With the power of the inner eyes: The Late Positive Potential during mental time travel through positive and negative experiences. An event-related potential study.

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Abstract

Mental time travel utilizes mental imagery to recollect past experiences and to prospect hypothetical future events. This elicits anticipatory affect responses that are pivotal to motivate goal-directed behavior towards pleasurable and away from threatening experiences. However, the temporal dynamics of neural, physiological and affective processing of mental time travel remain elusive. Here, we aimed to examine the Late Positive Potential (LPP), skin conductance responses (SCR) and behavioral affect ratings in response to mental time travel through emotionally salient experiences. Forty-eight participants (52% females) viewed 16 neutral, positive, and negative stimuli from the International Affective Picture System (‘encoding task’). Participants then imagined each stimulus as vividly as possible (‘recall task’) and experiencing each situation after leaving the laboratory (‘prospection task’). Results showed significantly potentiated electrocortical activity in the LPP in response to recalling negative and prospecting positive stimuli. Behavioral ratings also showed a significant potentiation of self-reported positive and negative affect and arousal in response to both recalling and prospecting positive as well as negative stimuli. SCR amplitudes were not significantly associated with recalling or prospecting these experiences. Our findings suggest that the retrieval and prospection of emotionally salient experiences are associated with neural anticipatory responses in the LPP. This could reflect a neural mechanism that facilitates affective responses to mental representations of emotional stimuli, thereby guiding goal-directed behavior. Future studies should compare clinical to non-clinical groups in this context to illuminate the mechanisms of aberrant mental time travel and emotional disturbances in psychopathology.

Keywords: Mental imagery; episodic memory; event-related potential; Late positive potential (LPP); anticipatory pleasure

Public Significance Statement

This study highlights how recalling past experiences and imagining future events can elicit strong emotional responses, which play a crucial role in motivating behavior. By examining brain activity and self-reported emotions, the research found that negative memories and positive future scenarios significantly increased emotional responses, suggesting that these mental processes are important for motivation. Understanding these mechanisms can inform treatments for emotional disturbances in various psychological conditions such as depression and schizophrenia.

Introduction

Mental time travel encompasses an individual's capacity to recall past events and to project themselves into the future (Addis, 2020). This cognitive process relies on mental imagery, defined as mental representations and the accompanying experience of sensory information without a direct external stimulus (Pearson et al., 2015). Drawing on past experiences, mental imagery allows individuals to simulate hypothetical future scenarios and thereby to anticipate potential outcomes such as reward and threat (Schacter et al., 2017). This elicits an anticipatory affect response that is pivotal for survival and life satisfaction. Anticipatory affect carries information about whether to approach pleasurable and rewarding stimuli or to avoid threats, thereby guiding decision-making and goal-directed behavior, even in the absence of immediate stimuli or sensory input (Lang & Bradley, 2010; Pearson, 2019; Wilson & Gilbert, 2003).

Dysfunctions in mental imagery are common in various mental health conditions (for a review: Ji et al., 2019). For example, major depression, posttraumatic stress disorder, and acute psychotic episodes are often associated with inflexibly persistent, intrusive, and extremely vivid distressing negative mental imagery. Reduced quality of positive mental imagery, in turn, is associated with amotivational psychopathology such as anhedonia and avolition, and low psychological well-being (Blackwell, 2018; Hallford et al., 2020; Pillny et al., 2024). These aberrancies in mental imagery may be fundamental to dysfunctional anticipatory affect and could thereby explain behavioral problems in psychopathology such as dysfunctional avoidance or attenuated reward seeking behavior. However, the neurocognitive mechanisms underlying the link between mental imagery and anticipatory affect in both healthy and clinical populations remain largely elusive.

Neuroimaging research suggests that during mental imagery, episodic memories are reactivated by a top-down process and maintained as mental representations in working memory, where they modulate neural, physiological, and affective responses, similar to the perception of original stimuli (Ji et al., 2016; Kosslyn et al., 2001; Schacter & Addis, 2007; Schacter et al., 2017).

Indeed, studies show similar patterns of neural activation in the medial temporal, prefrontal, parietal, and occipital lobes of healthy individuals when recalling past events and prospecting future scenarios (e.g., Bellana et al., 2017). This indicates that mental imagery activates a network of brain structures that are associated with memory and perceptual processing of sensory input and could explain the significant association between memory impairment and psychopathology (e.g., Pillny et al., 2022). While neuroimaging studies are well suited to localize the brain structures involved neural processing of mental representations, they offer little insight into the temporal dynamics of neural and physiological processes associated with mental imagery and anticipatory affect.

In contrast, event-related potentials (ERPs) and skin conductance responses (SCRs) are valuable tools for examining the temporal dynamics of neural and physiological processes and allow to disentangle the overlap between attention, memory and affective responses. The late positive potential (LPP) is an ERP that has been extensively investigated as a neural marker of heightened attention and cognitive processing to emotional and motivationally salient stimuli in both non-clinical (e.g., Paul et al., 2016) and clinical populations (e.g., Clayson et al., 2022). The LPP can be observed approximately 300-400 ms after stimulus onset and reflects a sustained positive deflection that is larger in response to positive and negative stimuli than to neutral stimuli at predominantly centroparietal electrodes (Keil et al., 2002; Luck & Kappenman, 2011; Schupp et al., 2003). Previous research using combined functional magnetic resonance imaging and EEG indicated that the LPP is generated and modulated by a neural network composed of both cortical and subcortical structures associated with visual and emotional processing such as the amygdala and the visual cortex (e.g., Liu et al., 2012). The LPP is therefore thought to reflect attention allocation, cognitive elaboration, and emotional processing of intrinsically motivating information (Hajcak et al., 2010; Weinberg & Hajcak, 2010) and has also been found to be associated with autonomic and self-reported indices of arousal (Cuthbert et al., 2000). Similarly, the SCR is referred to as an indirect measure of sympathetic autonomic activity and has been found to be associated with both emotional reactivity and attention (e.g., Critchley, 2002). The SCR reflects an elevated sympathetic activation, which increases the conductivity of the skin (Dawson et al., 2000). These phasic changes in electrical conductivity of the skin can be triggered by sustained attention and processing of motivationally salient stimuli (Bradley et al., 2001; Dawson et al., 2017). However, there is a paucity of research investigating whether the LPP and SCR can index anticipatory affect responses to mental time travel through emotionally relevant experiences. This would have implications for our understanding of how past and future events influence current emotional states and how aberrant mental imagery translates into emotional disorders, and particularly anhedonia.

In fact, initial evidence suggests that both the LPP and the SCR can be modulated by imagined and anticipatory processes. In healthy individuals, potentiated LPP amplitudes have been found to reward predicting cues in reward learning tasks (e.g., Glazer et al., 2018), when asked to recall arousing details of previously presented threatening stimuli (Thiruchselvam et al., 2012), to recall previously presented angry and happy faces (Suess & Abdel Rahman, 2015), to imagine previously presented positive photographs (Jackson et al., 2024), and to imagine negative scenes after listening to an audio description of these scenes (MacNamara, 2018). Similarly, increased SCRs have been observed during reward (e.g., Agren et al., 2019) and threat (e.g., Davies & Craske, 2015) anticipation in healthy individuals. One important study has explored LPP responses in the context of mental time travel (Speed et al., 2020). This study demonstrated that when healthy participants recalled negative autobiographical experiences, prompted by individualized cue words, their LPP responses were potentiated compared to recalling neutral cues. While Speed et al. provided a sound rationale for individualizing their experimental design (i.e., each participant received individual prompts to recall individual autobiographical events), this approach does not allow for a direct comparison between subjects. Although this was not a concern in the study by Speed et al., it poses a challenge for future research comparing clinical and non-clinical groups. Clinical samples may tend to recall negative experiences more readily, potentially due to greater exposure to social adversity (Jaya & Lincoln, 2016; Pillny & Lincoln, 2020). Also, the fact that each participant will imagine individual events is an obstacle to between-subject comparability in general. Lastly, given that attenuated LPP responses to positive stimuli are discussed as a neural marker for amotivational psychopathology such as anhedonia (Weinberg, 2023) and that the prospection of future experiences is likely to be particularly relevant for motivational processes (Gilbert & Wilson, 2007), it is crucial to compare positive and negative experiences during both recall and prospection. The lack of standardized experimental tasks to objectively investigate anticipatory affective responses to mental time travel may have precluded prior research from conducting such studies.

The current study set out to develop a standardized experimental paradigm and to investigate anticipatory affect responses to mental imagery during mental time travel through positive and negative 'autobiographical' experiences in healthy participants from the general population. We hypothesized that, compared to recalling and prospecting neutral experiences, recalling and prospecting positive and negative experiences would elicit potentiated anticipatory responses in LPP and SCR amplitudes as well as in behavioral ratings of arousal, pleasantness, and unpleasantness.

Methods

Transparency and Openness

We report how we determined the sample size, data exclusion, manipulations, and measures in the experiment. The experiment was preregistered prior to data collection. The study protocol, data, analysis code, and materials are publicly available on Open Science Framework (LINK *WILL BE REVEALED AFTER PEER-REVIEW*). All experimental procedures were approved by the local ethics committee of Universität Hamburg (Az: 2022_025).

Participants

An a priori sample size calculation was performed using the Power Contour Estimation Algorithm for experimental psychology and human neuroscience (Baker et al., 2021). Since studies on LPP responses during mental time travel are scarce, and the long-term aim was to develop a standardized procedure for comparing LPP responses between clinical and control groups, the effect-size estimation was based on a study comparing LPP amplitudes in response to positive, negative, and neutral stimuli in people with schizophrenia compared with healthy controls (Horan et al., 2010). Assuming a pooled within-person mean difference of 1.62 (SD_{pooled} = 3.99) in LPP responses to positive, negative, and neutral stimuli, and using $\alpha = .05$, $\beta = .80$, and $k = 48$ trials, an optimal sample size of $N = 48$ was determined. We considered the results of Horan et al. to provide the more reliable and conservative estimate, as Speed et al. recruited only healthy psychology students and did not include positive stimuli, which may explain the relatively larger effect in their study (mean within-person difference of 2.72; SD_{pooled} = 6.32).

Fifty-four participants were recruited from the general population via online advertisements. Inclusion criteria were age (ranged between 18 and 60 years), vision (normal or corrected-to-normal), and language (sufficient German language skills to provide written informed consent). Individuals with left- or both-handedness, a history of a neurological disorder or a current DSM-5 diagnosis (established with the Mini Diagnostic Interview for Mental Disorders – Open Access; Margraf et al., 2017) were excluded from participation. Of the 54 recruited individuals, four met DSM-5 criteria for a mental disorder and were excluded from participation. Two subjects withdrew from participation after informed consent had been provided and two further participants had incomplete EEG data due to technical problems with the EEG recording, resulting in a final sample of $N = 48$ participants (52% identifying as female). The final sample had a mean age of 32.17 years (SD = 9.08, range = 19-58) with an average of 11.94 years of school education (SD = 1.29, range 8-13). Most participants were employed (59%). The remaining participants were either self-employed (12%), unemployed (12%), university student (10%) or either in high-school or on job-training (7%). Six participants (12%) identified themselves as part of an ethnic, religious, political, sexual, or any other minority. All participants provided written informed consent and were reimbursed with 50€ for their participation.

Tasks and procedure

The study design comprised four experimental tasks, namely (1) the word reading task, (2) the encoding task, (3) the recall task, and (4) the prospection task. All stimuli were presented against the black background of a 19-inch LCD monitor (resolution: 1920 x 1200, refresh rate: 60Hz, viewing distance: 80 cm) using Presentation software (Neurobehavioral Systems, San Francisco, CA).

In the first phase of the experiment, the word reading task was used to assess a baseline measure of LPP responses to reading emotional words. This allowed us to examine whether the words presented as cues in the subsequent recall and prospection tasks elicited potentiated LPP responses before they were paired with the emotion-evoking stimuli. For the word reading task, participants were first presented with 16 neutral 'habituation words' that were irrelevant for subsequent tasks (see Figure 1, Panel A). This aimed at allowing participants to habituate to the laboratory and task environment. Following the 'habituation block', participants were presented with blocks of neutral, positive, and negative 'task-relevant' cue words in a semi-randomized order (i.e., these words were used to prompt mental imagery in the following recall and prospection tasks). The cue words were selected to be comparable in length and complexity across valence conditions and to relate only to one specific stimulus of the encoding task (see Supplement S1 for a full list of words). All words were presented for 1,000 milliseconds (ms), followed by a black screen with a fixation cross for 3,000 ms. Participants were asked to read each word while their continuous electroencephalogram and electrodermal activity were recorded.

For the encoding task (see Figure 1, Panel B), participants were instructed to view 16 positive, 16 negative, and 16 neutral pictures that were selected from The International Affective Picture System (Bradley & Lang, 2007). The selection of stimuli was made based on the normative IAPS ratings and participant ratings in a pilot version (*N*=12) of this study. Identification numbers, mean normative ratings, and picture-to-condition assignment can be found in Supplement S2. Stimuli were presented in three blocks that differed by valence of the presented pictures (i.e., positive vs. negative vs. neutral). The order of blocks was semi-randomized across participants with randomized order of stimuli within each block. Each stimulus was presented for 4,000 ms followed by three unipolar visual analogue scales on which participants rated the pleasantness, unpleasantness, and arousal of each stimulus on a 9-point Likert-scale from 1 (“not at all”) to 9 (“very strong”). Intertrial intervals had a length of 500-1,500 ms.

The recall and the prospection tasks (see Figure 1, Panel C) followed a 20-minute 'consolidation break', during which participants were offered refreshments to relax and completed a questionnaire battery of a different study. Both the recall and the prospection task followed the same experimental structure as the encoding task, despite differing in instructions given to the participants. For the recall task, participants were instructed that they would now be presented with a series of 'cue words', each relating to one of the previously presented stimuli (see Supplement S2 for stimulus-cue word pairings) and that they should recall each picture as vividly as possible when the respective cue word was presented. For the prospection task, participants were instructed that they would be presented with the same cue words again, but that they should now imagine themselves experiencing the respective situation as vividly as possible right after leaving the lab. In both tasks, cue words were presented in blocks sorted by their valence. The order of blocks was semi-randomized across participants with randomized order of cue words within each block. Each cue word was presented for 1,000 ms followed by a black screen for 3,000 ms. Intertrial intervals varied randomly between 500 and 1,500 ms. After each trial, participants were asked to rate the pleasantness, unpleasantness, arousal, and vividness of their respective mental representation. Additional ratings were done after each block asking participants to rate how much effort they exerted to imagine the stimuli and how well they succeeded in recalling or prospecting the stimuli. The prospection task included an additional block-wise rating of approach motivation. All ratings were done on the same 9-point Likert-scale.

Electroencephalographic recording and processing

Electroencephalographical (EEG) activity was measured with 60 active Ag/AgCl scalp electrodes (Easycap, Herrsching, Germany) based on the standard 10-10 international electrode montage with additional external electrodes placed at the left (IO1) and right (IO2) infraorbital site. Recording reference was set to FCz with FPz as ground electrode. All impedances were kept <25 kΩ.

Continuous EEG signals were digitized at a sampling rate of 1,000 Hz with a 64-channel actiCHamp Plus amplifier (Brain Products GmbH, Gilching, Germany) and recorded with a band-pass filter from DC to 250 Hz.

Raw data were preprocessed using the EEGLAB and ERPLAB toolboxes (vers. 2023.1) implemented in MATLAB (vers. 2023a). Continuous EEG signals were digitally filtered with low and high cutoffs of 0.1 and 30 Hz, respectively (24dB/oct roll-off), and a notch filter of 50 Hz. Eye movement artifacts and eye blinks were removed manually based on an independent component analysis. Components including eye movement or eye blink artifacts were identified by visual inspection of the component activation, scalp distribution, and their comparison to IO1 and IO2 signals. Before segmentation, electrodes were re-referenced using the averaged left and right mastoids, which is in line with previous LPP studies (Cuthbert et al., 2000; Kausche et al., 2022). Segmentation was done by computing stimulus-locked ERPs between -200 ms and 4,000 ms after stimulus presentation. The epochs were baseline corrected (i.e., −200 ms to stimulus presentation). Artifacts were identified automatically, and contaminated epochs were excluded from further analysis based on following criteria: a) absolute voltage range exceeding 200 μV or b) voltage steps exceeding 75 μV between consecutive data points or c) maximum voltage difference of less than 0.5 μV within 100 ms intervals. Based on these criteria, 1.2%, 6.5%, 4.8% and 6.4% of trials in the baseline, encoding, recall and prospections task, respectively, were identified as artifacts and removed from the data. In the recall task, two participants had less than 50% artifact free trials and were therefore excluded from the analysis of the recall task. The exclusion criterion for participants was set to < 50% artifact free trials in any task or condition (Moran et al., 2013; Paul et al., 2016). ERPs were averaged separately for each condition. The LPP was quantified as the mean amplitude between 400 ms and 4,000 ms post-stimulus at a centro-parietal cluster of electrodes comprising Cz, CPz, CP1, CP2, and Pz (Hajcak et al., 2009). To account for potential differences that have been reported between early and late components of the LPP (e.g., Weinberg & Hajcak, 2010), the LPP was scored in four successive time windows following stimulus onset ranging from 0.4 to 1 s, 1–2 s, 2–3 s, and 3–4 s.

Acquisition and processing of skin conductance responses

During each trial, participants' electrodermal activity was measured using two Ag/AgCl electrodes with 12mm sensor diameter placed at the distal and proximal hypothenar eminence of the non-dominant hand. Electrodes were applied at least 5 minutes prior to measurement onset. A low constant-voltage of 0.5 V was passed through the electrodes. The data was digitized at a sampling rate of 1000 Hz using AUX channels of the actiCHamp Plus amplifier. Offline, data were down-sampled to 10Hz. Continuous decomposition analysis was performed using the "optimize" function implemented in Ledalab (Benedek et al., 2010) running in Matlab (Mathworks®, Natick, Massachusetts, USA). Phasic SCR responses were automatically scored in a response window of 0.9 s to 3.5 s after stimulus onset . The threshold for SCR was a minimum amplitude of 0.01µS. Undetectable responses were scored as zeros and included into the analysis. Participants with less than 25% SCRs per task were excluded from subsequent SCR analyses.

Statistical Analysis

Numerical data were analyzed using the 'lme4' (Bates et al., 2015) and the 'lmerTest' (Kuznetsova et al., 2017) packages and visualized using 'sjPlot' (Lüdecke, 2023) and 'ggplot2' (Wickham, 2016) implemented in RStudio (version 2023.06.0+421). The threshold for statistical significance was set to $\alpha = .05$. Separate linear mixed models were calculated for each outcome (LPP, SCR, ratings) in each task (word reading, encoding, recall, prospection). Models were conservatively fitted following recommendations of using 'maximal random effect structures', to control for Type I error rates (Barr et al., 2013; Bell et al., 2018; Volpert-Esmond et al., 2021). Condition (positive vs. negative vs. neutral) was entered as fixed effect. The random effect structure of all models included random intercepts by participant with restricted maximum likelihood estimation and an unstructured covariance structure. Because models predicting behavioral ratings (i.e. participant-reported pleasantness, unpleasantness, arousal, and vividness) and SCRs including a random slope by condition failed to converge, we conducted a backwards model selection first reducing complexity in random effects. Only models predicting LPP amplitudes included a random slope by condition and an additional random intercept by electrode (i.e., Cz, CPz, CP1, CP2, and Pz) as recommended by Volpert-Esmond et al., The models are described using Wilkinson notation as:

$$LPP \sim condition\ +\ (condition|participant)\ +\ (1|electrode)$$

$$SCR \sim condition\ +\ (1|participant)$$

$$Rating \sim condition\ +\ (1|participant)$$

The model fit is reported as marginal and conditional R^2. Significant main effects were followed up by pairwise comparisons of condition based on the estimated marginal means. The Tukey method was used to adjust 95% confidence intervals and *p*-values to correct for multiple testing. Effect sizes are reported as partial η^2 with .01, .06 and .14 using the 'effectsize' package (Ben-Shachar et al., 2020) representing small, medium and large effects, respectively (Richardson, 2011).

Results

Word reading task

The Late Positive Potential

The effect of condition on LPP amplitudes between 400 ms and 1,000 ms during the word presentation was not significant, $F(3,46) = 0.66$, $p = .584$, $\eta^2 = 0.04$, indicating that word valence did not modulate the ERP response. As the visual inspection of the ERP waveform indicated a second ERP starting with stimulus offset at 1,000 ms (see Figure 2A), a second LPP was scored from 1,400 to 2,000 ms (see Figure 2B). However, the effect of condition was not statistically significant between 1,400 and 2,000 ms, $F(3,47) = 1.16$, $p = .334$, $\eta^2 = 0.07$, nor between 2,000 and 3,000 ms, $F(3,47) = 1.11$, $p = .354$, $\eta^2 = 0.07$, or between 3,000 and 4,000 ms, $F(3,47) = .82$, $p = .491$, $\eta^2 = 0.05$.

Skin conductance response

The effect of condition on SCRs during word reading was significant with a large effect size, $F(3,32) = 3.26$, $p = .034$, $\eta^2 = 0.23$. Compared to habituation words, neutral words elicited significantly lower SCRs, γ = -0.04, *SE* = 0.02, 95%CI[2.10, 3.12], whereas all other comparisons were non-significant (see Figure 2C).

Encoding task

The Late Positive Potential

The effect of condition on LPP amplitude during encoding was significant between 400 ms and 1,000 ms, $F(2,47) = 7.40$, $p = .002$, $\eta^2 = 0.24$, between 1,000 ms and 2,000 ms, $F(2,47) = 5.57$, $p = .007$, $\eta^2 = 0.19$, between 2,000 ms and 3,000 ms, $F(2,47) = 4.02$, $p = .025$, $\eta^2 = 0.15$, and marginally significant between 3,000 ms and 4,000 ms, $F(2,47) = 2.98$, $p = .060$, $\eta^2 = 0.11$, with medium to large effect sizes (see Figure 3A). LPP amplitudes were significantly higher to negative than to neutral stimuli in all time windows and significantly higher to positive than to neural stimuli between 400 ms and 1,000 ms. LPP amplitudes were significantly higher to negative than to positive stimuli between 400 ms and 1,000 ms (see Table 1).

Skin conductance response

Thirty-six participants (75%) had less than 25% null responses in SCR during the encoding task and were included in the following analyses. The effect of condition of SCRs was significant with a small effect size, $F(2,1690) = 36.47$, $p < .001$, $\eta^2 = 0.04$ (see Figure 3B). Compared to neutral stimuli, SCRs were significantly higher to positive, γ = 0.08, *SE* = 0.01, 95%CI[0.05, 0.12] and negative stimuli, γ = 0.11, *SE* = 0.01, 95%CI[0.08, 0.14]. The difference in SCRs in response to negative and positive stimuli was not significant, γ = -0.03, *SE* = .01, 95%CI[-0.01, 0.06].

Behavioral ratings

Pleasantness, $F(2, 94) = 244.98$, $p < .001$, $\eta^2 = 0.84$, unpleasantness, $F(2,94) = 356.65$, $p < .001$, $\eta^2 = 0.88$, and arousal ratings, $F(2,94) = 111.05$, $p < .001$, $\eta^2 = 0.70$ differed significantly across conditions with large effect sizes (see Figure 3C). Compared to neutral stimuli, positive stimuli were rated as more pleasant, γ = 1.35, *SE* = 0.21, 95%CI[0.94, 1.76], and more arousing, γ = 2.61, *SE* = 0.26, 95%CI[2.10, 3.12] but similarly unpleasant, γ = 0.04, *SE* = .20, 95%CI[-0.37, 0.44]. Negative stimuli were rated as less pleasant, γ = -3.13, *SE* = 0.21, 95%CI[-3.54, -2.72], more unpleasant, γ = 4.75, *SE* = 0.20, 95%CI[4.35, 5.16] and more arousing, γ = 3.77, *SE* = 0.26, 95%CI[3.26, 4.28] than neutral stimuli. Compared to negative stimuli, positive stimuli were rated as more pleasant, γ = 4.48, *SE* = 0.21, 95%CI[4.97, 3.98], less unpleasant, γ = -4.71, *SE* = 0.21, 95%CI[-5.20, -4.23], and less arousing, γ = -1.16, *SE* = 0.26, 95%CI[-1.78, -4.54].

Recall task

The Late Positive Potential

The effect of condition on LPP amplitudes was marginally above the significant threshold between 400 ms and 1,000 ms, $F(2,45) = 3.10$, $p = .055$, $\eta^2 = 0.12$. Between 1,000 ms and 2,000 ms, the effect of condition on LPP amplitudes was significant, $F(2,45) = 5.25$, $p = .009$, $\eta^2 = 0.19$ but non-significant between 2,000 ms and 3,000 ms, $F(2,45) = 2.17$, $p = .129$, $\eta^2 = 0.09$ and between 3,000 ms and 4,000 ms, $F(2,45) = 1.32$, $p = .276$, $\eta^2 = 0.06$ with small to large effect sizes (see Figure 4A). LPP amplitudes were larger to recalling negative than to recalling neutral stimuli between 400 ms and 1,000 ms and between 1,000 ms and 2,000 ms. LPP amplitudes to recalling negative stimuli were also larger than to recalling positive stimuli between 1,000 ms and 2,000 ms (see Table 2).

Skin conductance response

Thirty-one participants (65%) had less than 25% null responses in SCR during the recall task. The effect of condition of SCRs was not significant, $F(2,1446) = 0.99$, $p = .372$, $\eta^2 = 0.001$ (see Figure 4B).

Rating results

Pleasantness, $F(2,94) = 243.73$, $p < .001$, $\eta^2 = 0.84$, unpleasantness, $F(2,94) = 304.75$, $p < .001$, $\eta^2 = 0.87$, and arousal ratings, $F(2,94) = 93.64$, $p < .001$, $\eta^2 = 0.67$ differed significantly with large effect sizes across conditions (see Figure 4C). Compared to recalling neutral stimuli, recalling positive stimuli was rated as more pleasant, γ = 0.83, *SE* = 0.19, 95%CI[0.46, 1.20], and more arousing, γ = 2.25, *SE* = 0.24, 95%CI[1.76, 2.73] but similarly unpleasant, γ = 0.05, *SE* = 0.21, 95%CI[-

0.36, 0.47]. Recalling negative stimuli was rated as less pleasant, γ = -3.11, *SE* = 0.19, 95%CI[-3.48, -2.74], more unpleasant, γ = 4.51, *SE* = 0.21, 95%CI[4.10, 4.93] and more arousing, γ = 3.28, *SE* = 0.24, 95%CI[2.79, 3.76] than recalling neutral stimuli. Compared to recalling negative stimuli, recalling positive stimuli was rated as more pleasant, γ = 3.94, *SE* = 0.19, 95%CI[4.39, 3.49], less unpleasant, γ = -4.56, *SE* = 0.21, 95%CI[-3.96, -4.96], and less arousing, γ = -1.03, *SE* = 0.25, 95%CI[-0.45, -1.61]. Furthermore, vividness, $F(2,94) = 3.80$, $p = .025$, $\eta^2 = 0.07$ and success, $F(2,94) = 3.99$, $p = .022$, $\eta^2 = 0.08$, but not effort ratings, $F(2,94) = 1.18$, $p = .313$, $\eta^2 = 0.02$ differed significantly across conditions, yet with marginal effects sizes (see Figure 4D). Compared to recalling neutral stimuli, participants rated recalling positive, γ = -0.34, *SE* = 0.14, 95%CI[-0.62, -0.06] and negative stimuli, γ = -0.34, *SE* = .14, 95%CI[-0.62, -0.06] as less vivid with no significant differences in vividness between positive and negative mental representations, γ = 0.00, *SE* = .14, 95%CI[-0.34, 0.34]. They also rated themselves as being less successful in recalling positive, γ = -0.44, *SE* = .18, 95%CI[-0.80, -0.08] and negative, γ = -0.46, *SE* = .18, 95%CI[-0.82, -0.10] than of neutral stimuli, with no differences between recalling positive and recalling negative stimuli, γ = -0.02, *SE* = .18, 95%CI[-0.46, 0.42].

Prospection task

The Late Positive Potential

The effect of condition on LPP amplitudes between 400 ms and 1,000 ms was significant with a large effect size, $F(2,47) = 4.58$, $p = .015$, $\eta^2 = 0.16$ whereas no significant condition effects were observed between 1,000 ms and 2,000 ms, $F(2,47) = 1.03$, $p = .364$, $\eta^2 = 0.04$, between 2,000 ms and 3,000 ms $F(2,47) = 0.41$, $p = .667$, $\eta^2 = 0.02$, and between 3,000 ms and 4,000 ms, $F(2,47) = 0.60$, $p = .556$, $\eta^2 = 0.02$ (see Figure 5A). Compared to prospecting neutral stimuli, prospecting positive, but not negative stimuli elicited significantly higher LPP amplitudes between 400 ms and 1,000 ms. LPP amplitudes to positive and negative prospections did not differ from each other (see Table 3).

Skin conductance response

Twenty-nine participants (60%) had less than 25% null responses in SCR during the prospection task. The effect of condition of SCRs was not significant, $F(2,1361) = 0.84$, $p = .431$, $\eta^2 = 0.001$ (see Figure 5B).

Behavioral ratings

Pleasantness, $F(2,94) = 307.22$, $p < .001$, $\eta^2 = 0.87$, unpleasantness, $F(2,94) = 303.86$, $p < .001$, $\eta^2 = 0.87$, and arousal ratings, $F(2,94) = 109.82$, $p < .001$, $\eta^2 = 0.70$ differed significantly with large effect sizes across conditions. Compared to neutral prospections, positive prospections were rated as more pleasant, $\gamma = 0.88$, $SE = .18$, 95%CI[0.53, 1.24], and more arousing, $\gamma = 2.38$, $SE = 0.26$, 95%CI[1.87, 2.90] but similarly unpleasant, $\gamma = 0.28$, $SE = 0.23$, 95%CI -0.18, 0.73]. Negative prospections were rated as less pleasant, $\gamma = -3.36$, $SE = 0.18$, 95%CI[-3.72, -3.00], more unpleasant, $\gamma = 5.05$, $SE = 0.23$, 95%CI[4.60, 5.51] and more arousing, $\gamma = 3.81$, $SE = 0.26$, 95%CI[3.30, 4.32] than neutral prospections. Compared to negative prospections, positive prospections were rated as more pleasant, $\gamma = 4.24$, $SE = 0.18$, 95%CI[3.81, 4.67], less unpleasant, $\gamma = -4.77$, $SE = 0.23$, 95%CI[-5.32, -4.23], and less arousing, $\gamma = -1.43$, $SE = 0.26$, 95%CI[-2.04, -0.81] (see Figure 5C). Furthermore, vividness, $F(2,94) = 5.09$, $p = .008$, $\eta^2 = 0.10$ and approach motivation ratings, $F(2,94) = 78.50$, $p < .001$, $\eta^2 = 0.63$ differed significantly across conditions with small and large effect sizes, respectively. Whereas ratings of success, $F(2,94) = 1.28$, $p = .283$, $\eta^2 = 0.03$, and effort, $F(2,94) = 0.30$, $p = .743$, $\eta^2 = 0.01$, did not differ significantly across conditions. Compared to neutral prospections, participants rated negative, $\gamma = -0.46$, $SE = 0.15$, 95%CI[-0.76, -0.17] but not positive, $\gamma = -0.13$, $SE = 0.15$, 95%CI[-0.43, 0.17] prospections as less vivid. Negative prospections were rated as less vivid than positive prospections, $\gamma = -0.34$, $SE = 0.15$, 95%CI[-0.69, 0.02]. Approach motivation ratings were higher in response to positive prospections than to negative, $\gamma = 3.15$, $SE = 0.25$, 95%CI[2.55, 3.76] and neutral prospections, $\gamma = 1.19$, $SE = 0.25$, 95%CI[0.58, 1.79], and were lower to negative than to neutral prospections, $\gamma = -1.96$, $SE = 0.25$, 95%CI[1.36, 2.57], (see Figure 5D).

Additional Analyses

Explorative analyses were performed by testing the association between behavioral ratings, LPP amplitudes (400 ms- 1,000 ms) and SCR amplitudes. During encoding, neither LPP nor SCR amplitudes were associated with pleasantness, unpleasantness, or arousal ratings (see Supplement S3-S5). During recall, arousal ratings to recall of positive stimuli significantly associated with larger LPP amplitudes to recall of positive stimuli, γ = 0.52, *SE* = 0.20, 95%CI[.12, .31]. Whereas all other associations between behavioral ratings and LPP or SCR amplitudes during recall were non-significant (see Supplement S6-S9). During prospection, higher vividness ratings of negative prospections showed a significant inverse relationship with LPP amplitudes during negative prospections, γ = - .20, *SE* = 0.19, 95%CI[-.89, -.17]. All other associations between behavioral ratings, LPP and SCR amplitudes during prospection were non-significant (see Supplement S10-S13). Associations between LPP and SCR amplitudes were nonsignificant in each task.

Discussion

The aim of this study was to develop a standardized experimental mental time travel paradigm and to investigate anticipatory affect responses to mental imagery during mental time travel through positive and negative 'autobiographical' experiences. In the recall and prospection tasks, there was evidence that mental imagery of emotionally salient experiences is associated with anticipatory responses as reflected in potentiated early LPP responses and behavioral ratings of pleasantness, unpleasantness, arousal, and approach motivation.

The present findings of potentiated LPP responses to positive and negative mental imagery substantiate the evidence showing that activating mental representations of rewarding and threatening outcomes elicits neural anticipatory responses akin to those observed during actual perception, prompting comparable motivational and affective reactions (Jackson et al., 2024; MacNamara, 2018; Speed et al., 2020; Suess & Abdel Rahman, 2015). Increased LPP amplitudes may reflect the neural processes underlying affect anticipation that is relevant to motivate future behavior and could explain how mental imagery shapes our current and future behavior. Notably, despite similar magnitudes in affect ratings across tasks, there was a remarkable decline in the early LPP amplitudes from the 'encoding task' (negative: M = 6.37, SE = 1.18; neutral: M = 1.45, SE = 0.89; positive: M = 3.16, SE = 0.82), to the recall task (negative: M = 0.59, SE = 0.67; neutral: M = -0.76, SE = 0.60; positive: M = -0.13, SE = 0.67) and the prospection task (negative: M = 0.47, SE = 0.70; neutral: M = -0.49, SE = 0.70; positive: M = 1.07, SE = 0.736). This is in line with a previous study showing significantly lower LPP amplitudes during negative mental imagery than during perception of stimuli (Suess & Abdel Rahman, 2015). Despite the significant differentiation between neutral and emotionally salient stimuli during prospection, reactivation of emotional experiences by mental imagery might be less potent than the perception of actual stimuli in eliciting electrocortical responses.

More specifically, the potentiation between emotionally salient and neutral mental imagery in LPP responses was only significant in the early (i.e., 400 ms – 1,000 ms), but not in the late LPP components (i.e. 1,000 ms – 4,000 ms). While the early LPP is typically referred to as reflecting automatic or rapid attentional processing of emotional and motivational significance of stimuli, late components are usually referred to as reflecting sustained and elaborative processing of stimuli (Hajcak & Olvet, 2008), which has been found to be modulated by higher-order cognitive processes such as cognitive appraisal (Kim et al., 2021; Speed et al., 2020). Previous studies assessing LPP responses to emotionally salient mental imagery found sustained LPP responses beyond the early components of up to 3,000 to 20,000 ms. However, in these studies, cues prompting participants to imagine the stimuli either remained on screen across the entire trial (Speed et al., 2020), were presented for a relatively long duration (i.e., 10,000 ms), allowed participants to elaborate the stimuli more precisely (MacNamara, 2018) or asked participants to imagine only certain specific aspects or details of a stimulus (Thiruchselvam et al., 2012) rather than imagining more complex daily-life experiences as depicted in the stimuli of the current study. Consequently, sustained late LPPs during mental imagery in previous studies could indeed reflect higher-order elaborative processing of mental representations, whereas the design of the present study (i.e. short presentation of cues) prevented participants from engaging in detailed elaborative processes. Furthermore, it suggests that envisioning a future positive outcome can result in rapid neural activation indicative of rather automatic activity, which is independent of strategic top-down control. Thus, potentiated early LPPs in the current study are likely to indicate automatic anticipatory reward or threat processing rather than a detailed elaboration of mental representations.

During the recall task, LPP amplitudes were specifically potentiated during recall of negative but not positive stimuli. Conversely, LPP amplitudes were potentiated during prospection of positive, but not negative experiences. Although speculative at this stage, this may suggest an evolutionary and adaptive learning pattern of a recall bias for negative stimuli that protects the individual from potential threat as well as a positive prospection bias of advanced processing of positive anticipation that drive motivation to seek positive experiences (Gilbert & Wilson, 2007; Wilson & Gilbert, 2003). On the neural level, this may be related to an interaction of an optimism bias in expectations and a reward-related bias in attention (Kress & Aue, 2017). Nevertheless, albeit descriptive effects in the expected direction (i.e., potentiated LPP responses to positive and negative recall and prospection), this pattern of task and valence specific LPP potentiation was unexpected and requires further investigation in future studies. If this bias proves to be robust, it could be utilized to explore differences between non-clinical and clinical populations, which would enhance our understanding of the mechanisms that underlie alterations in prospection and motivation across clinical populations. Given that healthy individuals show a positive bias in anticipating positive affect (Pilin, 2021), one could speculate that this adaptive bias is attenuated in clinical populations, which could explain the alterations in positive mental imagery and anticipatory pleasure in these individuals (Frost & Strauss, 2016).

The finding that participants rated the recall and prospection of emotionally salient stimuli as less vivid and less successful compared with neutral stimuli was unexpected. This contradicts previous studies suggesting enhanced mental imagery of emotionally salient stimuli (e.g., Kensinger

& Corkin, 2003). One explanation could be the fact that the positive and negative stimuli used in this study presented significantly more complex and potentially less familiar images than the neutral stimuli (e.g., a shark attack or a Ferris wheel vs. a stapler). Therefore, it cannot be ruled out that the participants' vividness ratings were confounded by the detailedness of their mental representations. Thus, the current pattern of vividness and success ratings could indicate that the subjects perceived themselves as less successful in imagining all the details of positive and negative stimuli.

Together with the pattern of findings in the behavioral ratings, the LPP responses during the recall and the prospection task suggest that recalling negative and potentially threatening events and prospecting positive events elicits anticipatory responses on both the neural and the behavioral level. These are likely to translate into attenuated versus enhanced behavioral approach motivation. However, the current study did not find potentiated SCRs during recall or prospection, which contradicts the findings of the few previous studies reporting elevated SCRs to mental imagery of emotionally salient stimuli. These prior studies found significant potentiation of the SCR in response to mental imagery, yet with large latencies using scoring windows of seven seconds (Agren, 2023) to up to 30 seconds (Lang et al., 1983; Weerts & Lang, 1978). By contrast, the current study used the empirically informed scoring window of 0.9 s to 3.5 s for the SCR to the perception of visual stimuli (Sjouwerman & Lonsdorf, 2019). Our finding of potentiated SCRs to negative and positive stimuli during the encoding task thus indicates a successful manipulation of the SCR. Together with prior research, this might however also suggest a delayed SCR to mental imagery when compared to immediate sensory input. Consequently, we cannot exclude that the relatively short trial length of four seconds in the current study has obscured a potentially delayed SCR potentiation during the recall and prospection tasks.

Several limitations of the current study must be acknowledged. First, due to the lack of available studies investigating LPP during mental time travel, the sample size calculation for the current study was based on a study assessing LPP amplitudes to positive, negative, and neutral pictures. However, consistent with the findings of a previous study (Suess & Abdel Rahman, 2015), LPP amplitudes and effects between valence conditions were significantly lower in mental imagery tasks compared to the encoding task. Consequently, it cannot be ruled out that the current study was underpowered and may have yielded false negative findings. Therefore, future studies using more sensitive analytical approaches with increased statistical power, such as multivariate pattern analysis (Carrasco et al., 2024), or recruiting larger sample sizes based on the effect sizes found in the current study, are needed to further investigate LPP responses during mental time travel.

To conclude, we successfully developed a mental time travel paradigm that allows to examine the neural processes underlying mental imagery and affect anticipation with a high degree of standardization and between-subject comparability. Our findings indicate that both recall, and prospection of emotionally salient experiences are associated with potentiated electrocortical activity in the LPP and behavioral affect and motivation ratings. These are likely to represent anticipatory responses that drive affect, motivation, and goal-directed behavior. Future studies could build on these findings to investigate aberrancies in mental time travel deficits and affect anticipation in psychopathology.

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Table 1. Mixed Linear Models predicting LPP amplitudes during the encoding task

	400 ms-1000 ms	**1000 ms-2000 ms**	**2000 ms-3000 ms**	**3000 ms-4000 ms**
Predictors	*Estimate (95% CI)*	*Estimate (95% CI)*	*Estimate (95% CI)*	*Estimate (95% CI)*
Intercept	1.45 (-0.28,3.17)	1.30 (-0.49,3.09)	1.40 (-0.35,3.15)	0.14 (-2.16,2.44)
Negative vs. neutral stimuli	4.92*** (2.41,7.44)	3.88** (1.56,6.19)	3.18** (0.90,5.46)	4.74* (0.73,8.75)
Positive vs. neutral stimuli	1.71* (0.15,3.28)	1.79 (-0.23,3.81)	2.07 (-0.47,4.61)	3.40 (-0.14,6.94)
Negative vs. positive stimuli	3.21** (.70,5.71)	2.09 (-0.13,4.31)	1.11 (-0.99,3.22)	1.34 (-0.47,3.16)
Random Effects				
σ^2	4.04	4.72	5.33	5.94
τ_{00}	34.60 $_{ID}$	36.95 $_{ID}$	35.79 $_{ID}$	63.95 $_{ID}$
	0.16 $_{electrode}$	0.20 $_{electrode}$	0.14 $_{electrode}$	0.09 $_{electrode}$
τ_{11}	77.04 $_{ID.conditionNegative}$	64.92 $_{ID.conditionNegative}$	62.55 $_{ID.conditionNegative}$	197.91 $_{ID.conditionNegative}$
	29.05 $_{ID.conditionPositive}$	48.86 $_{ID.conditionPositive}$	78.25 $_{ID.conditionPositive}$	153.40 $_{ID.conditionPositive}$
ρ_{01}	-0.46 $_{ID.conditionNegative}$	-0.41 $_{ID.conditionNegative}$	-0.46 $_{ID.conditionNegative}$	-0.75 $_{ID.conditionNegative}$
	-0.53 $_{ID.conditionPositive}$	-0.59 $_{ID.conditionPositive}$	-0.55 $_{ID.conditionPositive}$	-0.77 $_{ID.conditionPositive}$
ICC	0.91	0.91	0.90	0.93
N	48 $_{ID}$	48 $_{ID}$	48 $_{ID}$	48 $_{ID}$
	5 $_{electrode}$	5 $_{electrode}$	5 $_{electrode}$	5 $_{electrode}$
Observations	720	720	720	720
Marginal R^2 / Conditional R^2	0.081 / 0.921	0.048 / 0.910	0.031 / 0.905	0.047 / 0.930

σ^2 *= Amount of variability or dispersion of the random effects;* τ_{00} = variance of the random intercept; τ_{11} = variance of the random slope; ρ_{01} *= correlation between random effects;*
** p<0.05 ** p<0.01 *** p<0.001*

Table 2. Mixed Linear Models predicting LPP amplitudes during the recall task

	400 ms-1000 ms	**1000 ms-2000 ms**	**2000 ms-3000 ms**	**3000 ms-4000 ms**
Predictors	*Estimate (95% CI)*	*Estimate (95% CI)*	*Estimate (95% CI)*	*Estimate (95% CI)*
Intercept	-0.76 (-1.94,0.41)	-0.71 (-2.01,0.60)	-0.94 (-2.21,0.32)	-0.68 (-1.95,0.59)
Negative vs. neutral recall	1.36 *(0.27,2.44)	1.69 *(0.31,3.07)	1.04 (-0.31,2.40)	0.99 (-0.40,2.39)
Positive vs. neutral recall	0.63 (-0.76,2.03)	-0.22 (-1.87,1.43)	-0.46 (-2.67,1.75)	-0.12 (-1.80,1.57)
Negative vs. positive stimuli	0.72 (-.84,2.29)	1.91* (0.23,3.56)	1.50 (-0.81,3.82)	1.11 (-0.94,3.16)
Random Effects				
σ^2	1.58	2.40	3.95	4.32
τ_{00}	16.05 $_{ID}$	18.55 $_{ID}$	16.97 $_{ID}$	17.85 $_{ID}$
	0.02 $_{electrode}$	0.13 $_{electrode}$	0.14 $_{electrode}$	0.06 $_{electrode}$
τ_{11}	13.38 $_{ID.conditionNegative}$	21.87 $_{ID.conditionNegative}$	20.35 $_{ID.conditionNegative}$	21.36 $_{ID.conditionNegative}$
	22.51 $_{ID.conditionPositive}$	31.49 $_{ID.conditionPositive}$	56.52 $_{ID.conditionPositive}$	32.14 $_{ID.conditionPositive}$
ρ_{01}	-0.32 $_{ID.conditionNegative}$	-0.15 $_{ID.conditionNegative}$	-0.21 $_{ID.conditionNegative}$	-0.31 $_{ID.conditionNegative}$
	-0.51 $_{ID.conditionPositive}$	-0.19 $_{ID.conditionPositive}$	-0.10 $_{ID.conditionPositive}$	-0.41 $_{ID.conditionPositive}$
ICC	0.92	0.93	0.91	0.85
N	46 $_{ID}$	46 $_{ID}$	46 $_{ID}$	46 $_{ID}$
	5 $_{electrode}$	5 $_{electrode}$	5 $_{electrode}$	5 $_{electrode}$
Observations	690	690	690	690
Marginal R^2 / Conditional R^2	0.015 / 0.923	0.021 / 0.930	0.009 / 0.907	0.008 / 0.854

σ^2 = *Amount of variability or dispersion of the random effects;* τ_{00} = variance of the random intercept; τ_{11} = variance of the random slope; ρ_{01} = *correlation between random effects;*
** p<0.05 ** p<0.01 *** p<0.001*

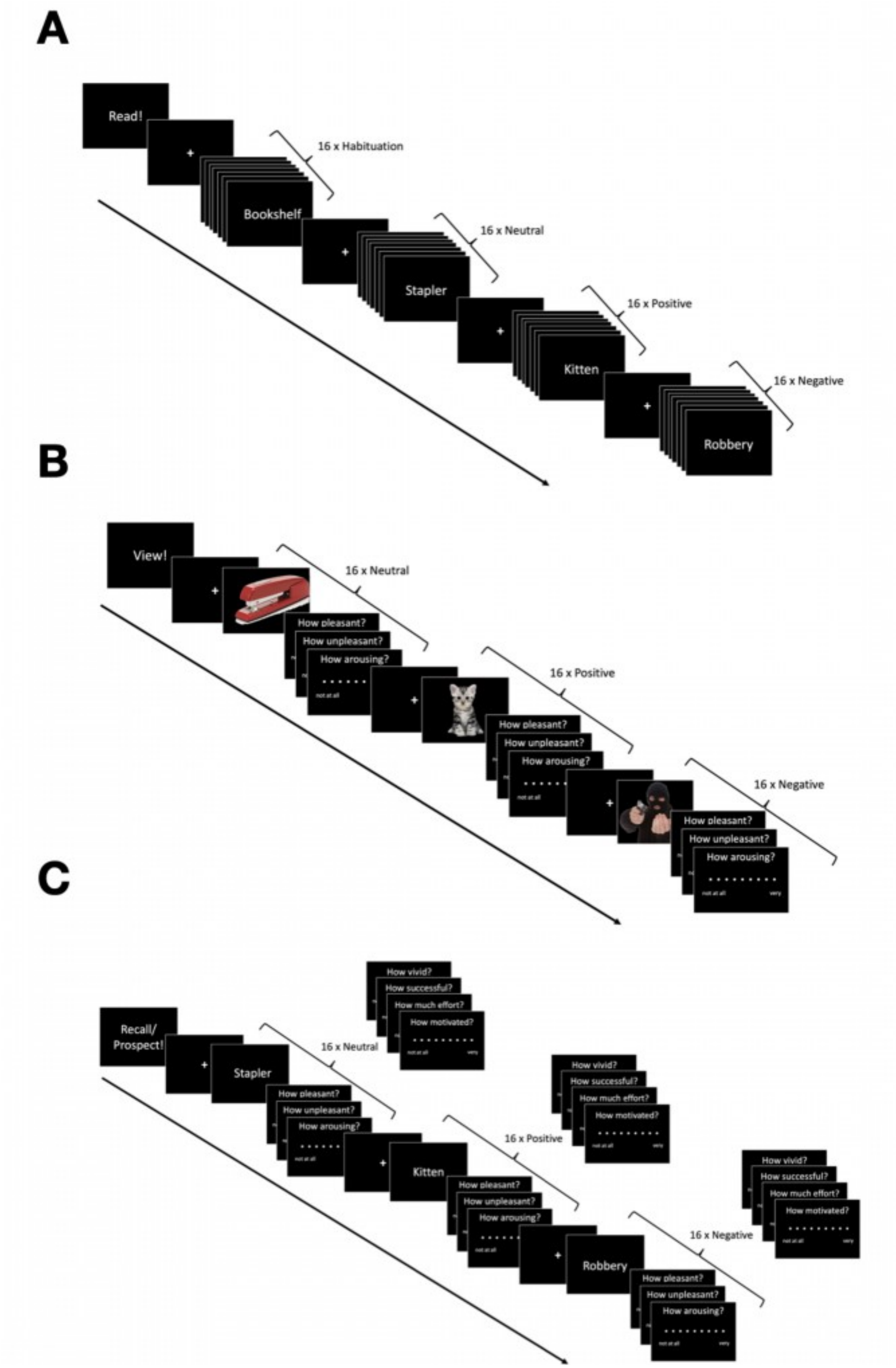
Table 3. Mixed Linear Models predicting LPP amplitudes during the prospection task

	400 ms-1000 ms	**1000 ms-2000 ms**	**2000 ms-3000 ms**	**3000 ms-4000 ms**
Predictors	*Estimate (95% CI)*	*Estimate (95% CI)*	*Estimate (95% CI)*	*Estimate (95% CI)*
Intercept	-0.49 (-1.86,0.89)	-0.69 (-2.39,1.02)	-1.44 (-2.94,0.05)	-2.34* (-4.61,-0.07)
Negative vs. neutral prospection	0.95 (-0.06,1.97)	0.58 (-0.80,1.97)	0.37 (-1.14,1.88)	0.83 (-0.74,2.40)
Positive vs. neutral prospection	1.56**(0.51,2.61)	1.09 (-0.41,2.58)	0.73 (-0.90,2.37)	0.62 (-0.88,2.11)
Negative vs. positive stimuli	-0.60 (-2.03,0.82)	-0.50 (-2.34,1.34)	-0.36 (-2.64,1.91)	0.22 (-1.67,2.10)
Random Effects				
σ^2	2.17	3.30	4.19	4.67
τ_{00}	23.04 ID	31.38 ID	22.42 ID	60.68 ID
	0.01 electrode	0.43 electrode	0.47 electrode	0.26 electrode
τ_{11}	11.99 ID.conditionNegative	22.54 ID.conditionNegative	26.82 ID.conditionNegative	28.87 ID.conditionNegative
	12.82 ID.conditionPositive	26.61 ID.conditionPositive	31.60 ID.conditionPositive	25.95 ID.conditionPositive
ρ_{01}	-0.37 ID.conditionNegative	-0.46 ID.conditionNegative	-0.53 ID.conditionNegative	-0.66 ID.conditionNegative
	-0.25 ID.conditionPositive	-0.65 ID.conditionPositive	-0.37 ID.conditionPositive	-0.43 ID.conditionPositive
ICC	0.92	0.89	0.87	0.91
N	48 ID	48 ID	48 ID	48 ID
	5 electrode	5 electrode	5 electrode	5 electrode
Observations	720	720	720	720
Marginal R^2 / Conditional R^2	0.015 / 0.920	0.006 / 0.894	0.003 / 0.866	0.002 / 0.914

σ^2 *= Amount of variability or dispersion of the random effects;* τ_{00} = variance of the random intercept; τ_{11} = variance of the random slope; ρ_{01} *= correlation between random effects;*

** p<0.05 ** p<0.01 *** p<0.001*

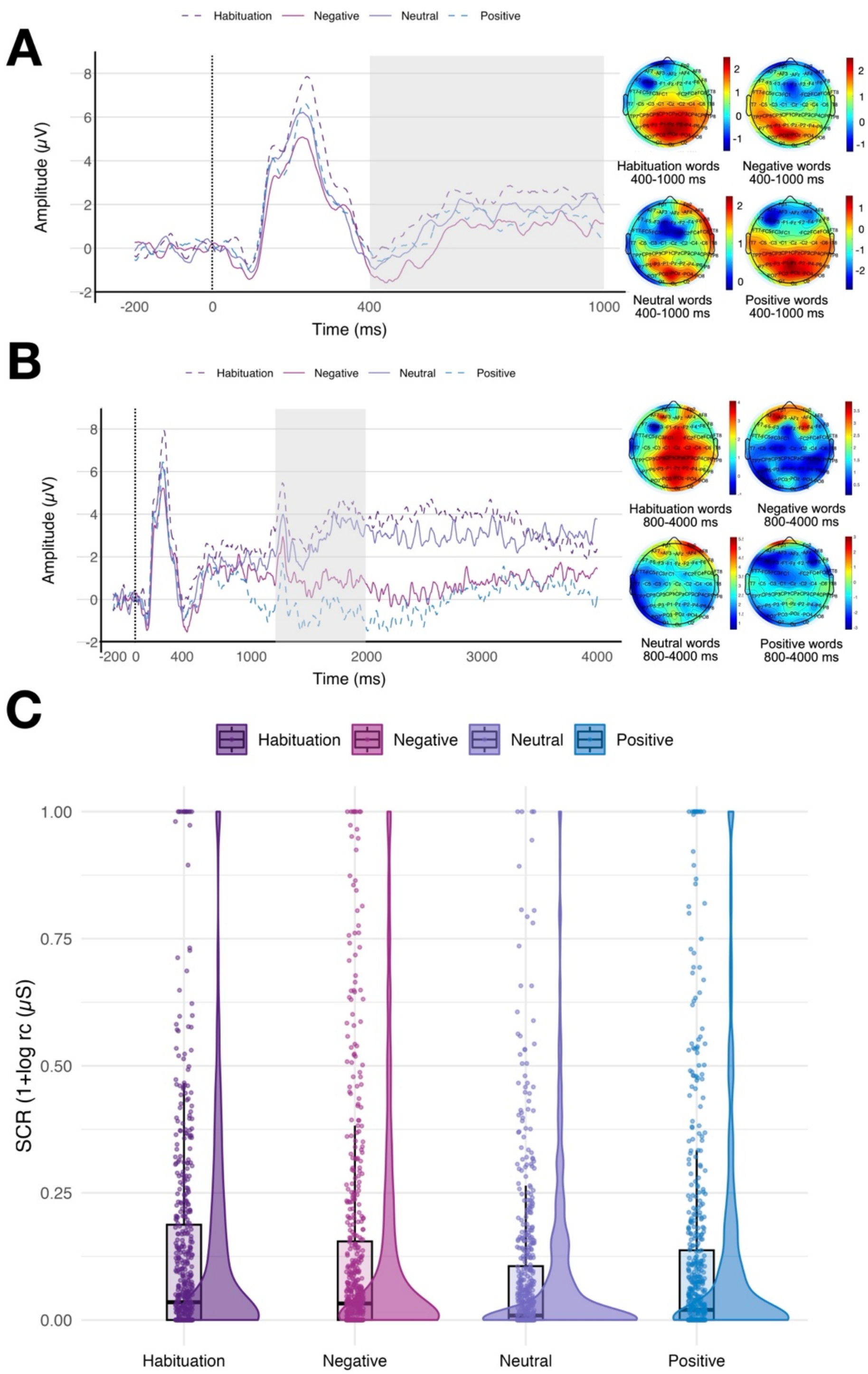
Figure 1.
Trial structure of experimental tasks



Note. Panel A depicts the structure of the word reading task, Panel B depicts the structure of the encoding task, Panel C depicts the structure of the recall and the prospections tasks.

Figure 2

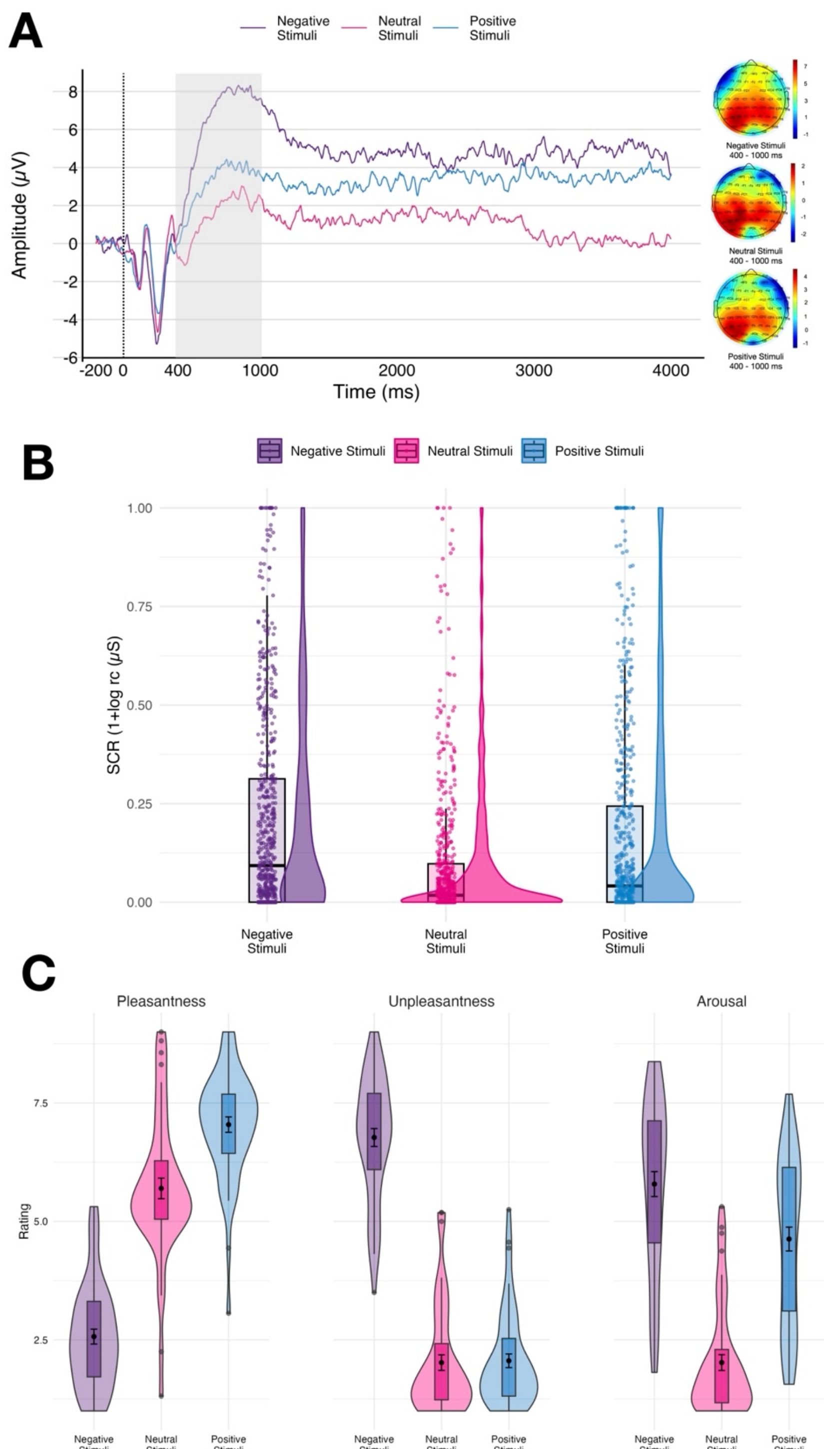
The Late Positive Potential and skin conductance responses during the word reading task



Note. Grand averaged late positive potential and scalp topography during word reading task. Stimulus-locked activity with at ROI (Cz, CPz, CP1, CP2, and Pz) with a baseline correction of -200 and 0 ms. Panel A: LPP scoring from 400 to 1000 ms. Panel B: LPP scoring from 1400 ms to 2000 ms. Panel C: Log.-range corrected skin conductance responses during the word reading task.

Figure 3

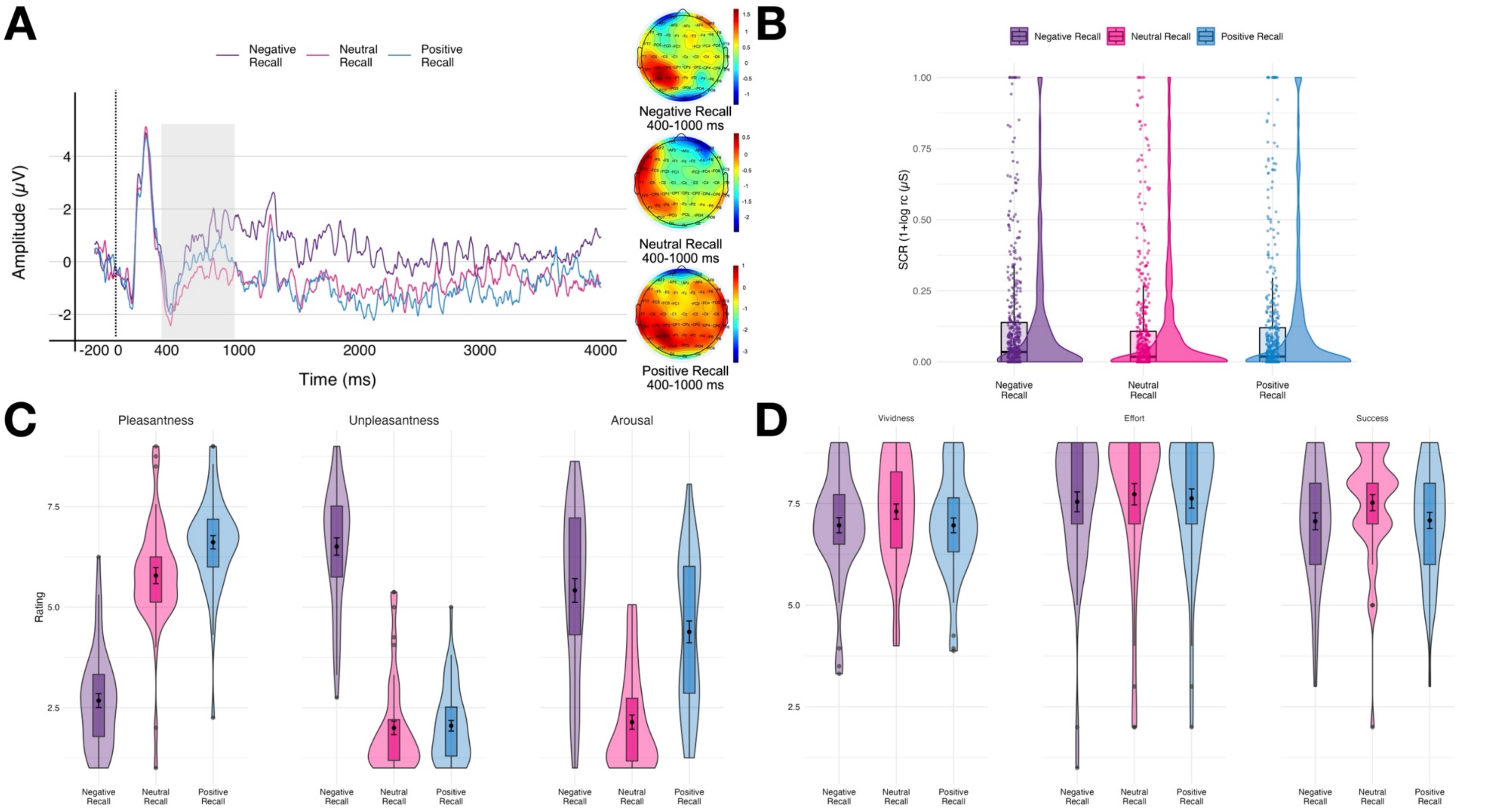
The Late Positive Potential, skin conductance responses and behavioral ratings during the encoding task



Note. Panel A: Event related potential and scalp topographies (400-1000 milliseconds) during encoding task. Panel B: Log.-range corrected skin conductance responses during the word reading task. Panel C: Behavioral ratings during encoding task.

Figure 4

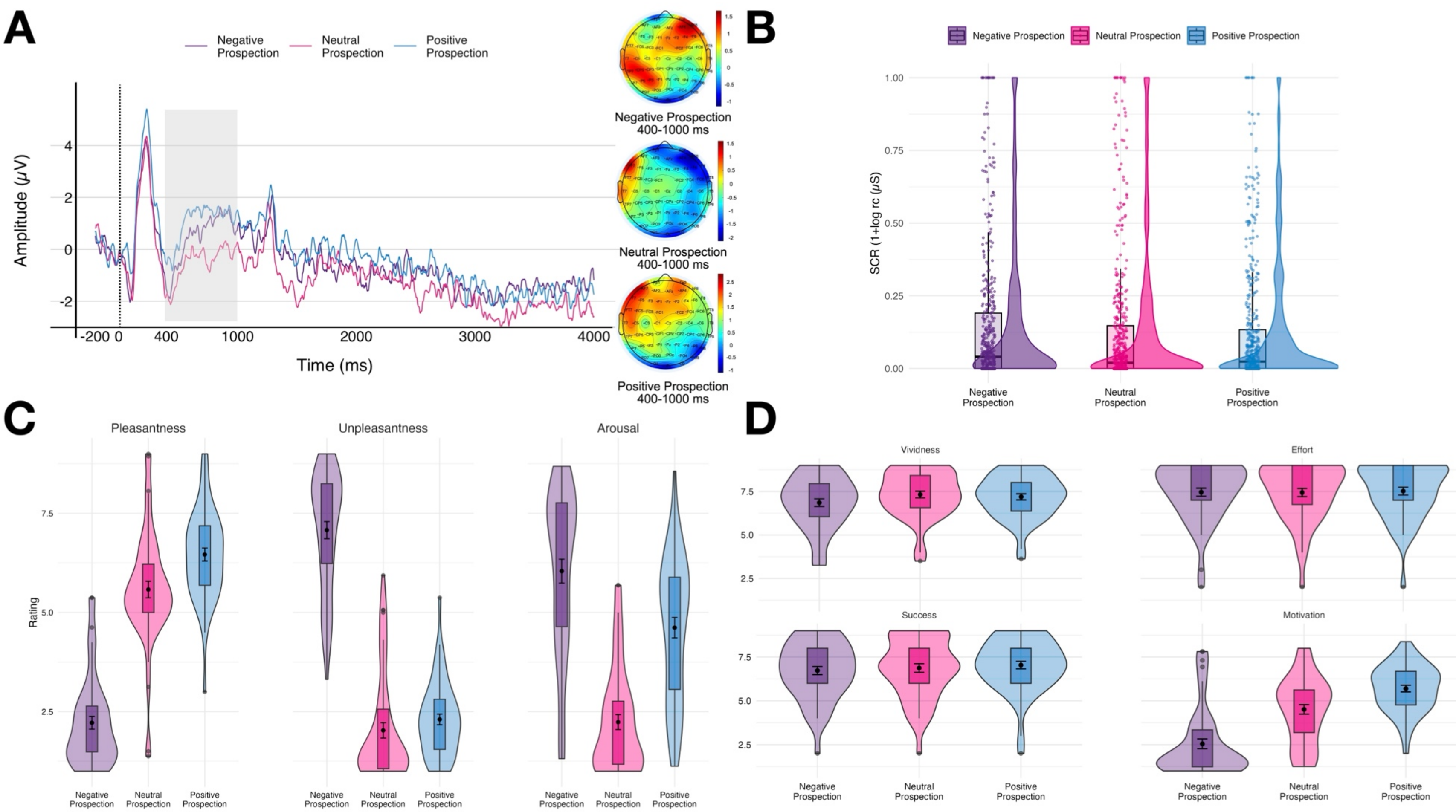
The Late Positive Potential, skin conductance responses and behavioral ratings during the recall task



Note. Panel A: Event related potential and scalp topographies (400-1000 milliseconds) during recall task. Panel B: Log.-range corrected skin conductance responses during the recall task. Panel C: Pleasantness, Unpleasantness, and arousal ratings during recall task (trial wise). Panel C: Block wise ratings of vividness, effort, and success during recall task.

Figure 5

The Late Positive Potential, skin conductance responses and behavioral ratings during the prospection task



Note. Panel A: Event related potential and scalp topographies (400-1000 milliseconds) during prospection task. Panel B: Log.-range corrected skin conductance responses during the prospection task. Panel C: Pleasantness, Unpleasantness, and arousal ratings during prospection task (trial wise). Panel C: Block wise ratings of vividness, effort, and success during prospection task.

Supplement

S1. List of cue words

Habituation	Negative	Neutral	Positive
“moonlight”	“snake”	“fisherman”	“kitten”
“nose”	“tiger”	“mushrooms”	“seal”
“computer”	“bomb”	“rolling pin”	“puppy”
“mouse”	“gun”	“buttons”	“baby”
“hunter”	“headshot”	“towel	“thongs”
“bookshelf”	“mutilated hand”	“cup”	“windsurfer”
“dream”	“chest ulcer”,	“spoon”	“sex”
“radiator”	“electric chair”	“scissors”	“child with watermelon”
“tree trunk”	“kidnapping”	“screw”	“muffins”
“watch”	“plane crash”	“bar stool”	“pancakes”
“trouser”	“heroin injection”	“hammer”	“concert”
“bike”	“tarantula”	“beer glass”	“ferris wheel”
“landscape”	“horse carcass”	“zipper”	“high diver”
“tablecloth”	“shark attack”	“clothespins”	“bungee jump”
“office”	“hanging”	“fork”	“water ski”
“window frame”	“shipwreck”	“umbrella”	“water slide”

S2. List of cue-stimulus-assignment

Valence	IAPS	Valence_*M*	Valence_*SD*	Arousal_*M*	Arousal_*SD*	German	English
positive	1440	8.19	1.53	4.61	2.54	Robbe	Seal
positive	1460	8.21	1.21	4.31	2.63	Kätzchen	Kitten
positive	1710	8.34	1.12	5.41	2.34	Hundewelpen	Puppies
positive	2070	8.17	1.46	4.51	2.74	Baby	Baby
positive	4130	5.36	2.17	5.15	2.29	Stringtangas	Thongs
positive	4220	8.02	1.93	7.17	2.69	Windsurferin	Windsurfer (female)
positive	4668	6.67	1.69	7.13	1.62	Sex	Sex
positive	7325	7.06	1.65	3.55	2.07	Kind mit Wassermelone	Child with watermelon
positive	7405	7.38	1.73	6.28	2.16	Muffins	Muffins
positive	7470	7.08	1.6	4.64	2.26	Pancakes	Pancakes
positive	7499	6.47	1.57	5.58	2.16	Konzert	Concert
positive	7508	7.02	1.46	5.09	2.11	Riesenrad	Ferris wheel
positive	8041	6.65	1.67	5.49	2.29	Turmspringer	High diver
positive	8179	6.48	2.18	6.99	2.35	Bungeesprung	Bungee jump
positive	8200	7.54	1.37	6.35	1.98	Wasserski	Water skiing
positive	8496	7.58	1.63	5.79	2.26	Wasserrutsche	Water slide
negative	1033	3.87	1.94	6.13	2.15	Schlange	Snake
negative	1201	3.55	1.88	6.36	2.11	Vogelspinne	Tarantula
negative	1726	4.79	2.1	6.23	2.19	Tiger	Tiger
negative	1932	3.85	2.11	6.47	2.2	Haiangriff	Shark attack
negative	2692	3.36	1.61	5.35	2.19	Bombe	Bomb
negative	2811	2.17	1.38	6.9	2.22	Pistole	Gun
negative	3068	1.8	1.56	6.77	2.49	Kopfschuss	Headshot
negative	3150	2.26	1.57	6.55	2.2	Verstümmelte Hand	Mutilated hand
negative	3261	1.82	1.34	5.75	2.64	Brustgeschwür	Breast ulcer
negative	6020	3.41	1.98	5.58	2.01	Elektrischer Stuhl	Electric chair
negative	6312	2.48	1.52	6.37	2.3	Entführung	Kidnapping
negative	9050	2.43	1.61	6.36	1.97	Flugzeugabsturz	Plane crash
negative	9102	3.34	1.76	4.84	2.5	Heroin-Injektion	Heroin injection

negative	9181	2.26	1.85	5.39	2.41	Pferdekadaver	Horse carcass
negative	9413	1.76	1.08	6.81	2.09	Erhängen	Hanging
negative	9600	2.48	1.62	6.46	2.31	Schiffuntergang	Shipwreck
neutral	2384	5.92	1.47	3.41	2.04	Angler	Angler/Fisherman
neutral	5500	5.42	1.58	3	2.42	Pilze	Mushrooms
neutral	7000	5	0.84	2.42	1.79	Nudelholz	Rolling pin
neutral	7001	5.32	1.19	3.2	2.15	Knöpfe	Buttons
neutral	7002	4.97	0.97	3.16	2	Handtuch	Towel
neutral	7004	5.04	0.6	2	1.66	Löffel	Spoon
neutral	7009	4.93	1	3.01	1.97	Tasse	Cup
neutral	7014	5.15	0.97	3.25	2.03	Schere	Scissors
neutral	7018	4.81	0.88	3.91	1.97	Schraube	Screw
neutral	7025	4.63	1.17	2.71	2.2	Barhocker	Bar stool
neutral	7034	4.95	0.87	3.06	1.95	Hammer	Hammer
neutral	7035	4.98	0.96	2.66	1.82	Bierglas	Beer glass
neutral	7045	4.97	0.76	3.32	1.96	Reißverschluss	Zipper
neutral	7052	5.33	1.32	3.01	2.02	Wäscheklammern	Clothes pegs
neutral	7080	5.27	1.09	2.32	1.84	Gabel	Fork
neutral	7150	4.72	1	2.61	1.76	Regenschirm	Umbrella

	Valence		**Arousal**	
	M	*SD*	*M*	*SD*
Positive	7.26375	1.623125	5.503125	2.280625
Negative	2.851875	1.681875	6.145	2.24875
Neutral	5.088125	1.041875	2.940625	1.97375

S3. Associations between positive affect ratings, the LPP and SCR during the encoding task

	volt			logrange scr		
Predictors	*Estimates*	*CI*	*p*	*Estimates*	*CI*	*p*
(Intercept)	4.05	-5.03 – 13.13	0.380	0.30	0.11 – 0.49	**0.002**
mean pos	-0.17	-1.44 – 1.10	0.791	-0.02	-0.04 – 0.01	0.237
Random Effects						
σ^2	4.00			0.06		
τ_{00}	24.17 $_{ID}$			0.01 $_{ID}$		
	0.11 $_{electrode}$					
ICC	0.86			0.11		
N	48 $_{ID}$			36 $_{ID}$		
	5 $_{electrode}$					
Observations	240			2880		
Marginal R^2 / Conditional R^2	0.001 / 0.859			0.005 / 0.116		

S4. Associations between negative affect ratings, the LPP and SCR during the encoding task

	volt			logrange scr		
Predictors	*Estimates*	*CI*	*p*	*Estimates*	*CI*	*p*
(Intercept)	5.32	-6.83 – 17.48	0.389	0.20	-0.04 – 0.44	0.101
mean neg	0.08	-1.68 – 1.84	0.927	0.00	-0.03 – 0.04	0.943
Random Effects						
σ^2	3.21			0.05		
τ_{00}	63.60 $_{ID}$			0.02 $_{ID}$		
	0.20 $_{electrode}$					
ICC	0.95			0.28		
N	48 $_{ID}$			36 $_{ID}$		
	5 $_{electrode}$					
Observations	240			2880		
Marginal R^2 / Conditional R^2	0.000 / 0.952			0.000 / 0.281		

S5. Associations between arousal ratings, the LPP and SCR during the encoding task

	volt			logrange scr		
Predictors	*Estimates*	*CI*	*p*	*Estimates*	*CI*	*p*
(Intercept)	1.10	-0.88 – 3.07	0.275	0.10	0.05 – 0.15	**<0.001**
mean aro	0.26	-0.43 – 0.95	0.459	0.00	-0.02 – 0.02	0.955
condition [Negative]	3.01	0.21 – 5.81	**0.035**	0.08	-0.07 – 0.23	0.295
condition [Positive]	1.38	-1.00 – 3.76	0.255	0.14	0.04 – 0.24	**0.005**
mean aro × condition [Negative]	0.05	-0.71 – 0.80	0.906	0.01	-0.03 – 0.04	0.732
mean aro × condition [Positive]	-0.18	-0.90 – 0.54	0.621	-0.01	-0.04 – 0.01	0.347
Random Effects						
σ^2	24.44			0.05		
τ_{00}	19.36 $_{ID}$			0.01 $_{ID}$		
	0.03 $_{electrode}$					
τ_{11}	0.00 $_{electrode.conditionNegative}$			0.02 $_{ID.conditionNegative}$		
	0.00 $_{electrode.conditionPositive}$			0.01 $_{ID.conditionPositive}$		
ρ_{01}	1.00 $_{electrode.conditionNegative}$			-0.24		
	1.00 $_{electrode.conditionPositive}$			-0.61		
ICC				0.19		
N	48 $_{ID}$			36 $_{ID}$		
	5 $_{electrode}$					
Observations	720			8640		
Marginal R^2 / Conditional R^2	0.120 / NA			0.041 / 0.220		

S6. Associations between positive affect ratings, the LPP and SCR during the recall task

	volt			logrange scr		
Predictors	*Estimates*	*CI*	*p*	*Estimates*	*CI*	*p*
(Intercept)	0.20	-7.30 – 7.71	0.957	0.17	-0.00 – 0.34	0.051
mean pos	-0.05	-1.17 – 1.07	0.929	-0.01	-0.03 – 0.02	0.610
Random Effects						
σ^2	1.60			0.05		
τ_{00}	19.65_{ID}			0.01_{ID}		
	$0.02_{\text{electrode}}$					
ICC	0.92			0.12		
N	46_{ID}			31_{ID}		
	$5_{\text{electrode}}$					
Observations	230			2425		
Marginal R^2 / Conditional R^2	0.000 / 0.925			0.001 / 0.120		

S7. Associations between negative affect ratings, the LPP and SCR during the recall task

	volt			lograngé scr		
Predictors	*Estimates*	*CI*	*p*	*Estimates*	*CI*	*p*
(Intercept)	0.21	-5.70 – 6.12	0.944	0.11	0.02 – 0.20	**0.015**
mean neg	0.06	-0.83 – 0.95	0.896	0.00	-0.01 – 0.02	0.747
Random Effects						
σ^2	1.57			0.04		
τ_{00}	20.63 $_{ID}$			0.00 $_{ID}$		
	0.22 $_{electrode}$					
τ_{11}	0.00 $_{electrode.mean\_neg}$					
ρ_{01}	-1.00 $_{electrode}$					
ICC				0.07		
N	46 $_{ID}$			31 $_{ID}$		
	5 $_{electrode}$					
Observations	230			2480		
Marginal R^2 / Conditional R^2	0.005 / NA			0.000 / 0.069		

S8. Associations between arousal ratings, the LPP and SCR during the recall task

	volt			logrange scr		
Predictors	*Estimates*	*CI*	*p*	*Estimates*	*CI*	*p*
(Intercept)	-0.49	-1.86 – 0.87	0.476	0.10	0.06 – 0.15	**<0.001**
mean aro	-0.13	-0.52 – 0.27	0.526	0.00	-0.01 – 0.02	0.748
condition [Negative]	1.60	0.19 – 3.01	**0.027**	0.01	-0.05 – 0.06	0.843
condition [Positive]	-1.32	-2.59 – -0.05	**0.041**	0.01	-0.05 – 0.06	0.866
mean aro × condition [Negative]	0.03	-0.37 – 0.44	0.872	0.00	-0.02 – 0.02	0.971
mean aro × condition [Positive]	0.52	0.12 – 0.91	**0.010**	0.00	-0.02 – 0.02	0.911
Random Effects						
σ^2	7.79			0.04		
τ_{00}	12.28 $_{\text{ID}}$			0.00 $_{\text{ID}}$		
	0.00 $_{\text{electrode}}$					
τ_{11}	0.00 $_{\text{electrode.conditionNegative}}$			0.00 $_{\text{ID.conditionNegative}}$		
	0.00 $_{\text{electrode.conditionPositive}}$			0.00 $_{\text{ID.conditionPositive}}$		
ρ_{01}				-0.48		
				-0.06		
ICC				0.09		
N	46 $_{\text{ID}}$			31 $_{\text{ID}}$		
	5 $_{\text{electrode}}$					
Observations	690			7385		
Marginal R^2 / Conditional R^2	0.061 / NA			0.002 / 0.095		

S9. Associations between vividness ratings, the LPP and SCR during the recall task

	volt			logrange scr		
Predictors	*Estimates*	*CI*	*p*	*Estimates*	*CI*	*p*
(Intercept)	0.67	-2.51 – 3.85	0.679	0.14	0.03 – 0.24	**0.011**
mean viv	-0.20	-0.61 – 0.22	0.347	-0.00	-0.02 – 0.01	0.588
condition [Negative]	5.75	2.64 – 8.85	**<0.001**	-0.01	-0.15 – 0.12	0.835
condition [Positive]	-2.11	-5.06 – 0.85	0.163	-0.03	-0.17 – 0.12	0.696
mean viv × condition [Negative]	-0.64	-1.07 – -0.21	**0.004**	0.00	-0.01 – 0.02	0.644
mean viv × condition [Positive]	0.39	-0.03 – 0.80	0.066	0.01	-0.01 – 0.03	0.546
Random Effects						
σ^2	7.64			0.04		
τ_{00}	12.18 $_{ID}$			0.00 $_{ID}$		
	0.00 $_{electrode}$					
τ_{11}	0.00 $_{electrode.conditionNegative}$			0.00 $_{ID.conditionNegative}$		
	0.00 $_{electrode.conditionPositive}$			0.00 $_{ID.conditionPositive}$		
ρ_{01}				-0.47		
				-0.05		
ICC				0.09		
N	46 $_{ID}$			31 $_{ID}$		
	5 $_{electrode}$					
Observations	690			7385		
Marginal R^2 / Conditional R^2	0.088 / NA			0.001 / 0.094		

S10. Associations between positive affect ratings, the LPP and SCR during the prospection task

	volt			logrange scr		
Predictors	*Estimates*	*CI*	*p*	*Estimates*	*CI*	*p*
(Intercept)	-0.20	-9.06 – 8.67	0.965	0.11	-0.02 – 0.24	0.091
mean pos	0.20	-1.16 – 1.55	0.775	0.00	-0.02 – 0.02	0.679
Random Effects						
σ^2	1.87			0.04		
τ_{00}	27.85 $_{\text{ID}}$			0.00 $_{\text{ID}}$		
	0.04 $_{\text{electrode}}$					
ICC	0.94			0.09		
N	48 $_{\text{ID}}$			29 $_{\text{ID}}$		
	5 $_{\text{electrode}}$					
Observations	240			2320		
Marginal R^2 / Conditional R^2	0.002 / 0.937			0.001 / 0.089		

S11. Associations between negative affect ratings, the LPP and SCR during the prospection task

	volt			lograng scr		
Predictors	*Estimates*	*CI*	*p*	*Estimates*	*CI*	*p*
(Intercept)	-0.07	-7.03 – 6.88	0.983	0.13	-0.02 – 0.28	0.084
mean neg	0.08	-0.88 – 1.04	0.876	0.00	-0.02 – 0.02	0.804
Random Effects						
σ^2	2.50			0.05		
τ_{00}	23.27_{ID}			0.01_{ID}		
	$3.27_{\text{electrode}}$					
τ_{11}	$0.06_{\text{electrode.mean\_neg}}$					
ρ_{01}	$-1.00_{\text{electrode}}$					
ICC				0.10		
N	48_{ID}			29_{ID}		
	$5_{\text{electrode}}$					
Observations	240			2320		
Marginal R^2 / Conditional R^2	0.005 / NA			0.000 / 0.102		

S12. Associations between arousal ratings, the LPP and SCR during the prospection task

	volt			logrange scr		
Predictors	*Estimates*	*CI*	*p*	*Estimates*	*CI*	*p*
(Intercept)	-0.47	-1.99 – 1.05	0.547	0.11	0.04 – 0.19	**0.003**
mean aro	-0.01	-0.35 – 0.33	0.958	0.01	-0.02 – 0.04	0.632
condition [Negative]	2.24	0.86 – 3.63	**0.002**	0.08	-0.03 – 0.19	0.132
condition [Positive]	2.43	1.19 – 3.66	**<0.001**	0.00	-0.08 – 0.08	0.994
mean aro × condition [Negative]	-0.21	-0.56 – 0.15	0.252	-0.02	-0.05 – 0.02	0.341
mean aro × condition [Positive]	-0.18	-0.52 – 0.16	0.291	-0.00	-0.03 – 0.03	0.841
Random Effects						
σ^2	6.88			0.05		
τ_{00}	20.10 $_{ID}$			0.01 $_{ID}$		
	0.00 $_{electrode}$					
τ_{11}	0.00 $_{electrode.conditionNegative}$			0.01 $_{ID.conditionNegative}$		
	0.00 $_{electrode.conditionPositive}$			0.01 $_{ID.conditionPositive}$		
ρ_{01}				-0.70		
				-0.76		
ICC				0.12		
N	48 $_{ID}$			29 $_{ID}$		
	5 $_{electrode}$					
Observations	720			6960		
Marginal R^2 / Conditional R^2	0.070 / NA			0.003 / 0.122		

S13. Associations between vividness ratings, the LPP and SCR during the prospection task

	volt			logrange scr		
Predictors	*Estimates*	*CI*	*p*	*Estimates*	*CI*	*p*
(Intercept)	-2.70	-5.79 – 0.40	0.087	0.08	-0.10 – 0.25	0.386
mean viv	0.30	-0.08 – 0.68	0.123	0.01	-0.02 – 0.03	0.519
condition [Negative]	4.72	2.08 – 7.36	**<0.001**	0.10	-0.11 – 0.31	0.366
condition [Positive]	3.05	0.19 – 5.90	**0.036**	0.05	-0.13 – 0.23	0.594
mean viv × condition [Negative]	-0.53	-0.89 – -0.17	**0.004**	-0.01	-0.04 – 0.02	0.458
mean viv × condition [Positive]	-0.20	-0.59 – 0.19	0.310	-0.01	-0.03 – 0.02	0.621
Random Effects						
σ^2	6.86			0.05		
τ_{00}	19.62 $_{\text{ID}}$			0.01 $_{\text{ID}}$		
	0.00 $_{\text{electrode}}$					
τ_{11}	0.00 $_{\text{electrode.conditionNegative}}$			0.01 $_{\text{ID.conditionNegative}}$		
	0.00 $_{\text{electrode.conditionPositive}}$			0.01 $_{\text{ID.conditionPositive}}$		
ρ_{01}				-0.70		
				-0.75		
ICC				0.12		
N	48 $_{\text{ID}}$			29 $_{\text{ID}}$		
	5 $_{\text{electrode}}$					
Observations	720			6960		
Marginal R^2 / Conditional R^2	0.069 / NA			0.002 / 0.122		