (2019-CP-10057).

3.1.2 Materials

3.1.2.1 Experimental task: Day 1 – Encoding of emotional episodes

Participants watched two positive, two negative, and two neutral movie clips (as well as six additional neutral movie clips that are not further investigated here). After each clip, participants indicated how the clip made them feel in terms of valence and arousal by moving a slider on a VAS from ‘negative’ (0) to ‘positive’ (100), and a tick-mark in the center to indicate ‘neutral’ (50), and on a VAS from ‘calm’ (0) to ‘excited’ (100). Further, they indicated how well they managed to imagine themselves in the depicted scene on a VAS ranging from ‘not at all’ (0) to ‘very well’ (100). The stimuli were presented in semi-random order, such that no more than two emotional clips were presented consecutively. Before starting the task, participants were familiarized with the task by completing one practice trial with a short neutral movie clip.

3.1.2.2 Experimental task: Day 2 – Recollection of emotional episodes

Similar to Experiment 1, participants were asked to remember the movie clips that they had seen on Day 1. **Figure 3** provides a schematic representation of a memory trial. A fixation cross (3 s) preceded each trial. During each trial, participants viewed two retrieval cues that unambiguously referred to one of the movie clips from Day 1 (5 s, *reminder phase*). After the retrieval cues, the instruction “Remember the clip and your experiences while watching it.” appeared on the screen for 10 s (*recall phase*). Next, participants rated how the memory of the movie clip made them feel in terms of valence on a VAS ranging from ‘negative’ (0) to ‘positive’ (100) with a tick mark in the center to indicate ‘neutral’ (50). They also rated how the memory made them feel in terms of arousal on a scale ranging from ‘calm’ (0) to ‘excited’ (100). Finally, participants indicated their subjective memory vividness by answering the question “Thinking back to the film clip, how well could you remember it?” by selecting one of four options: ‘Not at all’, ‘Vaguely familiar’, ‘Pretty well’, and ‘Very vividly’. Trials were separated with a black screen that lasted 15 s to allow potential affective states to wear off between trials. Trials were presented in semi-random order such that no more than two emotional movie clips were probed in successive trials. After remembering some of the movie clips, participants were presented with a novel negative, neutral, or positive movie clip. Data

of these trials were not further investigated for this manuscript (see **S7** for an overview of the complete experimental design). Before starting the task, participants were familiarized with the task by completing a practice trial, in which they remembered the movie clip of the practice trial from Day 1.

3.1.2.3 Stimuli

In Experiment 1, we used positive and negative movie clips that have been validated in previous studies. However, some of the clips seemed out of date and several participants noted that the clips felt unreal or unconvincing. Therefore, in Experiment 2, we selected positive and negative movie clips ourselves, regardless of whether they have been employed in previous studies (see **S1**, **Table S2** for a descriptions of the scenes). We searched for clips that elicit strong happy and sad emotions, that involved the interaction of multiple people, that included at least a basic narrative such as a conversation or an interaction, that did not vary too much in duration, and that were not too recent (to avoid that a large proportion of the sample had seen the clips). Potential clips were discussed in the research team until a consensus on the final selection was reached. The negative movie clips were excerpts from the movies “The Champ”, “Signs”, and “Secret in Their Eyes”, and “Basketball Diaries”. The positive movie clips were excerpts from “About Time”, “Untouchable”, “Marley And Me”, and “Péle: Birth Of A Legend”. The neutral movie clips were excerpts from the movies “Meet Joe Black”, “The Founder”, “Dead Poet Society”, and “Big Night”. Each participant was presented with two of the four movie clips per condition (counterbalanced). Similar to Experiment 1, two cropped screenshots of each movie served as retrieval cues for the respective clip (see **S2** for descriptions of the cues). In contrast to Experiment 1, the screenshots were taken from the Day 1 excerpts (instead of from the movie in general). The screenshots were neutral elements that were not central to the movie clip and that did not depict a main character nor a salient facial expression (e.g., a picture in the background of a bar, a door, or a kitchen table). For each movie clip, we selected four reminder cues, resulting in two pairs of two cues. On day 2, half of the participant were presented with one pair, the other half with the other pair.

Figure 3. Schematic overview of a memory trial in Experiment 2.

3.1.3 Procedure

People who were interested in participating were screened for eligibility by phone. Potential participants who reported to meet at least one exclusion criterion, who knew more than three movies that were used in the study, or who knew all movies in one condition were not invited for participation. Eligible participants came to the lab on three consecutive days. The third day and half of the conditions were designed to investigate memory updating and are not of interest for this report (see **S7** for an overview of the complete experimental design). We only analyzed and present data of the first two experimental sessions and the conditions relevant to the research question. Unless stated otherwise, the procedure was similar to Experiment 1.

On Day 1, participants were informed about the experimental procedures, completed a screening form that addressed the exclusion criteria, and provided written informed consent. Again, participants were not informed about the memory purpose of the study to prevent the use of cognitive strategies that might influence memory encoding or consolidation and would limit the ecological validity of the experiment. Following a medical screening and informed consent, the experimenter attached the fEMG mini-electrodes. After the signal quality was checked by the experimenter, the participants completed the PANAS and answered a few questions regarding their sleep and activities on the previous evening (see **S3** for additional information regarding the questionnaires). The participants completed the first part of the computerized episodic memory retrieval task, in which they viewed movie clips. Finally, the participants completed the PANAS a second time. On Day 2, the experimenter first attached

the psychophysiological sensors, before the participants completed the same questionnaires as on Day 1. The participants performed the episodic memory recollection task in which they remembered the movie clips of Day 1 and they saw several new movie clips. Finally, they completed the PANAS again. Day 3 followed the same procedure as Day 2, but participants completed additional questionnaires after completing the computer task: BDI, STAI-T, PSI-Q, the Perceived Awareness of the Research Hypothesis Scale (PARH; Rubin, 2016), and a questionnaire that assessed which movies they had seen before participating in the experiment. In the end, participants were debriefed about the study.

3.1.4 Data analysis

Facial EMG data acquisition, preprocessing, and analyses were similar to Experiment 1, with a few exceptions. First, Experiment 2 was preregistered. We had to make minor adjustments to the preregistered analysis plan that are listed in **S8**. Second, the event-related design allowed to baseline-correct the data by subtracting the mean during baseline (2 s prior to stimulus presentation) from the response while watching and remembering each movie, respectively. For the memory task, only fEMG data of the first 10 s during memory retrieval were analyzed (5 s retrieval cue presentation and 5 s free retrieval). The automated artefact rejection as described for Experiment 1 was applied within muscle (zygomaticus major, corrugator supercilii), within day (Day 1, Day 2), and within condition (negative, positive, neutral), but separately for the baselines across conditions within participants. We evaluated outliers separately for the baselines because a response that may be within the normal range when experiencing strong emotions would still comprise an outlier for a relatively neutral baseline. We did not log-transform the data prior to analysis, because a visual inspection of histograms indicated that the baseline-corrected data was not heavily skewed, and log-transformation did not result in a more normal distribution of response values.

For the multilevel models, we included all valid trials for all subjects that were tested. We excluded trials as invalid that concerned movie clips that participants did not remember on Day 2 or on Day 3, or that participants confused with another movie clip in a memory trial (based on their written response on Day 3). A model selection procedure similar to Experiment 1 showed that a model that included a random intercept for participant and a random slope for condition-mean centered response on Day 1 was the best fitting model and therefore further analyzed.

In addition to the fEMG responses, we investigated differences in the subjective valence ratings of the movie clips on Day 1 and of the memories on Day 2, respectively. Specifically,

we conducted two preregistered one-way repeated-measures ANOVAs with three levels (negative, neutral, positive) and valence ratings as dependent variables.

3.2 Results

3.2.1 Preregistered manipulation check: Affective psychophysiological responses during the encoding of emotional episodes

Similar to Experiment 1, we investigated whether experiencing happy and sad emotional episodes elicited corresponding affective psychophysiological responses. Zygomaticus and corrugator activity while watching emotional movie clips are depicted in **Figure 4** (left and right panel). A one-way repeated measures ANOVA showed that the baseline-corrected zygomaticus activity differed when viewing positive, negative, and neutral movie clips ($F(2,116) = 17.175, p_{GG} < .001, g\eta^2 = 0.164$). The zygomaticus was significantly more active when viewing positive clips compared to neutral clips ($t(116) = 5.201, p < .001, MD = 4.316, SE = .83, 95\% CI [2.67, 5.96], d = 0.53$) and compared to negative clips ($t(116) = 4.941, p < .001, MD = 4.100, SE = .83, 95\% CI [2.46, 5.74], d = 0.61$). Zygomaticus activity did not differ significantly when watching neutral compared to negative clips ($t(116) = -0.260, p = .795, MD = -0.216, SE = .83, 95\% CI [-0.32, 0.19], d = -0.06$; this contrast was not preregistered). Moreover, a one-way repeated measures ANOVA showed that the baseline-corrected corrugator activity differed when viewing negative, positive, and neutral movie clips ($F(2,116) = 15.731, p_{GG} < .001, g\eta^2 = 0.164$). The corrugator was significantly more active when viewing negative clips compared to neutral clips ($t(116) = 2.512, p = .007, MD = 2.06, SE = .82, 95\% CI [0.436, 3.68], d = 0.29$) and compared to positive clips ($t(116) = 5.599, p < .001, MD = 4.59, SE = .82, 95\% CI [2.968, 6.22], d = 0.73$). Furthermore, corrugator activity was lower when watching positive clips compared to neutral clips ($t(116) = 3.088, p = .003, MD = 2.53, SE = .82, 95\% CI [0.908, 4.16], d = 0.47$; this contrast was not preregistered and a two-sided p-value is presented). Similar to Experiment 1, these results indicate that watching positive and negative movie clips resulted in zygomaticus and corrugator responses, respectively.

3.2.2 Preregistered hypotheses: Affective psychophysiological responses during the recollection of emotional episodes

Conceptually replicating Experiment 1, we tested whether remembering episodic memory retrieval led to a re-instatement of the affective psychophysiological responses. Zygomaticus and corrugator activity while remembering emotional episodes are depicted in **Figure 4** (middle and right panel). A one-way repeated measures ANOVA showed that

baseline-corrected zygomaticus activity differed when remembering positive, negative, and neutral movie clips ($F(2,116) = 6.556$, $p_{GG} = .008$, $g\eta^2 = 0.064$). The zygomaticus was more active when remembering positive movie clips compared to neutral movie clips ($t(116) = 2.758$, $p = .003$, $MD = 1.356$, $SE = 0.492$, 95% CI [0.382, 2.33], $d = 0.30$) and negative movie clips ($t(116) = 3.411$, $p = .001$, $MD = 1.677$, $SE = 0.492$, 95% CI [0.703, 2.65], $d = 0.39$). Zygomaticus activity did not differ significantly when remembering neutral compared to negative movie clips ($t(116) = 0.653$, $p = .515$, $MD = 0.321$, $SE = .492$, 95% CI [-0.653, 1.30], $d = 0.17$; this contrast was not preregistered). Moreover, a one-way repeated measures ANOVA showed that corrugator activity differed when remembering positive, negative, and neutral movie clips ($F(2, 116) = 9.062$, $p < .001$, $g\eta^2 = 0.084$). Corrugator activity was significantly higher when remembering negative movie clips compared to positive ($t(116) = 4.168$, $p < .001$, $MD = 1.186$, $SE = 0.285$, 95% CI [0.622, 1.749], $d = 0.50$) but not compared to neutral movie clips ($t(116) = 1.333$, $p = .093$, $MD = 0.379$, $SE = 0.285$, 95% CI [-0.184, 0.943], $d = 0.18$). Corrugator activity was significantly higher when remembering neutral compared to positive movie clips ($t(116) = 2.835$, $p = .005$, $MD = 0.807$, $SE = 0.285$, 95% CI [0.243, 1.370], $d = 0.39$; this contrast was not preregistered). Again, these results indicate that remembering positive episodes elicited affective psychophysiological responses that corresponded to the valence of the original event. Even though remembering negative episodes elicited corrugator responses, these did not differ from the retrieval of neutral episodes (similar to experiment 1).

Figure 4. Zygomaticus and corrugator activity while experiencing and remembering emotional episodes in Experiment 2. The upper and lower panel present zygomaticus and corrugator activity, respectively. The left panel presents muscle activity over time while viewing emotional movie clips on Day 1. The movie clips varied in duration. Therefore, some data points towards the end of the x-axes only represent data for one movie. The middle panel shows muscle activity over time while remembering the movie clips on Day 2. The first vertical line indicates the onset of the memory cues (0 s), the second vertical line indicates the offset of the memory cues (5 s). For the remaining 10 s, participants kept silently reliving the memory. The error bands represent the standard error of the mean. The data was averaged across memories within each subject before calculating the average and standard error for each time point across subjects. The left and the middle panels are based on the full sample ($n = 68$). The right panel shows the average of the baseline-corrected zygomaticus and corrugator responses during 10 s memory retrieval starting at stimulus onset (0 s – 10 s) and is based on the participants that have data in all conditions and are investigated in the pre-registered ANOVAs ($n = 59$). Some individual data points are omitted because they would not fit on the same y-axis. The error bars represent the mean plus/minus one standard deviation.

3.2.3 Subjective feelings during encoding and retrieval

We conducted two preregistered one-factorial repeated-measures ANOVAs to assess whether experiencing and remembering negative, positive, and neutral episodes resulted in corresponding subjective feelings. Descriptive statistics of the preregistered sample are presented in **Table 2** (descriptive statistics of the full sample showed a similar pattern and are presented in **S10, Table S9**). A significant main effect of condition indicated that viewing negative, neutral, and positive movie clips resulted in different subjective feelings ($F(2,116) = 805.513, p < .001, g\eta^2 = 0.906$). Positive movies elicited more positive feelings than neutral ($t(116) = 14.777, p < .001, MD = 28.2, SE = 1.91, 95\% CI [24.4, 32.0], d = 1.95$) and negative movie clips ($t(116) = 39.707, p < .001, MD = 75.9, SE = 1.91, 95\% CI [72.1, 79.6], d = 4.94$). Negative movie clips elicited more negative feelings than neutral movie clips ($t(116) = 24.931, p < .001, MD = 47.6, SE = 1.91, 95\% CI [43.8, 51.4], d = 3.37$). Furthermore, a significant main effect of condition indicated that remembering the movie clips again resulted in different subjective feelings ($F(2,116) = 438.921, p_{GG} < .001, g\eta^2 = 0.841$). Remembering positive movie clips elicited more pleasant self-reported valence than remembering neutral ($t(116) = 10.173, p < .001, MD = 23.5, SE = 2.31, 95\% CI [18.9, 28.1], d = 1.45$) or negative movie clips ($t(116) = 29.185, p < .001, MD = 67.4, SE = 2.31, 95\% CI [62.8, 71.9], d = 3.32$). Remembering negative movie clips elicited more unpleasant self-reported valence than remembering neutral movie clips ($t(116) = 19.013, p < .001, MD = 43.9, SE = 2.31, 95\% CI [39.3, 48.5], d = 2.67$).

We conducted an exploratory one-factorial repeated measures ANOVA to test whether subjective feelings of arousal differed when viewing negative, positive, and neutral movie clips ($F(2, 116) = 31.466, p < .001, g\eta^2 = 0.288$). Post hoc contrasts showed that participants felt more aroused when viewing positive or negative compared to neutral movie clips (positive versus neutral: $t(116) = 7.624, p < .001, MD = 29.13, SE = 3.82, 95\% CI [19.85, 38.4], d = 1.13$; negative versus neutral: $t(116) = 5.710, p < .001, MD = 21.81, SE = 3.82, 95\% CI [12.53, 31.1], d = 0.69$). Feelings of arousal did not differ significantly when viewing positive or negative episodes ($t(116) = 1.914, p = .174, MD = 7.31, SE = 3.82, 95\% CI [-1.97, 16.6], d = 0.24$). Moreover, we conducted an exploratory one-factorial repeated measures ANOVA to test whether arousal differed when remembering the negative, positive, and neutral episodes ($F(2, 116) = 43.735, p < .001, g\eta^2 = 0.280$). Post hoc contrasts revealed that participants felt more aroused when remembering positive or negative compared to neutral episodes (positive versus neutral: $t(116) = 9.124, p < .001, MD = 28.38, SE = 3.11, 95\% CI [20.83, 35.9], d = 1.25$; negative versus neutral: $t(116) = 6.340, p < .001, MD = 19.72, SE = 3.11, 95\% CI [12.16, 27.3], d = 0.73$). Additionally, participants felt more aroused when remembering positive compared

to negative episodes ($t(116) = 2.784, p = .019, MD = 8.66, SE = 3.11, 95\% CI [1.11, 16.2], d = 0.40$).

Finally, we explored whether memories that elicited stronger psychophysiological reactions also resulted in stronger subjective feelings. In line with the results of Experiment 1, there was no significant multilevel correlation between zygomaticus activity and subjective valence ratings when remembering positive memories ($r = .13, 95\% CI [-0.04, 0.29], t(133) = 1.52, p = .131$), nor between the corrugator activity and valence ratings when remembering negative memories ($r = .05, 95\% CI [-0.12, 0.22], t(142) = 0.61, p = .543$). These results indicate that there was no or only a weak relationship between subjective feelings and affective psychophysiological responses while remembering emotional events.

Descriptive statistics per movie clip are presented in **S5 (Table S6 & S7)**. Notably, while most participants did not know the negative or neutral movie clips before they participated in the study, many of them did know the positive clips. For example, 50% and 57% of the participants knew the positive clips ‘Marley and Me’ and ‘Untouchable’, respectively, whereas none of the participants knew the neutral clips ‘Big Night’ and ‘Meet Joe Black’.

3.2.4 Relationship between affective responses during encoding and retrieval

Similar to Experiment 1, we investigated whether the strength of affective responses during the experience of an emotional event predicted the strength of affective responses while remembering the event, while controlling for other variables that are likely to influence affect expression during recollection. We included data from all participants with at least one valid trial. First, we investigated zygomaticus activity while remembering emotional events. We included 68 participants with 388 observations in 201 conditions. A type III Wald χ^2 test yielded a significant fixed effect of whether participants knew a movie before the study ($\chi^2(1) = 4.242, p = .039$), a significant effect of memory vividness ($\chi^2(2) = 6.835, p = .033$), and a significant effect of subject-mean zygomaticus response on day 1 ($\chi^2(1) = 4.449, p = .033$). In contrast to the results of the earlier ANOVA, there was no significant effect of condition ($\chi^2(2) = 3.082, p = .214$) nor of the condition-mean centered response on Day 1 ($\chi^2(1) = 0.020, p = .887$). Importantly for the primary aim of these analyses, there was no significant interaction between condition and condition-mean centered zygomaticus response on Day 1 ($\chi^2(2) = 2.958, p = .228$).

Second, we investigated predictors of corrugator activity while remembering emotional events. We included 68 participants with 392 observations in 203 conditions. A type III Wald χ^2 test yielded a significant effect of the condition-mean centered corrugator response on Day

1 ($\chi^2(2) = 5.685, p = .017$) and of memory vividness ($\chi^2(1) = 21.853, p < .001$). There was no significant effect of condition ($\chi^2(2) = 3.980, p = .137$), subject-mean response on day 1 ($\chi^2(1) = 2.296, p = .130$), or whether participants knew a movie before the study ($\chi^2(1) = 2.500, p = .114$). The interaction between condition and condition-mean centered zygomaticus response on Day 1 was also not significant ($\chi^2(2) = 0.783, p = .676$). However, we found a significant relationship between Day 1 and Day 2 corrugator activity within participants ($\beta = 0.102, SE = 0.036, t(29.3) = 2.817, p = .009$). In contrast to Experiment 1, these results suggest that there might be a relationship between corrugator responses during encoding and retrieval of emotional episodes (independent of the condition) such that stronger corrugator responses during encoding relate to stronger responses during subsequent remembering.

Table 2.

Encoding and retrieval of episodes in Experiment 2.

		positive	negative	neutral
Movies	Zygomaticus	3.385 (6.432)	-0.715 (2.316)	-0.931 (3.826)
	Corrugator	-0.771 (3.723)	3.822 (5.496)	1.762 (3.286)
	Valence rating	87.271 (9.724)	11.415 (8.444)	59.042 (11.950)
	Arousal rating	65.483 (17.343)	58.169 (21.773)	36.356 (19.566)
	Vividness rating	70.102 (17.896)	55.441 (24.892)	60.237 (18.021)
Memories	Zygomaticus	1.663 (4.517)	-0.014 (1.098)	0.307 (1.356)
	Corrugator	-0.525 (1.710)	0.661 (1.903)	0.281 (1.280)
	Valence rating	82.390 (11.462)	15.017 (12.792)	58.907 (12.463)
	Arousal rating	65.381 (17.485)	56.720 (20.797)	37.00 (19.214)

Note. Presented are means and standard deviations in parentheses based on the preregistered exclusion criteria with $n = 59$. Data was averaged within participants before calculating means and standard deviations.

4. General Discussion

We investigated whether the recollection of past emotional episodes elicited affective psychophysiological expressions that reflect the valence of the original events. Results from two experiments revealed that not only the initial experience of a positive event but also the recollection of the event elicited enhanced zygomaticus activity, indicating smiling and positive

affect. The experience of negative episodes elicited enhanced corrugator activity indicating frowning and negative affect, but corrugator activity during the recollection of negative episodes was only higher compared to positive but not neutral episodes. These observations suggest that affective responses during recollection generally align with the valence of the original event, supporting the notion that recollection enables the affective re-enactment of past episodes (Tulving, 2002).

Evidence for affective psychophysiological responses during episodic recollection corroborates and extends theories that understand episodic recollection as the holistic re-experience of multimodal events (Horner, Bisby, Bush, Lin, & Burgess, 2015; Tulving, 2002). Specifically, remembering past events has been suggested to encompass episodic, contextual, sensory and affective elements (Rubin, 2006). While this notion of multimodality is prominent in episodic memory research, it is often not reflected in experimental studies that investigate recollection as the reinstatement of simple associations between non-emotional items of the same modality (e.g., words or pictures; Horner et al., 2015). Our results, however, indicate that episodic recollection can elicit affective psychophysiological responses and therefore extend beyond the mere retrieval of neutral declarative information. This notion also supports broader theories of embodied or grounded cognition that suggest that cognitive processes are based on modal simulations, bodily states, and situated action rather than on abstract computational processes (Barsalou, 2008).

The recollection of happy episodes induced a clear psychophysiological expression of positive affect, but the recollection of sad episodes was associated with an enhanced psychophysiological expression of negative affect only in comparison to positive memories. On a conceptual level, these observations might indicate that happy memories elicit more pronounced affective psychophysiological responses than sad memories. In that case, it might be possible that happy memories play a more prominent role in activating behavior than sad memories. The greater impact of positive memories might be particularly pronounced in healthy individuals (as in our sample) because they tend to have a positively biased view of themselves and their past, favoring the retrieval of positive memories (Hitchcock, Rees, & Dalgleish, 2017). Furthermore, sad or depressed affective states might be symptomatic for behavioral deactivation (Dimidjian, Martell, Addis, & Herman-Dunn, 2008) and therefore elicit weaker action tendencies or even decrease motivational drive. These ideas challenge the common tendency to regard negative emotions as more potent motivators while positive emotions are often regarded as less important for cognitive processes and behavior (Fredrickson, 1998). On a methodological level, however, it is also possible that the sad

episodes in this study were less intense than the happy ones, therefore eliciting weaker responses. This notion seems to be corroborated by the observation that positive memories were consistently rated as eliciting higher arousal than the negative memories. In addition, cognitive-effort induced frowning in the neutral condition might have obscured affect-driven differences between the negative and the neutral condition, because neutral memories are harder to remember than emotional memories (Cohen, Davidson, Senulis, Saron, & Weisman, 1992; Yonelinas & Ritchey, 2015). In sum, even though a few methodological considerations require future investigation, our results suggest that positive memories elicit particularly pronounced affective psychophysiological responses, which might indicate an important role of positive memories for motivating behavior.

Our findings generally align with a classic view of episodic memory (Tulving, 2002) that emphasizes the re-enactment of past encoding processes during episodic recollection (Liang & Preston, 2017). However, if recollection specifically re-enacts encoding processes, memories should not only broadly mirror the respective valence of the original experience, they should also relate to the experience on a trial-by-trial base. In other words, if an event elicits stronger affective responses than other events, the corresponding memory should also elicit stronger affective responses compared to other memories. However, we did not find strong evidence for such a relationship for either positive (zygomaticus) or negative (corrugator) episodic memories in exploratory multilevel models. Only in experiment 2, we found that stronger corrugator responses to events on Day 1 were related to stronger corrugator responses to the memories of these events on Day 2, regardless of whether the events were negative, neutral, or positive. Even though we would have primarily expected an alignment of corrugator responses to negative events and memories thereof, it is noteworthy that we observed reduced corrugator responses to positive events and memories (consistent with previous studies; Larsen et al., 2003). Thus, the trial-by-trial corrugator relationship of events and memories across conditions may reflect that affect as assessed by the corrugator represents a continuum, ranging from positive to negative valence. While these results tentatively suggest that psychophysiological responses to memories may at least sometimes represent a specific re-instatement of responses of the original event over and above a general effect of valence, they must be interpreted with caution because they were not consistent across experiments. Furthermore, recent theories consider episodic memory as a constructive process rather than a pure re-enactment of the past. From such a stance, affective responses to memories would not have to proportionally relate to affective responses to the respective events. The consistent absence of evidence for a trial-by-trial relationship in our experiments is seemingly in line with at least a partial constructive

notion on memory retrieval (Madore et al., 2019; Schacter et al., 2007; Xiao et al., 2017), but note that the absence of evidence does not necessarily imply evidence of absence (Wagenmakers, Verhagen, & Ly, 2016).

The multilevel analyses did reveal consistent evidence that participants with stronger psychophysiological responses when experiencing happy or sad episodes also display stronger psychophysiological responses when remembering these episodes one day later. This corroborates previous research that underscored the importance of individual differences in affective psychophysiological responses (Cacioppo et al., 1992) and indicates that such differences are stable across time. Importantly, individual differences in affective psychophysiological responses may be relevant in emotion disorders. For example, depressed patients show reduced zygomaticus responses to positive stimuli and imagery which may reflect prolonged behavioral deactivation and reduced action propensity (Schwartz, Fair, Mandel, Salt, & Klerman, 1976; Sloan, Bradley, Dimoulas, & Lang, 2002). Finally, knowing a movie beforehand predicted zygomaticus responses in experiment 2, likely because many participants knew the positive but not the neutral or negative movies before participating (with almost half of the sample knowing the two most positive movie clips: ‘Untouchable’ and ‘Marley and Me’). This may also explain why the exploratory multilevel analysis did not fully replicate the finding from the preregistered ANOVA that participants smiled more when remembering happy compared to neutral or negative memories (i.e., the condition overlapped with movie knowledge before participation). In sum, even though the multilevel models revealed some mixed findings, the approach is a promising application in memory research as it not only differentiates effects of specific memories from those due to individual differences (Hamaker & Grasman, 2014), it also allows the inclusion of other predictors such as memory vividness that likely influences the affective psychophysiological expression of memories as well.

We also explored whether memories that elicited stronger psychophysiological responses were subjectively experienced as more emotional, because previous research suggested that the strength of fEMG responses to emotional events and imagery covaries with self-reports of the experienced intensity of positive and negative affect (Brown & Schwartz, 1980; Lang, Greenwald, Bradley, & Hamm, 1993; Larsen et al., 2003). However, in our study, affective psychophysiological responses and subjective feelings were not related, which aligns with more recent notions that psychophysiological responses and subjective feelings may represent different components of emotional processes and do not always correlate (Scherer, 2009). Given that psychophysiological responses are indicative of

motivational states and may be important for preparing behavior (Elliot et al., 2013; Lang & Bradley, 2010; Pace-Schott et al., 2019), future studies that aim to investigate how episodic retrieval relates to subsequent behavior should incorporate psychophysiological measures such as fEMG in addition to subjective measures.

The current study has several strengths such as the combination of subjective and psychophysiological indices, the use of the multilevel modelling to investigate within and between subject effects, as well as a preregistered replication of the main findings. However, some limitations should be mentioned. Most importantly, results from the exploratory multilevel analyses must be interpreted with caution because there were relatively little data to estimate slopes within condition (a maximum of two and three values per condition per participant in Experiment 1 and 2, respectively). Additionally, there were several minor deviations from the preregistration. However, some deviations from an analysis plan are to be expected, especially in the case of complex psychophysiological data and analyses (Nosek et al., 2019). Finally, we chose movie clips as a proxy for naturalistic events because they mimic real-life experiences and are powerful inductors of emotions, while still enabling experimental control over the encoding and retrieval sessions. Nevertheless, retrieving memories of these movie clips does not necessarily elicit autonoetic consciousness (which is central to episodic memory; Tulving, 2002) similar to autobiographical memory retrieval. However, this limitation applies to most episodic memory research that employs simplistic stimuli (such as words or pictures). To achieve a comprehensive understanding of emotional episodic memory, it will be necessary to synthesize insights from studies on a continuum from simplistic lab stimuli to complex real-life experiences.

To conclude, our study provides strong evidence that episodic recollection can elicit affective psychophysiological responses. However, it is not yet clear whether these responses reflect a veridical re-instatement of past affective states or whether they result from a constructive simulative process that allows affective psychophysiological processes during recollection to differ from the original experience. Importantly, affective psychophysiological responses may indicate and prepare behavioral outcomes and action tendencies, thereby playing a crucial role for the motivational function of emotional episodic memory. Future studies on emotional episodic memory should incorporate affective psychophysiological responses and could investigate how these relate to action tendencies and behavioral outcomes.

Author Contributions

SD: conceptualization, data curation, formal analysis, funding acquisition, investigation, methodology, project administration, resources, software, validation, visualization, writing – original draft, writing – review & editing. **FN:** methodology, resources, writing – review & editing. **MK:** conceptualization, methodology, funding acquisition, supervision, writing – review & editing. **SO:** methodology, formal analysis, writing – review & editing. **VvA:** conceptualization, funding acquisition, methodology, formal analysis, project administration, resources, supervision, writing – original draft, writing – review & editing.

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