



# Phenomenal, bodily and brain correlates of fictional reappraisal as an implicit emotion regulation strategy

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## Abstract

The ability to modulate our emotional experience, depending on our current goal and context, is of critical importance for adaptive behavior. This ability encompasses various emotion regulation strategies, such as fictional reappraisal, at stake whenever one engages in fictional works (e.g., movies, books, video games, virtual environments). Neuroscientific studies investigating the distinction between the processing of real and fictional entities have reported the involvement of brain structures related to self-relevance and emotion regulation, suggesting a threefold interaction between the appraisal of reality, aspects of the Self, and emotions. The main aim of this study is to investigate the effect of implicit fictional reappraisal on different components of emotion, as well as on the modulatory role of autobiographical and conceptual self-relevance. While recording electrodermal, cardiac, and brain activity (EEG), we presented negative and neutral pictures to 33 participants, describing them as either real or fictional. After each stimulus, the participants reported their subjective emotional experience, self-relevance of the stimuli, as well as their agreement with their description. Using the Bayesian mixed-modeling framework, we showed that stimuli presented as fictional, compared with real, were subjectively appraised as less intense and less negative, and elicited lower skin conductance response, stronger heart-rate deceleration, and lower late positive potential amplitudes. Finally, these phenomenal and physiological changes did, to a moderate extent, rely on variations of specific aspects of self-relevance. Implications for the neuroscientific study of implicit emotion regulation are discussed.

**Keywords** Fictional reappraisal · Implicit emotion regulation · Fiction · Simulation monitoring · Sense of reality · Self-relevance

The ability to modulate our emotional experience, depending on our current goal and context, is of critical importance for

adaptive survival (Gross, 1998a). In our societies, efficient emotion regulation (ER) is correlated with culturally endorsed

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characteristics, such as well-being, job satisfaction, resilience, and mindfulness (Gross & John, 2003; Hülshöger, Alberts, Feinholdt, & Lang, 2013; John & Gross, 2004; Tugade & Fredrickson, 2007; Tugade, Fredrickson, & Feldman Barrett, 2004), and its deficits are associated with mental and personality disorders (Aldao, Nolen-Hoeksema, & Schweizer, 2010; Gross, 1998a, b). Rather than being a unitary process, ER is conceptualized as an umbrella term for various strategies (Webb, Miles, & Sheeran, 2012), differing in the moment (antecedent vs. response-focused strategies), the target of their action (the context, the attention focus, the cognitive representation of the event or the bodily state; Gross, 2002), the degree of voluntary control and the prominence of the ER goal (explicit vs. implicit; Braunstein, Gross, & Ochsner, 2017). These strategies were originally classified as inherently maladaptive or adaptive (positive vs. negative, healthy vs. unhealthy; John & Gross, 2004). Nevertheless, other conceptual frameworks do not emphasize such distinction, suggesting instead that a global ER efficiency would more likely depend on the flexible implementation of a given strategy, depending on the context (Aldao, 2013; Aldao & Nolen-Hoeksema, 2012; Troy, Shallcross, & Mauss, 2013).

In order to precisely map the neurocognitive correlates of each of these strategies, recent research has focused on sharpening and refining their definition. One of the most studied forms of ER, *cognitive change*, was at first presented as a unique strategy (with *reappraisal* as its core mechanism; Buhle et al., 2013). It has been recently reframed into a broader category, possibly supported by different neural pathways (Dörfel et al., 2014). This form of ER involves the voluntary or implicit change of the meaning or the nature of the mental representation of an event (Davis, Gross, & Ochsner, 2011). It encompasses strategies such as positive reappraisal (creating and focusing on a positive aspect of the stimulus; Moser, Hartwig, Moran, Jendrusina, & Kross, 2014), detachment (disengaging from all emotional implications; Shiota & Levenson, 2012), distancing or decentering (perspective change to consider an event “from the outside”; Bernstein et al., 2015; Kross & Ayduk, 2011), and fictional reappraisal (Sperduti et al., 2017).

The latter holds a particular place in the nebula of ER strategies, as it aims at changing the intrinsic nature of the mental representation of an event, appraising it as more or less real (Sperduti et al., 2017). Although the term “reappraisal” usually refers to a change occurring after the stimulus presentation, it can also take the form of a prior information that will bias its evaluation (Sperduti et al., 2016a). This strategy is at stake whenever engaging into fictional experiences, such as movies, books, video games, virtual environments, and possibly extending to memories and thoughts, to help us manage our emotional reaction (“it’s just a movie, it’s not *for real*”; “this video depicting a dramatic car crash must be a *fake*”). It has also been intuitively used by advertisers in an attempt to

increase the emotional appeal of a product (“a movie based on real events”). Moreover, it encounters an echo in modified states of consciousness (drug’s effects and mystical experiences; Carhart-Harris et al., 2012; Lebedev et al., 2015), as well as several psychiatric disorders and symptoms characterized by an improper appraisal of real and nonreal events, such as hallucinations, delusions, posttraumatic flashbacks, and depersonalization/derealization disorder (Bentall, 1990; Bryant & Mallard, 2003; Northoff & Duncan, 2016; Sedeño et al., 2014). Despite our frequent engagement with fiction in everyday life and its relationship with serious conditions affecting one’s core sense of self, fictional reappraisal has received, to date, only minimal attention from the scientific community.

In laboratory contexts, fictional reappraisal has been successfully operationalized by changing the context of a given stimulus, from real to fictional (e.g., “it’s not blood but ketchup”). The central finding highlighted by studies using this procedure is that presenting a realistic stimulus as fictitious attenuated the associated emotional experience (Sperduti et al., 2017), modulated the phenomenal and the neurophysiological emotional response (with a decreased late positive potential [LPP] amplitude; Mocaiber et al., 2009, 2010), and decreased the activity in brain regions usually associated with emotional processing (i.e., amygdala and insula; Mocaiber et al., 2011a). On the bodily signals side, one study investigating the heart-rate deceleration magnitude suggests that fictional reappraisal lowers the cardiac deceleration difference between negative and neutral stimuli (Mocaiber et al., 2011a, b). Nevertheless, its effect on skin-conductance response (SCR) remain unclear, as previous studies either did not directly compare fiction and reality conditions (Oliveira et al., 2009) or did not report significant differences between fiction and reality (Sperduti et al., 2017; Sperduti, Makowski, & Piolino, 2016b). Interestingly, the effect of fictional reappraisal has been shown to be modulated by the participants’ affective state (Mocaiber et al., 2009; Oliveira et al., 2009), their executive abilities (Sperduti et al., 2017), and the self-relevance of the stimuli (Sperduti et al., 2016a, b). It is important to note that these protocols were based on an implicit manipulation, designed to mimic real-world phenomena. Indeed, it is rather rare to see explicit use of fictional reappraisal (e.g., “I should regulate my emotions by thinking that what I see is fictitious”) in daily life. Most of the time, it takes the form of prior information that we have about our current experience (e.g., going to a movie theater, I know that what I am going to see is not real), leading us to adjust our reactions—or revise our expectations. Unfortunately, none of these studies controlled the level of belief in the experimental manipulation.

The core cognitive mechanism supporting fictional reappraisal is the one that discriminates between what is real and what is not, for which a more generic and neutral term than

“fiction” (referring to stories based on imaginary events) could be “simulation.” As such, the function of tagging the content of the experience as genuine or simulated can be referred to as simulation monitoring. This notion is to be distinguished from reality monitoring (more unambiguously referred to as source monitoring), a concept used in memory studies that covers the ability to decide whether a recollected information initially had an external or an internal source (Johnson, Hashtroudi, & Lindsay, 1993; Johnson & Raye, 1981). Instead, simulation monitoring deals with the nature of the experience: It covers the tagging of the content of an experience as genuine or simulated, and the adjustment to it. Although this mechanism could be considered as anecdotal until a few years ago, the exponential growth of technology urges psychological science to start exploring the cognitive features that will, tomorrow, be of critical importance. Through virtual and augmented reality, and new forms of fiction, simulations of all kinds will populate our everyday world, and distinguishing between the two, in order to adjust one’s behavior to their different implications and consequences, will withhold a major adaptive value.

A handful of neuroscientific works have explored the neural underpinning of the distinction between real and fictional events. These studies reported that appraising an event as fictional engaged the lateral prefrontal cortex and anterior cingulate cortex (Abraham, von Cramon, & Schubotz, 2008; Altmann, Bohrn, Lubrich, Menninghaus, & Jacobs, 2012; Metz-Lutz, Bressan, Heider, & Otzenberger, 2010), involved in cognitive control and ER (Ochsner & Gross, 2005; Ochsner, Silvers, & Buhle, 2012). On the other hand, reality engaged, to a greater extent, the cortical midline structures (Abraham et al., 2008; Han, Jiang, Humphreys, Zhou, & Cai, 2005; Hsu, Conrad, & Jacobs, 2014), known to be involved in autobiographical memory and self-referential processing (Martinelli, Sperduti, & Piolino, 2013; Northoff, 2005). While this network related to the Self modulates the emotional reactivity (Eippert et al., 2007; Herbert, Herbert, & Pauli, 2011; Yoshimura et al., 2009), it is unclear how the relationship between emotions and self-relevance interacts with simulation monitoring. For instance, Sperduti, Arcangeli, et al., (2016a) showed that high self-relevance increased the intensity of the emotional response, but also that this effect was independent of the reality (fictional or real) condition. However, self-reference was exclusively operationalized as the amount of autobiographical memory linked to the stimulus. This is important, as the Self is not a unitary system (Conway, Singer, & Tagini, 2004; Klein & Gangi, 2010; Prebble, Addis, & Tippett, 2013). The self-memory system model distinguishes between at least two levels of representations: a conceptual system, built upon generalized life experiences, values, and goals, and an autobiographical system, grounded in autobiographical episodic memories (Conway, 2005; Martinelli et al., 2013). Usual measures or modulations of self-relevance, including inquiry about how an item relates

to oneself (e.g., in case of adjectives), the amount of autobiographical memories elicited, or how a stimulus is relevant to one’s values, might indeed load specifically on different facets of the Self (Compère et al., 2016; Klein, Loftus, & Burton, 1989). Assessing different components of self-relevance might, thus, reveal new associations and interactions.

The main goal of this study was to investigate, through simultaneous multimodal recordings, the neural, bodily, and phenomenal changes induced by the appraisal of an emotional stimulus as simulation, and investigating the modulatory role of two facets of the Self: autobiographical and conceptual relevance. Using a procedure derived from our previous studies (Sperduti et al., 2016a, b; Sperduti et al., 2017), we presented realistic pictures as either simulation (fiction) or reality. To overcome limitations of previous studies (Mocaiber et al., 2009; Mocaiber et al., 2011a, b; Sperduti et al., 2016a, b), we assessed participants’ subjective belief regarding the nature of the stimulus in order to examine the effectiveness of experimental manipulation. Our hypotheses cover the experimental manipulation per se, its effect on emotion, and the relationship with self-relevance.

We expect that inherently realistic pictures will elicit higher adhesion (operationalized through a higher belief rate) when presented as real than when presented as simulations. However, we also posit that the judgment about the reality of the content experience is flexible, transient, and impermanent and can thus be easily modulated (resulting in a nonnegligible belief rate in the simulation condition). Moreover, we postulate that changes induced by simulation monitoring modulation are subordinate to subjective, nonautomatic, and slow cognitive elaboration. As such, objective components (physiological and neural responses) should be preferentially modulated by the objective (i.e., the experimentally attributed) condition (whether the picture was presented as real or as a simulation) while subjective components (the phenomenal experience) should be more dependent on the subjective elaboration of the condition (that includes whether the participant believed, or not, in the given context). Finally, we posit that simulation monitoring is a one-dimensional construct with two extremities: simulation and reality. If that is correct, a stimulus can either be appraised as one or the other (with varying degrees of certainty), implying that an item presented as real, and not believed to be so, will necessarily be appraised as simulation and vice versa.

Regarding emotions, we expect that presenting an emotional stimulus as simulation will have a down-regulatory effect on emotion (Mocaiber, Perikakis, et al., 2011a; Mocaiber et al., 2010; Sperduti, Arcangeli, et al., 2016a; Sperduti et al., 2017). However, the existing literature is unclear regarding the domain of action of fictional reappraisal. Indeed, while several studies have reported that presenting a stimulus as a simulation would decrease the subjective emotion experience (Sperduti, Arcangeli, et al., 2016a; Sperduti et al., 2017) and

the LPP (Mocaiber et al., 2009, 2010), a neural marker of emotional arousal (see Schupp et al., 2000), its effect on bodily signals remains controversial. Indeed, studies monitoring autonomic changes did not directly compare the simulation and reality conditions (Mocaiber et al., 2011a, b; Oliveira et al., 2009), and our own research group did not report any differences in electrodermal activity (Sperduti, Arcangel, et al., 2016a; Sperduti et al., 2017). To address the gap left open by those studies, we synchronously measured different emotion-related components, including neural (EEG) markers and bodily and phenomenal changes, expecting that simulation would mainly affect the phenomenal, conscious level of emotional experience and its neural correlate, the LPP, which has been shown to be responsive to comparable manipulations (Foti & Hajcak, 2008; Mocaiber, Perkakis, et al., 2011; Mocaiber et al., 2010), rather than the automatic autonomic responses such as heart rate or electrodermal activity.

Although the involvement of structures related to the Self was highlighted by fMRI studies on the distinction between reality and fiction (Abraham et al., 2008; Metz-Lutz et al., 2010), the role of processes related to the Self as modulators of the response toward fiction remain unclear. Previous research suggests that the emotional difference experienced toward reality and fiction is unaltered by autobiographical relevance (Sperduti et al., 2016a, b), but the impact of conceptual relevance has never been investigated. Therefore, we tried to replicate the previous results concerning the orthogonality of fiction and autobiographical relevance and looked for an interaction effect with conceptual relevance. Indeed, when engaging with fictional events to which our reactions have no “real”-world consequences, it can be assumed that there is less need to behave coherently with one’s values and goals. This cognitive state, favorable to impersonation and “plays,” might disconnect the influence of conceptual relevance. On the contrary, it is evolutionary plausible that the conceptual Self would preferably modulate the response toward real events, as their consequences are of “real” importance for adaptive survival.

## Method

### Participants

Thirty-five participants were recruited using Internet advertisement. Inclusion criteria were being between 18 and 29 years of age, right-handed, a native French-language speaker, and having no neurological or psychiatric disorders. Participants were warned that they might be exposed to emotional and shocking material and that they could withdraw anytime from the study. They were asked to provide informed and written consent and were given 25€ for their participation. Two participants were excluded, one because of technical

problem in the EEG recording and the other because of falling asleep. The final sample included 33 participants (age:  $24.14 \pm 2.67$  years, 78.79% ♀, years of superior education:  $3.00 \pm 1.89$ ). The study was approved by the local ethics committee of the Paris Descartes University.

### Protocol

Experimental sessions started at 1:30 p.m. in a sound-attenuated, dimly lit room. The task discussed in this study took place in the context of a broader protocol including questionnaires and neuropsychological tests. Tasks not relevant this current study will not be presented. Average duration, including participant briefing, electrophysiological setup preparation, tests, and debriefing was about 3 h.

### Materials

One hundred and twenty-eight pictures (64 negative and 64 neutral) were selected from the standardized, wide-range, high-quality, realistic Nencki Affective Picture System (NAPS; Marchewka, Żurawski, Jednoróg, & Grabowska, 2014). The stimuli were comparable in nature (all selected from the “faces” and “people” subcategories) and had diverse content (in particular, the negative items included pictures of mutilations, war images, diseases, car crashes, surgical operations, and natural disasters). Using the original validation ratings, the two sets of pictures (negative and neutral) statistically differed in terms of arousal ( $M_{\text{negative}} = 7.15 \pm 0.32$ ,  $M_{\text{neutral}} = 4.45 \pm 0.25$ ),  $t(126) = 52.77$ ,  $p < .001$ ; valence ( $M_{\text{negative}} = 2.42 \pm 0.54$ ,  $M_{\text{neutral}} = 5.82 \pm 0.33$ ),  $t(126) = -42.77$ ,  $p < .001$ ; approach/avoidance ( $M_{\text{negative}} = 2.74 \pm 0.90$ ,  $M_{\text{neutral}} = 5.63 \pm 0.35$ ),  $t(126) = -23.79$ ,  $p < .001$ ; but not in luminance ( $M_{\text{negative}} = 107.78 \pm 30.47$ ,  $M_{\text{neutral}} = 107.10 \pm 26.39$ ),  $t(126) = 0.13$ ,  $p > .05$ , or entropy (index of image complexity;  $M_{\text{negative}} = 7.54 \pm 0.34$ ,  $M_{\text{neutral}} = 7.60 \pm 0.27$ ),  $t(126) = -1.11$ ,  $p > .05$ .

### Procedure

Participants were tested on a 24-in. monitor ( $1920 \times 1080$ , 60 Hz) at a distance of 80 cm. The experiment was programmed in Python 3.5 using the Neuropsychia module (Makowski & Dutriaux, 2017). At the beginning of each session, the program randomly picked 96 images (48 in each emotion condition) out of the initial set. Each picture was randomly assigned to one of the two experimental conditions (“reality” or “simulation”), resulting in 24 pictures for each of the four combinations of emotion (neutral and negative) and condition. The 36 remaining stimuli were used as lures in a subsequent recognition task that is not discussed this study.

The task started with an instructions screen that also displayed the logo of the university, alongside the logo of



the European Film Academy. In order to amplify the credibility of the manipulation, the experimenter explained that this study was done in collaboration with this institute, taking interest in “the changes that might occur when we know that something is real or not.” It continued as follows:

The European Film Academy provided us with a database, where half were images extracted from documentaries or amateur pictures, representing real events and people, while the other half were images extracted from movies or pictures taken in studios or film sets. These include actors, movie props, stuntmen, movie makeup, or CGI and can be thus qualified as simulations. Before each picture, a cue, describing its nature, will be presented. The word *REAL* will be displayed when the content is genuine, while *SIMULATION* will indicate that the content is fictitious. Note that this information will be true most of the time. However, there might be a few cases where it won't. Therefore, after each picture, you will have to rate whether you believed in the given context or not.

This last instruction was meant to ensure that a picture for which the manipulation would be problematic (e.g., an obviously real picture coupled with the simulation context) would not cast doubt on the instructions or the trust in the experiment. Moreover, this transformed a passive manipulation into active, self-generated beliefs, as the participant explicitly had to state its opinion regarding the nature of the image, reinforcing its possible effect. Finally, the six scales assessing the emotional experience, self-relevance and subjective belief (see the Measures section) were introduced and explained to the participants.

This was followed by a training phase, consisting of four pictures selected from the GAPED database (Dan-Glauser & Scherer, 2011), containing credible examples of the real (H038: African child with burnings, and H106: tramps) and simulation (H123: movie-like image of an execution table, and H079: people wearing Ku Klux Klan outfits that could easily be disguised people) categories. The experimenter made sure that each subjective scale was understood.

The task structure was as follows (see Fig. 1): each trial started with a black fixation cross on a neutral grey screen (128, 128, 128 in RGB mode) with a randomly jittered duration (3–5 s). A cue (*REAL* or *SIMULATION*) was then displayed for 3 s. After another fixation cross (3–5 s), the picture was displayed for 3 s, followed by a gray screen (4 s). This stimulus presentation duration, shorter than in traditional ER studies, was chosen to preserve the response intuitiveness by minimizing the deep and elaborate analysis of pictures' details and images' features (such as view angle, focus and blur, image postediting) that might influence the participant's opinion.

Finally, six scales (see the Measures section), divided in three blocks assessing the emotional response (arousal, valence, and feeling of control), self-relevance (autobiographical and conceptual relevance), and simulation monitoring were displayed after each picture. To control for cross-contamination between measures, these three blocks were presented in a random order.

There was a short break (approx. 2 min) at the middle of the main task (also used to check the signal's recoding). Then, the protocol continued with several questionnaires and tests, and a recognition task took place at the end, requesting the participant to identify the pictures that were incidentally encoded. However, this task is not relevant for the current hypotheses and will thus not be discussed. The total experiment's duration was about 3 h (including neurophysiological equipment setup and postexperiment debriefing).

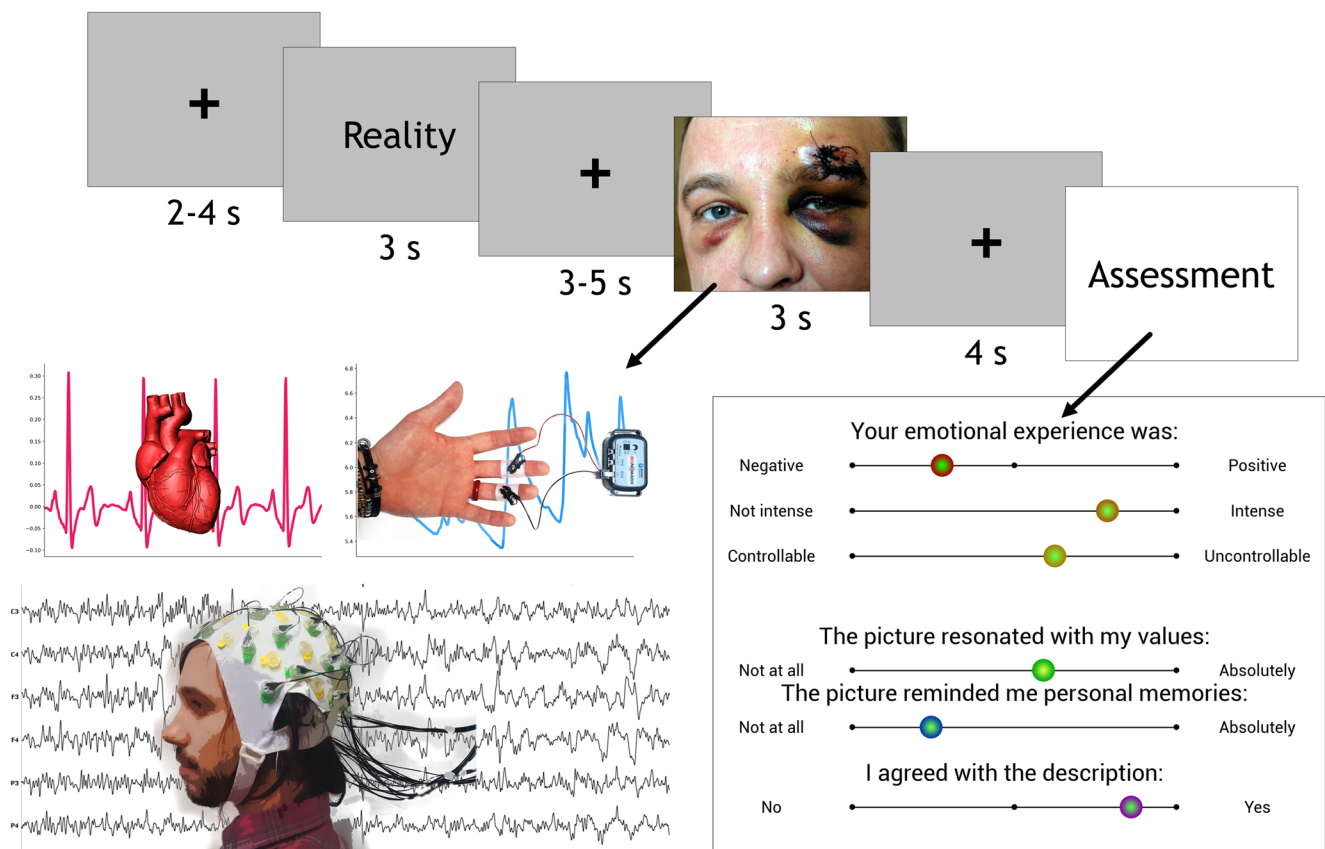
## Measures

### Phenomenal experience

Six behavioral variables were collected by visual analogue scales presented after each picture. As the scales axes were unmarked (aside from labeled extremities), the scores were normalized participant-wise to ensure homogeneity.

The emotional subjective response was assessed through three dimensions: arousal, valence, and feeling of control. Arousal was explained as “whether the emotion that you might have felt was intense or not” (with extremities labeled as *not intense* and *intense*). Valence attempted to capture “whether that emotion was rather positive and pleasant, or negative and unpleasant” (extremities: *negative* and *positive*). Finally, feeling of control was the subjective “amount of control that you felt toward that emotion. Whether you could easily control it or whether you got overwhelmed by it” (extremities: *controllable* and *uncontrollable*). However, to keep the paper concise, this last scale will not be discussed (but is included in the [Supplementary Materials](#)), as it showed the same pattern of results as arousal in all subsequent analyses.

Self-relevance was assessed through two dimensions: autobiographical relevance and conceptual relevance. The former was explained as “whether the content in the picture reminds you of an episode that you have personally experienced as an actor or an observer” (extremities: *not at all* and *absolutely*). Conceptual relevance was presented as the personal importance attributed to the picture's content (extremities: *not at all* or *absolutely*). The following example was given: “Some people are more or less involved in the animal cause. For the highly involved people, seeing pictures of animals under certain circumstances can be particularly important and generate particular feelings, as it echoes with their values.”



**Fig. 1** Implicit fictional reappraisal procedure. Ninety-six pictures, negative and neutral, were presented, cued by the experimental condition (reality/simulation). We recorded central and autonomic activity during stimulus presentation through EEG, ECG, and EDA. After each stimulus, we assessed features of the phenomenal

The last scale inquired about the participant's belief about the nature of the image, whether she thought the picture involved simulation or reality. The participant had to express its agreement with the description (extremities: *yes* and *no*). A central point was drawn on this scale, visually delimiting the *yes* and *no* answers. This scale was preferred to a more straightforward "personal opinion" scale (with *fiction* and *reality* as extremities) as it underlines the importance, for the participant, to pay attention to the visual cue. A simulation-monitoring index was created by orienting the belief scores condition-wise (i.e., the *yes* extremity was replaced by the cued condition and the *no* extremity by the remaining condition). Finally, the center-based dichotomization of the simulation-monitoring index led to the "subjective condition" factor (reality/simulation), used for further comparison with the "objective condition."

### Bodily signals

**Signal acquisition** Electrodermal (EDA) and cardiac (ECG) activity was recorded using Biopac MP150 system (Biopac Systems Inc., USA) and the AcqKnowledge Software 4.3

experience, such as the arousal, the valence, the self-relevance, and the degree of belief toward the condition. To control for cross-contamination between measures, the visual scales were presented by group in a random order. (Color figure online)

with a sampling frequency of 1000 Hz. EDA was measured using two Ag/AgCl electrodes attached to the intermediate phalanx of the index and ring fingers of the nondominant hand. To maximize the QRS signal, ECG electrodes were placed according to a modified Lead II configuration (Takuma et al., 1995), on the right and left subclavicular spaces (the deltopectoral fossae) and on the left lower rib. About 5 min of activity was recorded before starting the experiment to allow participants to adapt to the recording equipment, and to allow EDA levels to stabilize (Fowles et al., 1981). Event timings were also recorded by Biopac using a photosensor attached to a corner of the screen that sent a trigger whenever a small rectangle turned to black at the precise onset of each stimulus.

**Signal processing** Bodily signals processing was carried out using the NeuroKit package (Makowski, 2017). EDA signal was first normalized, downsampled to 100 Hz, then processed using the new cvxEDA algorithm based on convex optimization (Greco, Valenza, Lanata, Scilingo, & Citi, 2016). The ECG signal was FIR bandpass filtered (3–45 Hz, third order), and R peaks were identified using Hamilton's (2002)

segmenter. Next, R-R intervals were computed, and artifacts (including ectopic beats) were detected by physiological and statistical methods (see NeuroKit's *ecg\_hrv()* function). The signal was submitted to cubic spline interpolation and transformed into heart rate.

**Computed features** The phasic component of EDA was used to identify event-related skin-conductance responses (SCRs), of which onsets and subsequent peaks were in a 1–7-s post-stimulus window. The SCR magnitude was log transformed to approach a normal distribution (Braithwaite, Watson, Jones, & Rowe, 2013). The baseline heart rate was computed on the 3 s preceding each stimulus, and the heart-rate difference was computed by subtracting the mean heart rate on a 3-s post-stimulus onset window from the baseline.

## EEG

**Signal acquisition** EEG data were collected from 64 scalp sites using recording caps (EasyCap GmbH, Germany) based on the 10–20 international system. The EEG was amplified using a 64-channel BrainAmp amplifier (Brain Products GmbH, Munich, Germany) and sampled at 1000 Hz. The signal was recorded using a right mastoid reference electrode. Horizontal and vertical electrooculograms (HEOG and VEOG) were used to measure eye movements and detect eye blinks. Impedance was kept below 5 k $\Omega$  throughout the task with three correction phases: at the session's beginning, during the training phase, and during a pause at the middle of the main task. As for bodily signals, stimuli's actual display timings were recorded alongside the EEG with BrainVision Recorder 1.21, using a photosensor, ensuring the highest standards quality in terms of precision.

**Signal processing** EEG signal processing was carried out using Python packages MNE (Gramfort et al., 2013, 2014) and NeuroKit (Makowski, 2017). Data were rereferenced to mastoid electrodes (TP9–TP10), band-pass filtered (1–30 Hz), and downsampled to 250 Hz. Stimulus-synchronized epochs were extracted from 250 ms before to 30,00 ms after picture onset and baseline corrected. Next, epochs containing bad signal were automatically detected, then repaired or discarded (16.3%) using the newly developed *autoreject* algorithm (Jas, Engemann, Bekhti, Raimondo, & Gramfort, 2017). The number of rejected epochs did not differ between experimental conditions (see the [Supplementary Materials](#)). Finally, all sets were corrected for eye-blink artifacts by applying ICA.

**Computed features** Based on a large body of prior research (Cuthbert, Schupp, Bradley, Birbaumer, & Lang, 2000; Hajcak & Nieuwenhuis, 2006; Keil et al., 2002; Schupp et al., 2000), the LPP was quantified trial-wise as the mean activity of centroparietal electrodes (CP1, CP2, CP3, CP4,

CP5, CP6, CPz) in a window between 400 ms and 700 ms after stimulus onset (T. P. Moran, Jendrusina, & Moser, 2013; Pastor et al., 2008).

## Data analysis

Statistics were done using R (Version 3.4.1; R Development Core Team, 2008). As we decided to present a Bayesian version of the statistical models in the paper, the frequentist equivalent, as well as more details regarding the current analysis, can be found in the [Supplementary Materials](#).

## Bayesian mixed models

The mixed-modeling framework allows estimated effects to vary by group at lower levels while estimating population-level effects through the specification of fixed (explanatory variables) and random (variance components) effects. Outperforming traditional procedures such as repeated-measures ANOVAs (Kristensen & Hansen, 2004), these models are particularly suited to cases in which experimental stimuli are heterogeneous (e.g., images), as the item-related variance, in addition to the variance induced by participants, can be accounted for (Baayen, Davidson, & Bates, 2008; Magezi, 2015). Moreover, mixed models can handle unbalanced data, nested designs, crossed random effects, and missing data. However, maximum likelihood estimation of the parameters tends to underestimate uncertainties and overfit the data. More broadly, the frequentist approach has been associated with the focus on null hypothesis testing, and the misuse of *p* values has been shown to critically contribute to the reproducibility crisis of psychological science (Chambers, Feredoes, Muthukumaraswamy, Suresh, & Etchells, 2014; Szucs & Ioannidis, 2016). There is a general agreement that the generalization of the Bayesian approach is a way of overcoming these issues (Etz & Vandekerckhove, 2016). Beyond these methodological benefits, reasons to prefer this approach are better accuracy in noisy data, the possibility of introducing prior knowledge into the analysis, and, critically, results intuitiveness and their straightforward interpretation (Kruschke, 2011; Kruschke, Aguinis, & Joo, 2012; Wagenmakers et al., 2018).

Full Bayesian mixed linear models were fitted using the *rstanarm* R wrapper for the *stan* probabilistic language (Gabry & Goodrich, 2016), and their interpretation was carried out with the *psycho* package (Makowski, 2018b). Bayesian inference was done using Markov Chain Monte Carlo (MCMC) sampling. The prior distributions of all effects were set as weakly informative (normal distributions;  $M = 0$ ,  $SD = 1$ ), meaning that we did not expect effects different from null in any particular direction. For all our models (unless specified), we entered random intercepts for the participants

(to account for interindividual variability), the items (to account for item specificities), and the trial number (ranging from 1 to 96) to account for possible effects of redundancy, exposition, habituation and fatigue. For each model and each coefficient, we will present several characteristics of the posterior distribution, such as its median (a robust estimate comparable with the beta from frequentist linear models), MAD (median absolute deviation, a robust equivalent of standard deviation), and the 95% credible interval. Instead of the  $p$  value as an index of effect existence, we also computed the maximum probability of effect (MPE), that is, the maximum probability that the effect is different from zero in the median's direction (if 100%, we returned the 100% instead of the 95% CI). Overall, an effect was considered as inconsistent if its maximum probability (MPE) was lower than 95% (Makowski, 2018a). The frequentist version (mixed models) of all our analysis (that, in our case, returns similar results) is available in the [Supplementary Materials](#).

Finally, all outcome variables, unless specified, were standardized, so that the coefficients drawn from the different models are equivalent in many ways to Cohen's  $d$  (in particular, they are expressed in terms of standard deviations). This opens up the possibility of using Cohen's (1977) heuristics for effect size interpretation (very large  $>1.3$ ; large  $>0.8$ ; medium  $>0.5$ ; small  $>0.2$ ; very small  $<0.2$ ). As Bayesian analysis returns the actual probability distribution of the coefficients, it is therefore possible to compute the probability associated with each effect size.

## Model selection

We made the hypothesis that objective physiological components change might be better explained by the objective condition (tight to the cue displaying whether the subsequent picture was reality or simulation), while some late components (such as the phenomenal experience) will be better explained by the subjective condition (the participant's belief about the picture's nature). Comparing models with the objective condition versus the subjective condition as predictor and seeing which one better fits the data is a way of answering that proposition. We also made the hypothesis that simulation monitoring was unidimensional. This is the equivalent, in this study, of saying that items presented as one category, but nonbelieved, elicit the same changes that items presented as the other category, and believed to be so. If that is not the case, adding the belief factor (believed vs. nonbelieved) should increase its data-fitting aptitude, leading it to outperform other models.

With the aim of validating our model, we compared the predictive power of three models to explain each outcome variables. For that, we will use leave-one-out (LOO) cross-validation (Vehtari, Gelman, & Gabry, 2017), a comparable yet superior to AIC-like formulas (Gelman, Hwang, &

Vehtari, 2014). We will return the expected log point-wise predictive density (ELPD) and the LOO information criterion (LOOIC) of the best model and respective differences of the two other models. Similarly, to the AIC and the BIC, the model with the smallest absolute indices is preferred. All indices are summarized in Table 1.

For each outcome variable, models with either the objective condition as predictor (objective model), the subjective condition (subjective model), or the objective condition associated with the belief factor (belief model) will be compared. Other predictors (the emotion condition), random effects and priors, are unchanged. We will then describe and interpret the model that best explain the data.

## Model interpretation

The statistics of this paper are built upon two types of models, one predicting main outcome variables with two predictors (emotion [negative/neutral], reality/simulation condition (either objective or subjective, depending of the best model). The second type will add to those models linear covariates (autobiographical and conceptual relevance) to see their influence on the effect of simulation. We expect, indeed, that the variations induced by the fact that an item is presented or perceived as simulation will be either amplified or weakened by these covariates.

Multiple linear regression outputs' description and interpretation can be challenging. Throughout the paper, most of models will have a  $2 \times 2$  level structure of categorical predictors (negative/neutral vs. reality/simulation). Our baseline condition (referred to as the intercept) is reality-neutral. We will focus on three coefficients: the *emotion effect in reality* (the change from reality-neutral to reality-negative), the *simulation effect for neutral* pictures (the change from reality-neutral to simulation-neutral) and the *simulation effect for negative pictures* (the change from reality-negative to simulation-negative). The fourth coefficient, the *emotion effect in*

**Table 1** Model selection

Outcome	Objective	Subjective	Belief
Arousal	7768.43/–3884.22	<b>7729.28/–3864.64</b>	7739.99/–3869.99
Valence	5761.84/–2880.92	<b>5743.75/–2871.88</b>	5745.09/–2872.54
SCR	<b>8727.25/–4363.63</b>	8732.54/–4366.27	8730.12/–4365.06
Heart rate	8578.16/–4289.08	<b>8577.74/–4288.87</b>	8581.18/–4290.59
LPP	<b>5437.32/–2718.66</b>	5448.61/–2724.31	5445.99/–2723

*Note.* For each outcome variable, models with either the objective condition as predictor (Objective), the subjective condition (Subjective), or the objective condition associated with the belief factor (Belief) were compared using leave-one-out (LOO) cross-validation. Cells contain the LOO information criterion (LOOIC) and the expected log point-wise predictive density (ELPD). Bold results indicate the smallest absolute indices, and thus the model that better fits the data. SCR = skin conductance response



*simulation* (the change from simulation-neutral to simulation-negative) was also computed by changing the reference levels of the model.

In the last part, in order to see how self-relevance influences the previous effects, we will iteratively add its features to the previous models. This will estimate the parametric modulation of the outcome  $Y$ , in each condition, according to variations of a new variable  $X$ . All models' full description can be found in the [Supplementary Materials](#). However, to concisely answer our hypotheses and increase the clarity and readability of the Results section, we will only report two effects: the slope (the correlation) between  $X$  and  $Y$  in the reality condition (our reference level) and the modulation of this slope (the interaction) created by the simulation condition. These two effects allow us to answer whether higher scores of  $X$  modulates the difference between simulation and reality (in case the interaction effect is probable), and whether this modulation is caused by augmentation or reduction in either one or both conditions.

## Manipulation check

The first part of the Results section will focus on testing whether the experimental manipulation succeeded. In our study, manipulation check consists in showing that our manipulation induced effective changes in simulation monitoring, meaning that the experimental condition (reality or simulation) induced the corresponding modulation on the simulation-monitoring scale. Then, we will investigate the importance of the belief rate to see if simple instructions put on top of realistic pictures can consistently induce simulation-monitoring changes. The second part will systematically test the effect of simulation on each outcome for the best model,

and the last part will investigate the modulatory role of self-relevance. Additional (post hoc) analysis investigating the role of heart-rate variability on subjective belief (see Discussion section) are presented in [Supplementary Materials 2](#).

## Results

### Inducing simulation monitoring changes

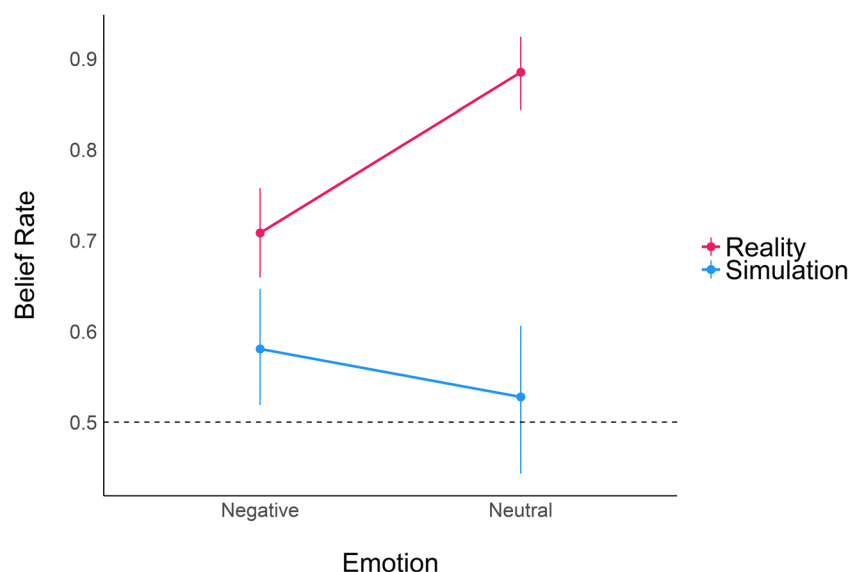
#### Simulation monitoring

We fitted a Bayesian mixed model to predict simulation monitoring, with the *objective condition* as unique predictor. Lower and higher scores indicate, respectively, “reality” and “simulation.” The intercept, corresponding to the reality condition, was  $-0.39$  ( $MAD = 0.036$ , 100% CI  $[-0.49, -0.26]$ ). Compared with it, there is a probability of 100% that the simulation condition led to an increase between 0.68 and 0.87 (median = 0.77,  $MAD = 0.031$ ). There is a probability of 81.33% that this effect size is medium and 18.67% that this effect size is large.

#### Belief rate

Data were grouped by participants, objective condition, and emotion, and the belief rate (number of “believed” answers in each category) was computed. The average belief rate ( $0.68 \pm 0.22$ ) was significantly higher than 0.5,  $t(32) = 8.95$ ,  $p < .001$ .

We fitted a Bayesian mixed model to predict the belief rate, with the objective condition and the emotion as predictors (see [Fig. 2](#)). We entered participants as a unique random factor.



**Fig. 2** The belief rate (i.e., percentage of believed descriptions) for negative and neutral pictures, depending on the objective condition. (Color figure online)

Within this model, the intercept (reality-neutral) was 0.87 (MAD = 0.028, 100% CI [0.77, 0.97]). Compared with that, there is a probability of 100% that the negative emotion, for the reality condition, led to a decrease of belief rate between  $-0.28$  and  $-0.051$  (median =  $-0.17$ , MAD = 0.032). The simulation effect in neutral was, with 100% of probability, between  $-0.48$  and  $-0.23$  (median =  $-0.35$ , MAD = 0.031). The simulation effect in negative was, with 100% of probability, between  $-0.24$  and  $-0.01$  (median =  $-0.13$ , MAD = 0.035). Finally, the negative emotion effect in simulation was superior to zero with only 75.7% of probability (median = 0.048, MAD = 0.033, 95% CI [ $-0.021$ , 0.11]).

## The effect of simulation monitoring

All effects are summarized in Table 2 and Fig. 3.

### Phenomenal experience

**Arousal** LOO cross-validation showed that the subjective model (LOOIC = 7729.28, ELPD =  $-3864.64$ ) outperformed the belief model ( $d_{\text{LOOIC}} = 10.71$ ,  $d_{\text{ELPD}} = -5.35$ ) and the objective model ( $d_{\text{LOOIC}} = 39.15$ – $19.58$ ,  $d_{\text{ELPD}} = -19.58$ ). Within this model, the intercept (reality-neutral) was  $-0.45$  (MAD = 0.046, 100% CI [ $-0.59$ ,  $-0.29$ ]). Compared with that, there is a probability of 100% that the emotion led, in the reality condition, to an increase of arousal between 0.81 and 1.27 (median = 1.05, MAD = 0.068). This effect is large with a probability of 100%. The simulation effect in neutral led, with 100% of probability, to a decrease of arousal between  $-0.31$  and  $-0.012$  (median =  $-0.15$ , MAD = 0.045). This effect is small or very small with respective probabilities of 10.80% and 89.20%. The simulation effect in negative led, with 100% of probability, to a decrease of arousal between  $-0.40$  and  $-0.13$  (median =  $-0.25$ , MAD = 0.043). This effect is small or very small with respective probabilities of 89.47% and 10.53%. Finally, the emotion effect in simulation led, with 100% of probability, to an increase of arousal between 0.70 and 1.17 (median = 0.94, MAD = 0.072). This effect is large

or medium with respective probabilities of 97.53% and 2.47%.

**Valence** LOO cross-validation showed that the subjective model (LOOIC = 5743.75, ELPD =  $-2871.88$ ) outperformed the belief model ( $d_{\text{LOOIC}} = 1.34$ ,  $d_{\text{ELPD}} = -0.66$ ) and the objective model ( $d_{\text{LOOIC}} = 18.09$ ,  $d_{\text{ELPD}} = -9.04$ ). Within this model, the intercept (reality-neutral) was 0.78 (MAD = 0.040, 100% CI [0.64, 0.92]). Compared with that, there is a probability of 100% that the negative emotion led, in the reality condition, to a decrease of valence between  $-1.79$  and  $-1.42$  (median =  $-1.61$ , MAD = 0.056). This effect is very large with a probability of 100%. The simulation effect in neutral led, with a probability of 96.93%, to a decrease of valence between  $-0.18$  and zero (median =  $-0.062$ , MAD = 0.032, 95% CI [ $-0.13$ ,  $-0.0037$ ]). This effect is very small or opposite with respective probabilities of 96.93% and 3.07%. The simulation effect in negative led, with a probability of 100%, to an increase of valence between 0.061 and 0.25 (median = 0.15, MAD = 0.032). This effect is small or very small with respective probabilities of 6.20% and 93.80%. Finally, the emotion effect in simulation led, with 100% of probability, to a decrease of valence between  $-1.59$  and  $-1.16$  (median =  $-1.39$ , MAD = 0.064). This effect is very large or large with respective probabilities of 91.40% and 8.60%.

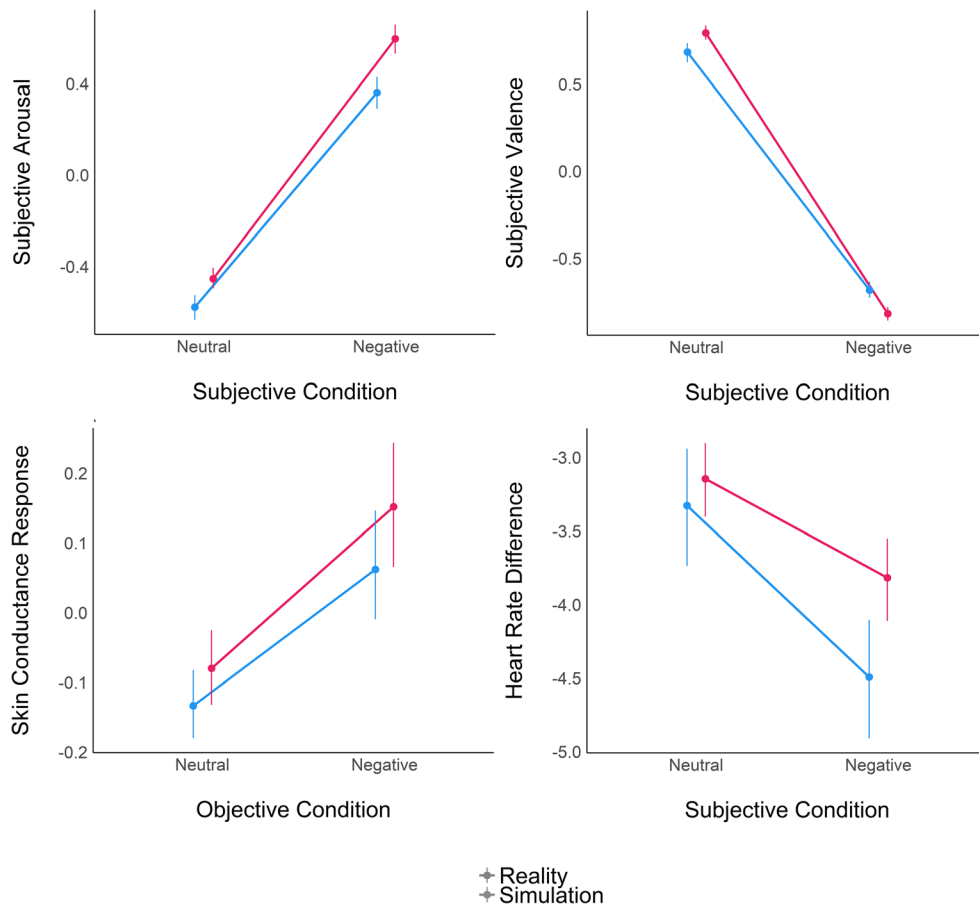
### Bodily signals

**Skin-conductance response (SCR)** LOO cross-validation showed that the objective model (LOOIC = 8727.25, ELPD =  $-4363.63$ ) outperformed the belief model ( $d_{\text{LOOIC}} = 2.87$ ,  $d_{\text{ELPD}} = -1.43$ ) and the subjective model ( $d_{\text{LOOIC}} = 5.29$ ,  $d_{\text{ELPD}} = -2.64$ ). Within this model, the intercept (reality-neutral) was  $-0.079$  (MAD = 0.064, 95% CI [ $-0.20$ , 0.058]). Compared with that, there is a probability of 100% that the negative emotion led, in the reality condition, to an increase of SCR magnitude between 0.033 and 0.42 (median = 0.23, MAD = 0.055). This effect is small or very small with respective probabilities of 73.07% and 26.93%. The simulation effect in neutral led, with a probability of 86.13%, to a

**Table 2** Main effects

Outcome	Model	Reality: Neutral → Negative	Simulation: Neutral → Negative	Negative: Reality → Simulation	Neutral: Reality → Simulation
Arousal	Subjective	1.05 (100%)	0.94 (100%)	$-0.25$ (100%)	$-0.15$ (100%)
Valence	Subjective	$-1.61$ (100%)	$-1.39$ (100%)	0.15 (100%)	$-0.062$ (96.93%)
SCR	Objective	0.23 (100%)	0.20 (100%)	$-0.093$ (97.47%)	$-0.054$ (86.13%)
Heart rate	Subjective	$-0.68$ (100%)	$-1.21$ (100%)	$-0.56$ (99.27%)	$-0.025$ (54.80%)
LPP	Objective	0.19 (100%)	0.035 (81.20%)	$-0.10$ (99.80%)	0.05 (93.67%)

*Note.* Values include the effect median as well as the maximum probability that the effect is in the same direction than the median. Apart from heart-rate variation coefficients (which unit is BPM), all other effects are standardized coefficients. SCR = skin conductance response; LPP = late positive potential



**Fig. 3** Effect of the reality condition (objective, i.e., as presented by the experimental cue or subjective, i.e., as believed by the participant) on arousal, valence, skin conductance response (expressed in standard deviations), and heart rate difference (expressed in bpm change compared with baseline). Error bars represent bootstrapped 95%

confidence interval. Note that these plots do not take into account the variability induced by random factors, thus not representing, with perfect fidelity, the models described in the Results section. (Color figure online)

decrease of SCR magnitude between  $-0.21$  and zero (median =  $-0.054$ , MAD =  $0.046$ , 95% CI [ $-0.15$ ,  $0.034$ ]). This effect is small, very small, or opposite with respective probabilities of 0.13%, 86%, and 13.87%. The simulation effect in negative led, with a probability of 97.47%, to a decrease of SCR magnitude between  $-0.23$  and zero (median =  $-0.093$ , MAD =  $0.048$ , 95% CI [ $-0.19$ ,  $-0.0069$ ]). This effect is small, very small, or opposite with respective probabilities of 0.93%, 96.53%, and 2.53%. Finally, the emotion effect in simulation led, with 100% of probability, to an increase of SCR magnitude between  $0.032$  and  $0.37$  (median =  $0.20$ , MAD =  $0.051$ ). This effect is small or very small with respective probabilities of 47.80% and 52.20%.

**Heart rate** LOO cross-validation showed that the subjective model (LOOIC = 8577.74, ELPD =  $-4288.87$ ) outperformed the objective model ( $d_{\text{LOOIC}} = 0.42$ ,  $d_{\text{ELPD}} = -0.21$ ) and the belief model ( $d_{\text{LOOIC}} = 3.44$ ,  $d_{\text{ELPD}} = -1.72$ ). Note that, for interpretation purposes, the parameters were obtained on a nonstandardized version of the variable (expressed in BPM

differences with baseline). The outcome was then standardized and the model refitted to compute effect sizes. Within this model, the intercept (reality-neutral) was  $-3.22$  (MAD =  $0.31$ , 100% CI [ $-4.22$ ,  $-1.97$ ]). Compared with that, there is a probability of 100% that the negative emotion led, in the reality condition, to a stronger heart-rate deceleration, between  $-1.52$  and  $-0.044$  (median =  $-0.68$ , MAD =  $0.20$ ). This effect is small or very small with respective probabilities of 10.80% and 89.20%. The simulation effect in neutral led, with a probability of only 54.80%, to a stronger heart-rate deceleration, between  $-0.91$  and zero (median =  $-0.025$ , MAD =  $0.24$ , 95% CI [ $-0.52$ ,  $0.46$ ]). This effect is very small or opposite with respective probabilities of 54.80% and 45.20%. The simulation effect in negative led, with a probability of 99.27%, to a stronger heart-rate deceleration, between  $-1.32$  and zero (median =  $-0.56$ , MAD =  $0.22$ , 95% CI [ $-0.99$ ,  $-0.12$ ]). This effect is small, very small, or opposite with respective probabilities of 5.13%, 94.14%, and 0.73%. Finally, the emotion effect in simulation led, with 100% of probability, to a stronger heart-rate deceleration, between  $-2.09$  and  $-0.41$  (median =

−1.21, MAD = 0.25). This effect is small or very small with respective probabilities of 86% and 14%.

## EEG

**Late positive potential (LPP)** LOO cross-validation showed that the objective model ( $LOOIC = 5437.32$ ,  $ELPD = -2718.66$ ) outperformed the belief model ( $d_{LOOIC} = 8.67$ ,  $d_{ELPD} = -4.34$ ) and the subjective model ( $d_{LOOIC} = 11.29$ ,  $d_{ELPD} = -5.65$ ). Within this model, the intercept (reality-neutral) was −0.14 (MAD = 0.15, 95% CI [−0.42, 0.14]). Compared with that, there is a probability of 100% that the negative emotion led, in the reality condition, to a higher LPP amplitude, between 0.034 and 0.33 (median = 0.19, MAD = 0.039). This effect is small or very small with respective probabilities of 39.07% and 60.93%. The simulation effect in neutral led, with a probability of 93.67%, to a higher LPP amplitude, between zero and 0.15 (median = 0.050, MAD = 0.036, 95% CI [−0.014, 0.12]). This effect is very small or opposite with respective probabilities of 93.67% and 6.33%. The simulation effect in negative led, with a probability of 99.80%, to a lower LPP amplitude, between −0.24 and zero (median = −0.10, MAD = 0.034, 95% CI [−0.18, −0.039]). This effect is small, very small or opposite with respective probabilities of 0.53%, 99.27%, and 0.20%. Finally, the emotion effect in

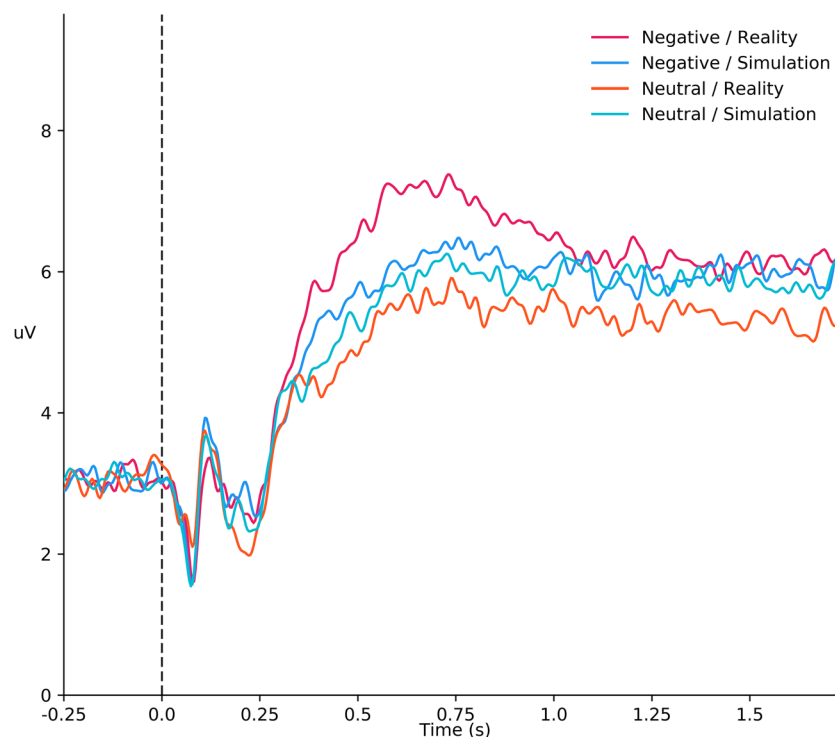
simulation led, with only 81.20% of probability, to a higher LPP amplitude, between zero and 0.17 (median = 0.035, MAD = 0.039, 95% CI [−0.043, 0.12]). This effect is very small or opposite with respective probabilities of 81.20% and 18.80%. See Fig. 4.

## Impact of self-relevance

In this part, the two self-relevance variables will successively be added to the best model explaining each of the outcomes presented above, to see how they modulate them in the negative condition (see Fig. 5).

**Autobiographical relevance** Autobiographical relevance is positively linked to subjective arousal in the reality condition (median = 0.064, MAD = 0.032, 95% CI [−0.004, 0.13], MPE = 96.87%). This relationship is not modulated by the simulation condition (median = 0.013, MAD = 0.050, 95% CI [−0.085, 0.11], MPE = 60.67%).

Autobiographical relevance is positively linked to subjective valence in the reality condition (median = 0.05, MAD = 0.024, 95% CI [0, 0.097], MPE = 97.47%). This relationship is decreased by the simulation condition (median = −0.069, MAD = 0.037, 95% CI [−0.15, −0.0039], MPE = 97.47%). In other words, autobiographical relevance diminishes the difference of valence between reality and simulation.



**Fig. 4** Evoked activity for the centroparietal sensors, depending on the objective condition extracted for a time window extending between 250 ms before and 1750 ms after stimuli onset. We showed an

attenuation of the late positive potential, extracted as the average activity in the 400–700 ms window, compared with the negative–reality condition. (Color figure online)



Autobiographical relevance is positively linked to skin conductance response magnitude in the reality condition (median = 0.065, MAD = 0.041, 95% CI [-0.015, 0.15], MPE = 95.27%). This relationship is not modulated by the simulation condition (median = 0.036, MAD = 0.058, 95% CI [-0.081, 0.14], MPE = 70.93%).

Autobiographical relevance was not linked, with enough certainty, to heart-rate difference in the reality condition (median = 0.22, MAD = 0.18, 95% CI [-0.15, 0.57], MPE = 86.53%). This was not modulated by the simulation condition (median = -0.048, MAD = 0.27, 95% CI [-0.6, 0.5], MPE = 57.73%).

Autobiographical relevance was not linked to the LPP amplitude in the reality condition (median = -0.0094, MAD = 0.03, 95% CI [-0.069, 0.055], MPE = 62.27%). This was not modulated by the simulation condition (median = -0.011, MAD = 0.043, 95% CI [-0.098, 0.075], MPE = 60%).

**Conceptual relevance** Conceptual relevance is positively linked to subjective arousal in the reality condition (median = 0.28, MAD = 0.028, 95% CI [0.22, 0.34], MPE = 100%). This relationship is not modulated by the simulation condition (median = -0.024, MAD = 0.041, 95% CI [-0.11, 0.058], MPE = 71.47%).

Conceptual relevance is positively linked to subjective valence in the reality condition (median = -0.13, MAD = 0.021, 95% CI [-0.17, -0.087], MPE = 100%). This relationship is not modulated by the simulation condition (median = -0.018, MAD = 0.029, 95% CI [-0.079, 0.043], MPE = 74.93%).

Conceptual relevance is, with moderate certainty, positively linked to skin conductance response magnitude in the reality condition (median = 0.056, MAD = 0.037, 95% CI [-0.015, 0.13], MPE = 93.87%). This relationship is, with moderate certainty, decreased by the simulation condition (median = -0.073, MAD = 0.048, 95% CI [-0.17, 0.02], MPE = 92.47%). In other words, conceptual relevance increases the difference of SCR between reality and simulation.

Conceptual relevance was not linked, with enough certainty, to heart-rate deceleration in the reality condition (median = -0.15, MAD = 0.15, 95% CI [-0.46, 0.16], MPE = 83.73%). However, this possible effect was, with moderate certainty, modulated by the simulation condition (median = 0.35, MAD = 0.24, 95% CI [-0.14, 0.8], MPE = 92.20%). In other words, conceptual relevance diminishes, with moderate certainty, the difference of heart-rate deceleration between reality and simulation.

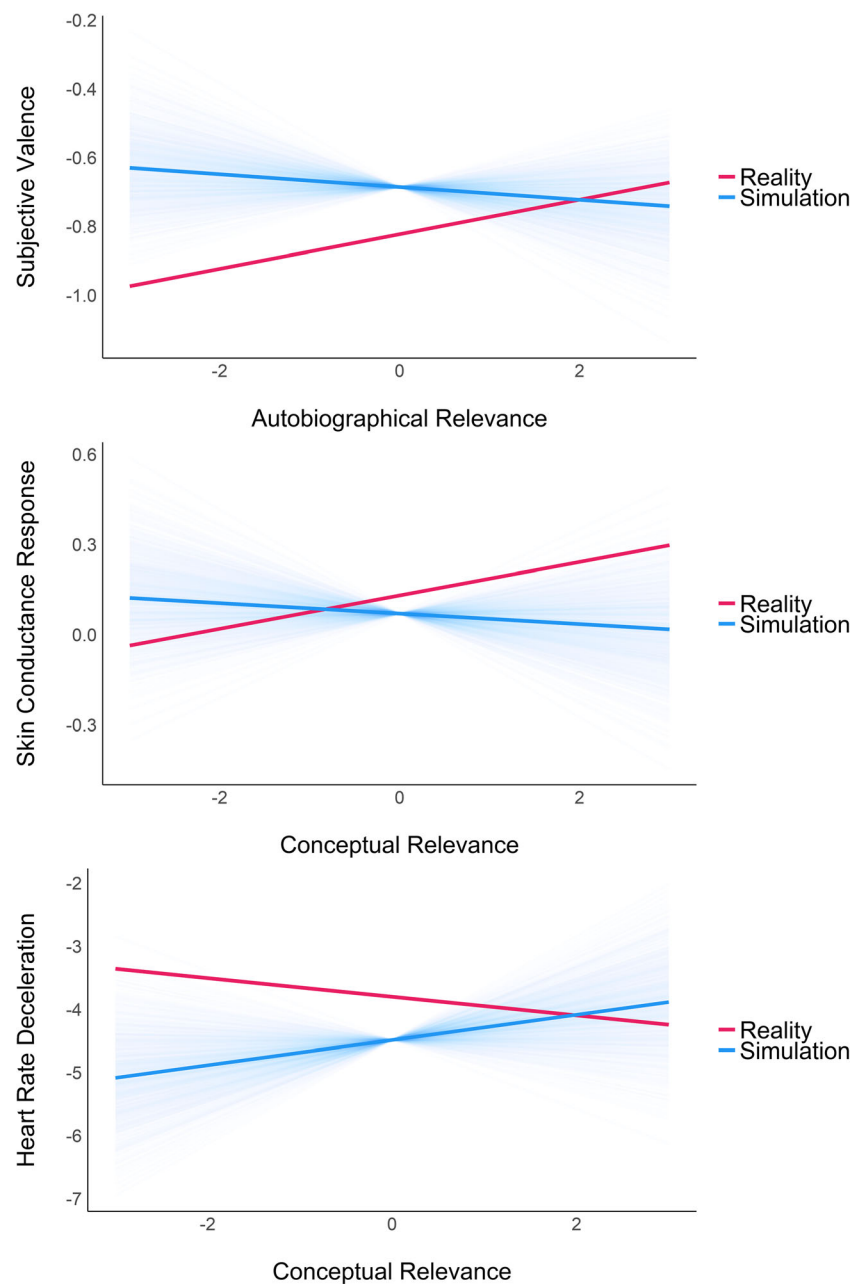
Conceptual relevance was not linked, with enough certainty, to the LPP amplitude in the reality condition (median = 0.033, MAD = 0.028, 95% CI [-0.024, 0.086], MPE = 87.67%). This was not modulated by the simulation condition (median = -0.021, MAD = 0.038, 95% CI [-0.096, 0.051], MPE = 71.40%).

## Discussion

The main aim of this study was to investigate the effect of fictional reappraisal on different components of emotion, as well as on the modulatory role of two facets of self-relevance. While recording brain and bod activity through EEG, EDA, and ECG, we presented negative and neutral pictures to participants, presenting them as either depicting real or simulated (i.e., involving, for instance, actors, makeup, props, CGI) events. We also monitored features of the participant's subjective experience, such as arousal, valence and his or her belief in the given description. Through Bayesian analyses that allowed us to neatly delineate between the probability of existence, direction, and importance of an effect, we showed that engagement in simulations acted as an ER mechanism, attenuating most of the components of the emotional experience, an effect that selectively interacted with facets of self-relevance. Critically, the measure of the subjective belief about the nature of the stimulus gave us a feedback on our experimental manipulation, allowing us to explore the actual effect of presenting a realistic stimulus as a simulation. Did the participant effectively adhere to the cue, believing that the content of their experience is not real, but a mere simulation of reality?

Simulations will become more and more common as technological advances continue to grow. And yet they are relatively recent. Mankind has long struggled with little more than dreams and imagination to escape unforgiving reality, where actions can have major survival-impacting consequences. This evolutionary view, suggesting that our brain is preferably and naturally tuned toward, or disposed to, experience, reality might withhold a key to the paradox of fiction (Radford & Weston, 1975), which seeks to explain why we experience emotions toward events and characters that we know do not exist. However, it renders counterintuitive the postulate that triggering simulation beliefs toward realistic material is easy. Contrary to other studies using a comparable procedure (Mocaiber et al., 2010; Sperduti et al., 2016a, b), we recorded the participant's belief toward the given context. Unsurprisingly, presenting realistic stimuli as real induced a higher belief rate than presenting them as simulations, in which the belief rate remained above 50%. Although showing that more than one of two stimuli was accepted as simulation is satisfying for our hypothesis (positing that simulation induction can be possible), it underlines the importance of measuring the belief component in future studies, as the noncomplete adherence to instructions might shadow the observations.

Interestingly, the simple fact that the pictures presented as reality were emotional significantly decreased the belief rate (i.e., most of them were considered as simulations). One possibility is that works of fiction (movies, stories) imply, most of the time, an emotional component. Therefore, as fiction and emotion are connected in



**Fig. 5** Interaction between simulation and the relationship between facets of self-relevance and subjective valence, skin conductance response, and heart rate deceleration in the negative condition. The red line represents the median value of the relationship between the outcome and the

covariate in the reality condition. Compared with that, the relationship in the simulation condition is represented by the blue lines (the bold line represents the effect's median, and transparent lines are all the possible effects based on the posterior distribution). (Color figure online)

everyday life, a simple process of classical conditioning might explain the tendency to classify emotional stimuli as simulations. Yet the literature taking interest in the concept of *presence* (the feeling of being located in the current experience and responding to it as if it was real) showed that emotions tend to increase the feeling of reality, rather than decreasing it (Baños et al., 2004; Baños et al., 2008; Makowski, Sperduti, Nicolas, & Piolino, 2017; Riva et al., 2007; Västfjäll, 2003). This apparent contradiction might

be better explained by the context of ER. As negative pictures were unpleasant and enjoyment from them hard to find, participants might have used fictional reappraisal spontaneously, as the general instructions were compatible with that option (i.e., they were told that a small portion of the descriptions would not be true). Based on the literature showing that engagement in spontaneous ER is associated with cognitive control abilities (Gyurak et al., 2009; Hofmann, Schmeichel, & Baddeley, 2012; Schmeichel &

Demaree, 2010), this “spontaneous fictional reappraisal” hypothesis could be tested by checking whether better executive abilities were associated with a lower belief rate in the negative-reality condition.

Finally, we investigated the status of the “nonbelieved” items. We made the hypothesis that simulation monitoring is a unidimensional construct, resulting in nonbelieved trials of a given nature to be equivalent to believed trials of the opposite nature. Our data support this hypothesis to the extent that models specifying whether the participant believed in the given context were outperformed by models where nonbelieved categories are assimilated with opposite conditions. In other words, stating that the participant “did not believe that the item was referring to simulation” is not more informative than stating that the participant “did believe that the item was referring to reality.” This suggests that the output of the simulation-monitoring mechanism evolves between two opposing extremities: simulation and reality, with varying degrees of certainty. What is not classified as simulation is appraised as reality and vice versa.

The subjective belief about the nature of the stimuli seems to play a role in several aspects of the participant’s response. Indeed, our data tend to support a distinction between objective condition (i.e., the experimentally induced nature) and the subjective condition (i.e., their own belief about the stimulus’ nature). Variations in some components (subjective arousal, valence, and heart-rate variations) were better explained by the subjective condition while variations in other components (skin conductance response and LPP amplitude) were better explained by the objective condition. Taking aside heart-rate variations, we interpret these results following the elaboration hypothesis. Simulation monitoring appears as a slow mechanism, possibly intertwined with many other processes and mechanisms and connected to external experience, internal states, current context, and future goals. Our experimental manipulation takes the form of a prior information that pulls the simulation monitoring output toward one or the other extreme, setting up expectations (predictions) regarding the external percept as well as expectations regarding the bodily state. Then, any mismatch between these components will push our opinion regarding the nature in opposite direction, through uncertainty to the other pole. As we hypothesized that this modulation is slow, we predicted that objective components variations would be mostly influenced by the prior information, while later components by the participants’ posterior conclusion regarding the stimulus’ nature. Our hypothesis was verified for late components, such as phenomenal experience, as well as for bodily and neural components such as LPP and skin conductance response. The latter, in spite of being a late response due to its slow physiological dynamics, is believed to be triggered by some sort of “gut” reaction, present in

implicit manipulations (Öhman, Flykt, & Esteves, 2001; Öhman & Soares, 1993) and related to the activation of emotion and interoception-related regions (Laine, Spitler, Mosher, & Gothard, 2009; Nagai, Critchley, Featherstone, Trimble, & Dolan, 2004; Williams et al., 2001).

However, contrary to our expectations, heart-rate changes were better explained by the subjective condition. What is different about the heart? Considering the fact that regression models do not describe causal interactions but are mere advocates of relationship, it is possible that it is not the subjective condition that induces heart-rate variations, but heart-rate variation that critically influences the subsequent appraisal of reality. This claim is backed up by additional post-hoc analyses (presented in Supplementary Materials 2) showing that stronger heart-rate deceleration was associated with a lower belief scores in the reality and higher scores in the simulation condition. In other words, heart-rate deceleration seems to bias the appraisal of a stimulus as simulation. Thus, it is coherent with our findings showing that this index was not attenuated (i.e., closer to neutral), but amplified in the subjective simulation condition. Given that believing that an event is a simulation is a form of ER, our results suggest that increased heart-rate deceleration could be seen as a marker of spontaneous engagement in ER.

Nevertheless, the discrepancies with previous findings investigating fictional reappraisal (Mocaiber et al., 2011a, b) could also be explained by methodological differences. In our paradigm, participants had to pay attention to the cue, the subsequent stimulus, and actively engage in simulation monitoring to be able to express their belief about it. This intensification of cognitive activity could be maximized in the simulation condition, where uncertainty was higher. This would result, in turn, in a heightened attention, known to be related to cardiac deceleration (Boutcher & Zinsser, 1990; Bradley, 2009; Graham & Clifton, 1966). Nevertheless, further studies are needed to address the interaction between cardiac activity, emotions, and fictional reappraisal.

Contrary to heart rate, the SCR amplitude was lower in the simulation condition. Although being in line with previous studies on cognitive reappraisal (Wolgast, Lundh, & Viborg, 2011), it contradicts the findings done by our own research team, which did not report EDA modulations by fictional reappraisal (Sperduti et al., 2016a; Sperduti et al., 2017). This could be due to methodological limitations. Indeed, in both previous studies, an attenuating trend was still present, although statistically not significant. Beyond differences related to the procedure itself, the current research is endowed with more statistical power (more stimuli, more participants), better signal EDA processing algorithms (Greco et al., 2016), and more powerful statistical models. Thus, all these findings, taken together, suggest that presenting a stimulus as fictitious lead to a small, yet effective, decrease of physiological arousal.

This decrease was in line with the neural correlate of emotional arousal, the LPP (Cuthbert et al., 2000; Schupp et al., 2000), whose amplitude was attenuated when negative pictures were presented as simulations. Following that, we also found a global attenuating effect of simulation on the phenomenal experience. Indeed, it reduced subjective arousal (for both negative and neutral stimuli), but also, and distinctively, valence: Negative pictures were judged less negative and neutral pictures less positive when presented as simulations. This suggests that valence and arousal are two features of the emotional experience affected by fictional reappraisal.

Interestingly, we also found a trend toward a lower LPP amplitude for neutral pictures presented as reality compared with neutral pictures presented as simulation. This could be related to the capture of another ERP component, namely the N400, whose time course overlaps with the window used in our analyses (Kutas & Federmeier, 2011). This component is believed to reflect the creation of meaning through expectations shaped by previous experiences and contextual information (Amoruso et al., 2013) and is sensitive to their violation (e.g., in semantic incongruities; Kutas & Hillyard, 1980). In our case, it is possible that the contextual information about the reality of the upcoming stimulus creates the expectation that the stimulus will be more emotional than if it was simulation. As the stimulus that appears is neutral, the mismatch between the prior expectation and the evidence generates an incongruity reflected by a stronger negative signal deflection. Although this hypothesis remains speculative, it highlights the predictive coding framework (Friston, 2010; Seth & Friston, 2016) as a candidate for understanding the effect of fictional reappraisal.

Finally, we made the hypothesis that the relationship between self-relevance and emotions would be differently impacted by the reality/simulation manipulation, depending on the facet of self-relevance. To test that, we monitored two features related to distinct aspects of the Self (Conway et al., 2004; Martinelli et al., 2013; Prebble et al., 2012): autobiographical (the link between the stimulus and one's personal memories) and conceptual (the link between the stimulus and one's values system) relevance. We made the hypothesis that the relationship between autobiographical relevance and emotion would be unaltered by the experimental condition, while the relationship between conceptual relevance and emotion would interact with simulation. However, this hypothesis was only partially supported by our data. Indeed, while we found a relationship between the two aspects of self-relevance and most of the emotional response measures in the reality condition, the simulation condition changed this effect only for a few variables.

Interestingly, autobiographical relevance did interact with simulation for subjective valence. Indeed, while

negative pictures with high autobiographical relevance elicited a more intense emotional experience, they were, if presented as reality, also judged less negatively. This “positivity” bias was less important in the simulation condition, leading to a shrinkage of the difference between reality and simulation. Although counterintuitive, this result is coherent with previous research that found a correlation between autobiographical relevance and valence only for positive stimuli (Sperduti et al., 2016a, b). This could be related to the self-positivity bias, suggesting that healthy individuals have, in general, better encoding and retrieval of self-referent, positive information (J. M. Moran, Macrae, Heatherton, Wyland, & Kelley, 2006; Watson, Dritschel, Obonsawin, & Jentsch, 2007). Moreover, a recent study suggests that this bias could be actively available online, meaning that individuals are more likely to expect positive information in self-relevant stimuli (Fields & Kuperberg, 2015). As such, the reality condition could prime autobiographical relevance and, therefore, less negative emotional expectations. However, testing this speculative hypothesis is beyond the scope of the present analyses, thus requiring further, precise investigation. It is also important to note that the neural marker of emotional experience was not modulated by either autobiographical or conceptual relevance, as those characteristics are known to modulate earlier ERP components (Fields & Kuperberg, 2012, 2015; Miyakoshi, Nomura, & Ohira, 2007; Watson et al., 2007). On a bodily level, the skin conductance response was positively associated with conceptual and autobiographical relevance in the reality condition. However, contrary to phenomenal variables, only the former was affected by simulation. Negative items with high conceptual relevance produced stronger SCR only when presented as real—this link being disrupted by the simulation condition. Heart-rate data yielded uncertain results, resulting in a trend suggesting that conceptual relevance was associated with a higher heart-rate deceleration, but only in the reality condition. Again, in fiction, conceptual relevance was unrelated to heart-rate deceleration. Taken together, this complex interaction between facets of self-relevance and aspects of the emotional response underlines the need for further research to delineate the role and underpinnings of each component. Critically to the aim of our work, it suggests that self-relevance is not a cardinal feature supporting the emotional changes induced by fictional reappraisal. While self-relevance is indeed a strong modulator of emotions, its effect on the difference between reality and simulation was only found for a small subset of dimensions. Our data suggest that autobiographical and conceptual relevance would modulate the difference for phenomenal (in particular valence) and bodily (electrodermal and cardiac activity) components of emotions, respectively.



## Limitations and further directions

A few points should be mentioned regarding the procedure used in this study. First of all, given the information that most of the cues (but not all) preceding the pictures were true allowed, in our opinion, a beneficial trade-off regarding the general trust in the instructions (creating a bias toward the presented information for ambiguous items and accounting for possible problematic stimuli in which the presented condition is obviously false). Nevertheless, this could also lead to a diminished belief rate, possibly exacerbating some of the findings surrounding the belief rate (for example, participants could have thought of the wonders and achievements of makeup and other movies techniques, creating distortions and misattributions of belief). Future studies should investigate the effect and strength of prior expectations on simulation monitoring. Furthermore, the mere presence of the belief scale could induce changes, as it implicitly triggers metacognitive processes, possibly causing distortions or psychological distance from the experience. While this is related to a more general critique of the use of self-reports, future studies should investigate their impact for simulation monitoring (contrasting experiments or blocks with and without self-reports) and explore the existence of implicit correlates. This demanding cognitive activity, as well as the randomized design (demanding flexibility and easing between-condition comparisons) could explain the unexpected (although coherent with regard to a broader ER literature) findings about heart rate. Nevertheless, this study highlights the need of a thorough exploration of the relationship between autonomic (re) activity, emotions, and simulation monitoring. We believe that bodily signals, as well as their influence and perception (Seth, Suzuki, & Critchley, 2011) might hold a key for understanding the appraisal of reality.

In summary, beyond opening many questions that will need to be addressed in future studies, our research showed that presenting emotional stimuli as fictional, as opposed to real, attenuates the emotional response. The stimulus is subjectively appraised as less intense and less negative, and elicits lower SCR and LPP amplitudes. Finally, these phenomenal and physiological changes did not exclusively rely on variations of autobiographical and conceptual self-relevance. We suggest that this implicit ER strategy might be supported by the engagement of executive functions, which is coherent with the reported increase of heart-rate deceleration when engaging in fiction. Thus, further studies should investigate other potential determinants of fictional reappraisal as an ER strategy.

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## References

- Abraham, A., von Cramon, D. Y., & Schubotz, R. I. (2008). Meeting George Bush versus meeting Cinderella: The neural response when telling apart what is real from what is fictional in the context of our reality. *Journal of Cognitive Neuroscience*, 20(6), 965–976. doi:<https://doi.org/10.1162/jocn.2008.20059>
- Aldao, A. (2013). The future of emotion regulation research: Capturing context. *Perspectives on Psychological Science*, 8(2), 155–172.
- Aldao, A., & Nolen-Hoeksema, S. (2012). The influence of context on the implementation of adaptive emotion regulation strategies. *Behaviour Research and Therapy*, 50(7), 493–501.
- Aldao, A., Nolen-Hoeksema, S., & Schweizer, S. (2010). Emotion-regulation strategies across psychopathology: A meta-analytic review. *Clinical Psychology Review*, 30(2), 217–237. doi:<https://doi.org/10.1016/j.cpr.2009.11.004>
- Altmann, U., Bohm, I. C., Lubrich, O., Menninghaus, W., & Jacobs, A. M. (2012). Fact vs fiction: How paratextual information shapes our reading processes. *Social Cognitive and Affective Neuroscience*, 9(1), 22–29.
- Amoruso, L., Gelormini, C., Aboitiz, F., González, M. A., Manes, F., Cardona, J. F., & Ibanez, A. (2013). N400 ERPs for actions: Building meaning in context. *Frontiers in Human Neuroscience*, 7.
- Baayen, R. H., Davidson, D. J., & Bates, D. M. (2008). Mixed-effects modeling with crossed random effects for subjects and items. *Journal of Memory and Language*, 59(4), 390–412. doi:<https://doi.org/10.1016/j.jml.2007.12.005>
- Baños, R. M., Botella, C., Alcañiz, M., Liaño, V., Guerrero, B., & Rey, B. (2004). Immersion and emotion: Their impact on the sense of presence. *Cyberpsychology & Behavior: The Impact of the Internet, Multimedia and Virtual Reality on Behavior and Society*, 7(6), 734–741. doi:<https://doi.org/10.1089/cpb.2004.7.734>
- Baños, R. M., Botella, C., Rubió, I., Quero, S., García-Palacios, A., & Alcañiz, M. (2008). Presence and emotions in virtual environments: The influence of stereoscopy. *CyberPsychology & Behavior*, 11(1), 1–8.
- Bentall, R. P. (1990). The illusion of reality: A review and integration of psychological research on hallucinations. *Psychological Bulletin*, 107(1), 82.
- Bernstein, A., Hadash, Y., Lichtash, Y., Tanay, G., Shepherd, K., & Fresco, D. M. (2015). Decentering and related constructs: A critical review and meta-cognitive processes model. *Perspectives on Psychological Science*, 10(2016), 599–617. doi:<https://doi.org/10.1177/1745691615594577>
- Boutcher, S. H., & Zinsser, N. W. (1990). Cardiac deceleration of elite and beginning golfers during putting. *Journal of Sport and Exercise Psychology*, 12(1), 37–47.
- Bradley, M. M. (2009). Natural selective attention: Orienting and emotion. *Psychophysiology*, 46(1), 1–11.
- Braithwaite, J. J., Watson, D. G., Jones, R., & Rowe, M. (2013). A guide for analysing electrodermal activity (EDA) & skin conductance responses (SCRs) for psychological experiments. *Psychophysiology*, 49, 1017–1034.
- Braunstein, L. M., Gross, J. J., & Ochsner, K. N. (2017). Explicit and implicit emotion regulation: A multi-level framework. *Social Cognitive and Affective Neuroscience*, 12(10), 1545–1557.
- Bryant, R. A., & Mallard, D. (2003). Seeing is believing: The reality of hypnotic hallucinations. *Consciousness and Cognition*, 12(2), 219–230.
- Buhle, J. T., Silvers, J. A., Wager, T. D., Lopez, R., Onyemekwu, C., Kober, H., ... Ochsner, K. N. (2013). Cognitive reappraisal of

- emotion : A meta-analysis of human neuroimaging studies. *Cerebral Cortex*, 24(11), 2981–2990. doi:<https://doi.org/10.1093/cercor/bht154>
- Carhart-Harris, R. L., Erritzoe, D., Williams, T., Stone, J. M., Reed, L. J., Colasanti, A., ... Nutt, D. J. (2012). Neural correlates of the psychedelic state as determined by fMRI studies with psilocybin. *Proceedings of the National Academy of Sciences of the United States of America*, 109(6), 2138–43. doi:<https://doi.org/10.1073/pnas.1119598109>
- Chambers, C. D., Feredoes, E., Muthukumaraswamy, Suresh, D., & Etchells, P. J. (2014). Instead of “playing the game” it is time to change the rules: Registered Reports at AIMS Neuroscience and beyond. *AIMS Neuroscience*, 1(1), 4–17. doi:<https://doi.org/10.3934/Neuroscience.2014.1.4>
- Cohen, J. (1977). Statistical power analysis for the behavioral sciences (Revised ed.). New York: Academic Press.
- Compère, L., Mam-Lam-Fook, C., Amado, I., Nys, M., Lalanne, J., Grillon, M.-L., ... Piolino, P. (2016). Self-reference recollection effect and its relation to theory of mind: An investigation in healthy controls and schizophrenia. *Consciousness and Cognition*, 42, 51–64.
- Conway, M. A. (2005). Memory and the self. *Journal of Memory and Language*, 53(4), 594–628.
- Conway, M. A., Singer, J. A., & Tagini, A. (2004). The self and autobiographical memory: Correspondence and coherence. *Social Cognition*, 22(5), 491–529. doi:<https://doi.org/10.1521/soco.22.5.491.50768>
- Cuthbert, B. N., Schupp, H. T., Bradley, M. M., Birbaumer, N., & Lang, P. J. (2000). Brain potentials in affective picture processing: Covariation with autonomic arousal and affective report. *Biological Psychology*, 52(2), 95–111.
- Dan-Glauser, E. S., & Scherer, K. R. (2011). The Geneva affective picture database (GAPED): A new 730-picture database focusing on valence and normative significance. *Behavior Research Methods*, 43(2), 468.
- Davis, J. I., Gross, J. J., & Ochsner, K. N. (2011). Psychological distance and emotional experience: What you see is what you get. *Emotion*, 11(2), 438. doi:<https://doi.org/10.1037/a0021783>
- Dörfel, D., Lamke, J. P., Hummel, F., Wagner, U., Erk, S., & Walter, H. (2014). Common and differential neural networks of emotion regulation by detachment, reinterpretation, distraction, and expressive suppression: A comparative fMRI investigation. *NeuroImage*, 101(September), 298–309. doi:<https://doi.org/10.1016/j.neuroimage.2014.06.051>
- Eippert, F., Veit, R., Weiskopf, N., Erb, M., Birbaumer, N., & Anders, S. (2007). Regulation of emotional responses elicited by threat-related stimuli. *Human Brain Mapping*, 28(5), 409–423. doi:<https://doi.org/10.1002/hbm.20291>
- Etz, A., & Vandekerckhove, J. (2016). A Bayesian perspective on the reproducibility project: Psychology. *PLoS ONE*, 11(2). doi:<https://doi.org/10.1371/journal.pone.0149794>
- Fields, E. C., & Kuperberg, G. R. (2012). It's all about you: An ERP study of emotion and self-relevance in discourse. *NeuroImage*, 62(1), 562–574.
- Fields, E. C., & Kuperberg, G. R. (2015). Loving yourself more than your neighbor: ERPs reveal online effects of a self-positivity bias. *Social Cognitive and Affective Neuroscience*, 10(9), 1202–1209.
- Foti, D., & Hajcak, G. (2008). Deconstructing reappraisal: Descriptions preceding arousing pictures modulate the subsequent neural response. *Journal of Cognitive Neuroscience*, 20(6), 977–988. doi:<https://doi.org/10.1162/jocn.2008.20066>
- Fowles, D. C., Christie, M. J., Edelberg, R., Grings, W. W., Lykken, D. T., & Venables, P. H. (1981). Publication recommendation for electrodermal measurements. *Psychophysiology*, 18, 232–239. doi:<https://doi.org/10.1111/j.1469-8986.2012.01384.x>
- Friston, K. (2010). The free-energy principle: A unified brain theory? *Nature Reviews Neuroscience*, 11(2), 127–138. doi:<https://doi.org/10.1038/nrn2787>
- Gabry, J., & Goodrich, B. (2016). rstanarm: Bayesian applied regression modeling via stan [Computer software]. Retrieved from <http://mc-stan.org/rstanarm/>. Accessed 31 Jun 2018
- Gelman, A., Hwang, J., & Vehtari, A. (2014). Understanding predictive information criteria for Bayesian models. *Statistics and Computing*, 24(6), 997–1016.
- Graham, F. K., & Clifton, R. K. (1966). Heart-rate change as a component of the orienting response. *Psychological Bulletin*, 65(5), 305.
- Gramfort, A., Luessi, M., Larson, E., Engemann, D. A., Strohmeier, D., Brodbeck, C., ... Hämäläinen, M. S. (2013). MEG and EEG data analysis with MNE-Python. *Frontiers in Neuroscience*, 7.
- Gramfort, A., Luessi, M., Larson, E., Engemann, D. A., Strohmeier, D., Brodbeck, C., ... Hämäläinen, M. S. (2014). MNE software for processing MEG and EEG data. *NeuroImage*, 86, 446–460. doi:<https://doi.org/10.1016/j.neuroimage.2013.10.027>
- Greco, A., Valenza, G., Lanata, A., Scilingo, E. P., & Citi, L. (2016). cvxEDA: A convex optimization approach to electrodermal activity processing. *IEEE Transactions on Biomedical Engineering*, 63(4), 797–804.
- Gross, J. J. (1998a). Antecedent- and response-focused emotion regulation: Divergent consequences for experience, expression, and physiology. *Journal of Personality and Social Psychology*, 74(1), 224–237. doi:<https://doi.org/10.1037/0022-3514.74.1.224>
- Gross, J. J. (1998b). The emerging field of emotion regulation: An integrative review. *Review of General Psychology*, 2(3), 271–299. doi:<https://doi.org/10.1037/1089-2680.2.3.271>
- Gross, J. J. (2002). Emotion regulation: Affective, cognitive, and social consequences. *Psychophysiology*, 39(3), 281–291.
- Gross, J. J., & John, O. P. (2003). Individual differences in two emotion regulation processes: Implications for affect, relationships, and well-being. *Journal of Personality and Social Psychology*, 85(2), 348–362. doi:<https://doi.org/10.1037/0022-3514.85.2.348>
- Gyurak, A., Goodkind, M. S., Madan, A., Kramer, J. H., Miller, B. L., & Levenson, R. W. (2009). Do tests of executive functioning predict ability to downregulate emotions spontaneously and when instructed to suppress? *Cognitive, Affective, & Behavioral Neuroscience*, 9(2), 144–52. doi:<https://doi.org/10.3758/CABN.9.2.144>
- Hajcak, G., & Nieuwenhuis, S. (2006). Reappraisal modulates the electrocortical response to unpleasant pictures. *Cognitive, Affective, & Behavioral Neuroscience*, 6(4), 291–297.
- Hamilton, P. (2002). Open source ECG analysis. *Computers in Cardiology*, 29, 101–104.
- Han, S., Jiang, Y., Humphreys, G. W., Zhou, T., & Cai, P. (2005). Distinct neural substrates for the perception of real and virtual visual worlds. *NeuroImage*, 24(3), 928–935. doi:<https://doi.org/10.1016/j.neuroimage.2004.09.046>
- Herbert, C., Herbert, B. M., & Pauli, P. (2011). Emotional self-reference: Brain structures involved in the processing of words describing one's own emotions. *Neuropsychologia*, 49(10), 2947–56. doi:<https://doi.org/10.1016/j.neuropsychologia.2011.06.026>
- Hofmann, W., Schmeichel, B. J., & Baddeley, A. D. (2012). Executive functions and self-regulation. *Trends in Cognitive Sciences*, 16(3), 174–180.
- Hsu, C.-T., Conrad, M., & Jacobs, A. M. (2014). Fiction feelings in Harry Potter: Haemodynamic response in the mid-cingulate cortex correlates with immersive reading experience. *Neuroreport*, 25(17), 1356–1361.
- Hülshager, U. R., Alberts, H. J. E. M., Feinholdt, A., & Lang, J. W. B. (2013). Benefits of mindfulness at work: The role of mindfulness in emotion regulation, emotional exhaustion, and job satisfaction. *Journal of Applied Psychology*, 98(2), 310.

- Jas, M., Engemann, D. A., Bekhti, Y., Raimondo, F., & Gramfort, A. (2017). Autoreject: Automated artifact rejection for MEG and EEG data. *NeuroImage*, 159, 417–429.
- John, O. P., & Gross, J. J. (2004). Healthy and unhealthy emotion regulation: Personality processes, individual differences, and life span development. *Journal of Personality*, 72(6), 1301–1334. doi:<https://doi.org/10.1111/j.1467-6494.2004.00298.x>
- Johnson, M. K., Hashtroudi, S., & Lindsay, D. S. (1993). Source monitoring. *Psychological Bulletin*, 114(1), 3. doi:<https://doi.org/10.1037/0033-2909.114.1.3>
- Johnson, M. K., & Raye, C. L. (1981). Reality monitoring. *Psychological Review*, 88(1), 67.
- Keil, A., Bradley, M. M., Hauk, O., Rockstroh, B., Elbert, T., & Lang, P. J. (2002). Large-scale neural correlates of affective picture processing. *Psychophysiology*, 39(5), 641–649.
- Klein, S. B., & Gangi, C. E. (2010). The multiplicity of self: Neuropsychological evidence and its implications for the self as a construct in psychological research. *Annals of the New York Academy of Sciences*, 1191(1), 1–15.
- Klein, S. B., Loftus, J., & Burton, H. A. (1989). Two self-reference effects: The importance of distinguishing between self-descriptiveness judgments and autobiographical retrieval in self-referent encoding. *Journal of Personality and Social Psychology*, 56(6), 853.
- Kristensen, M., & Hansen, T. (2004). Statistical analyses of repeated measures in physiological research: A tutorial. *Advances in Physiology Education*, 28(1–4), 2–14. doi:<https://doi.org/10.1152/advan.00042.2003>
- Kross, E., & Ayduk, O. (2011). Making meaning out of negative experiences by self-distancing. *Current Directions in Psychological Science*, 20(3), 187–191.
- Kruschke, J. K. (2011). Bayesian assessment of null values via parameter estimation and model comparison. *Perspectives on Psychological Science*, 6(3), 299–312.
- Kruschke, J. K., Aguinis, H., & Joo, H. (2012). The time has come: Bayesian methods for data analysis in the organizational sciences. *Organizational Research Methods*, 15(4), 722–752.
- Kutas, M., & Federmeier, K. D. (2011). Thirty years and counting: Finding meaning in the N400 component of the event-related brain potential (ERP). *Annual Review of Psychology*, 62, 621–647.
- Kutas, M., & Hillyard, S. A. (1980). Reading senseless sentences: Brain potentials reflect semantic incongruity. *Science*, 207(4427), 203–205.
- Laine, C. M., Spitler, K. M., Mosher, C. P., & Gothard, K. M. (2009). Behavioral triggers of skin conductance responses and their neural correlates in the primate amygdala. *Journal of Neurophysiology*, 101(4), 1749–1754.
- Lebedev, A. V., Lövdén, M., Rosenthal, G., Feilding, A., Nutt, D. J., & Carhart-Harris, R. L. (2015). Finding the self by losing the self: Neural correlates of ego-dissolution under psilocybin. *Human Brain Mapping*, 36(8), 3137–3153. doi:<https://doi.org/10.1002/hbm.22833>
- Magezi, D. A. (2015). Linear mixed-effects models for within-participant psychology experiments: An introductory tutorial and free, graphical user interface (LMMgui). *Frontiers in Psychology*, 6(January), 1–7. doi:<https://doi.org/10.3389/fpsyg.2015.00002>
- Makowski, D. (2017). NeuroKit: An open-source Python toolbox for neurophysiology [Com [uter software]. Retrieved from <https://github.com/neuropsychology/NeuroKit.py>. Accessed 31 Jun 2018
- Makowski, D. (2018a). Indices of effect existence in the Bayesian framework. *PsyArXiv*. doi:<https://doi.org/10.31234/osf.io/vsrdq>
- Makowski, D. (2018b). The psycho package: An efficient and publishing-oriented workflow for psychological science. *Journal of Open Source Software*, 3(22), 470.
- Makowski, D., & Dutriaux, L. (2017). Neuropsychia.py: A Python module for creating experiments, tasks and questionnaires. *Journal of Open Source Software*, 2(19). doi:<https://doi.org/10.21105/joss.00259>
- Makowski, D., Sperduti, M., Nicolas, S., & Piolino, P. (2017). “Being there” and remembering it: Presence improves memory encoding. *Consciousness and Cognition*. doi:<https://doi.org/10.1016/j.concog.2017.06.015>
- Marchewka, A., Żurawski, L., Jednoróg, K., & Grabowska, A. (2014). The Nencki Affective Picture System (NAPS): Introduction to a novel, standardized, wide-range, high-quality, realistic picture database. *Behavior Research Methods*, 46(2), 596–610. doi:<https://doi.org/10.3758/s13428-013-0379-1>
- Martinelli, P., Sperduti, M., & Piolino, P. (2013). Neural substrates of the self-memory system: New insights from a meta-analysis. *Human Brain Mapping*, 34(7), 1515–1529. doi:<https://doi.org/10.1002/hbm.22008>
- Metz-Lutz, M.-N., Bressan, Y., Heider, N., & Otzenberger, H. (2010). What physiological changes and cerebral traces tell us about adhesion to fiction during theater-watching? *Frontiers in Human Neuroscience*, 4(August), 1–10. doi:<https://doi.org/10.3389/fnhum.2010.00059>
- Miyakoshi, M., Nomura, M., & Ohira, H. (2007). An ERP study on self-relevant object recognition. *Brain and Cognition*, 63(2), 182–189.
- Mocaiber, I., Perakakis, P., Pereira, M. G., Pinheiro, W. M., Volchan, E., de Oliveira, L., & Vila, J. (2011a). Stimulus appraisal modulates cardiac reactivity to briefly presented mutilation pictures. *International Journal of Psychophysiology*, 81(3), 299–304.
- Mocaiber, I., Pereira, M. G., Erthal, F. S., Figueira, I., Machado-Pinheiro, W., Cagy, M., ... de Oliveira, L. (2009). Regulation of negative emotions in high trait anxious individuals: An ERP study. *Psychology & Neuroscience*, 2(2), 211.
- Mocaiber, I., Pereira, M. G., Erthal, F. S., Machado-Pinheiro, W., David, I. A., Cagy, M., ... de Oliveira, L. (2010). Fact or fiction? An event-related potential study of implicit emotion regulation. *Neuroscience Letters*, 476(2), 84–88. doi:<https://doi.org/10.1016/j.neulet.2010.04.008>
- Mocaiber, I., Sanchez, T. A., Pereira, M. G., Erthal, F. S., Joffily, M., Araujo, D. B., ... de Oliveira, L. (2011b). Antecedent descriptions change brain reactivity to emotional stimuli: A functional magnetic resonance imaging study of an extrinsic and incidental reappraisal strategy. *Neuroscience*, 193, 241–248. doi:<https://doi.org/10.1016/j.neuroscience.2011.07.003>
- Moran, J. M., Macrae, C. N., Heatherton, T. F., Wyland, C. L., & Kelley, W. M. (2006). Neuroanatomical evidence for distinct cognitive and affective components of self. *Journal of Cognitive Neuroscience*, 18(9), 1586–1594.
- Moran, T. P., Jendrusina, A. A., & Moser, J. S. (2013). The psychometric properties of the late positive potential during emotion processing and regulation. *Brain Research*, 1516, 66–75.
- Moser, J. S., Hartwig, R., Moran, T. P., Jendrusina, A. A., & Kross, E. (2014). Neural markers of positive reappraisal and their associations with trait reappraisal and worry. *Journal of Abnormal Psychology*, 123(1), 91.
- Nagai, Y., Critchley, H. D., Featherstone, E., Trimble, M. R., & Dolan, R. J. (2004). Activity in ventromedial prefrontal cortex covaries with sympathetic skin conductance level: A physiological account of a “default mode” of brain function. *NeuroImage*, 22(1), 243–251.
- Northoff, G. (2005). Emotional-cognitive integration, the self, and cortical midline structures. *Behavioral and Brain Sciences*, 28(02), 211–212.
- Northoff, G., & Duncan, N. W. (2016). How do abnormalities in the brain’s spontaneous activity translate into symptoms in schizophrenia? From an overview of resting state activity findings to a proposed spatiotemporal psychopathology. *Progress in Neurobiology*, 145, 26–45. doi:<https://doi.org/10.1016/j.pneurobio.2016.08.003>



- Ochsner, K. N., & Gross, J. J. (2005). The cognitive control of emotion. *Trends in Cognitive Sciences*. doi:<https://doi.org/10.1016/j.tics.2005.03.010>
- Ochsner, K. N., Silvers, J. A., & Buhle, J. T. (2012). Functional imaging studies of emotion regulation: A synthetic review and evolving model of the cognitive control of emotion. *Annals of the New York Academy of Sciences*, 1251, E1–E24. doi:<https://doi.org/10.1111/j.1749-6632.2012.06751.x>
- Öhman, A., Flykt, A., & Esteves, F. (2001). Emotion drives attention: Detecting the snake in the grass. *Journal of Experimental Psychology: General*, 130(3), 466–478. doi:<https://doi.org/10.1037/0096-3445.130.3.466>
- Öhman, A., & Soares, J. J. (1993). On the automatic nature of phobic fear: Conditioned electrodermal responses to masked fear-relevant stimuli. *Journal of Abnormal Psychology*, 102(1), 121.
- Oliveira, L. A. S., Oliveira, L., Joffily, M., Pereira-Junior, P. P., Lang, P. J., Pereira, M. G., ... Volchan, E. (2009). Autonomic reactions to mutilation pictures: Positive affect facilitates safety signal processing. *Psychophysiology*, 46(4), 870–873. doi:<https://doi.org/10.1111/j.1469-8986.2009.00812.x>
- Pastor, M. C., Bradley, M. M., Löw, A., Versace, F., Moltó, J., & Lang, P. J. (2008). Affective picture perception: Emotion, context, and the late positive potential. *Brain Research*, 1189, 145–151.
- Prebble, S. C., Addis, D. R., & Tippet, L. J. (2013). Autobiographical memory and sense of self. *Psychological Bulletin*, 139(4), 815. doi:<https://doi.org/10.1037/a0030146>
- R Development Core Team (2008). R: A language and environment for statistical computing [Computer software]. Vienna, Austria. Retrieved from <http://www.r-project.org>. Accessed 31 Jun 2018
- Radford, C., & Weston, M. (1975). How can we be moved by the fate of Anna Karenina? *Proceedings of the Aristotelian Society, Supplementary Volumes*, 49, 67–93.
- Riva, G., Mantovani, F., Capideville, C. S., Preziosa, A., Morganti, F., Villani, D., ... Alcañiz, M. (2007). Affective interactions using virtual reality: The link between presence and emotions. *Cyberpsychology & Behavior: The Impact of the Internet, Multimedia and Virtual Reality on Behavior and Society*, 10(1), 45–56. doi:<https://doi.org/10.1089/cpb.2006.9993>
- Schmeichel, B. J., & Demaree, H. A. (2010). Working memory capacity and spontaneous emotion regulation: High capacity predicts self-enhancement in response to negative feedback. *Emotion (Washington D.C.)*, 10(5), 739–44. doi:<https://doi.org/10.1037/a0019355>
- Schupp, H. T., Cuthbert, B. N., Bradley, M. M., Cacioppo, J. T., Ito, T., & Lang, P. J. (2000). Affective picture processing: The late positive potential is modulated by motivational relevance. *Psychophysiology*, 37(2), 257–261.
- Sedeño, L., Couto, B., Melloni, M., Canales-Johnson, A., Yoris, A., Baez, S., ... Ibanez. (2014). How do you feel when you can't feel your body? Interoception, functional connectivity and emotional processing in depersonalization-derealization disorder. *PLOS ONE*, 9(6), e98769.
- Seth, A. K., & Friston, K. J. (2016). Active interoceptive inference and the emotional brain. *Philosophical Transactions of the Royal Society of London. Series B, Biological Sciences*, 371. doi:<https://doi.org/10.1098/rstb.2016.0007>
- Seth, A. K., Suzuki, K., & Critchley, H. D. (2011). An interoceptive predictive coding model of conscious presence. *Frontiers in Psychology*, 3(JAN), 1–16. doi:<https://doi.org/10.3389/fpsyg.2011.00395>
- Shiota, M. N., & Levenson, R. W. (2012). Turn down the volume or change the channel? Emotional effects of detached versus positive reappraisal. *Journal of Personality and Social Psychology*, 103(3), 416–429. doi:<https://doi.org/10.1037/a0029208>
- Sperduti, M., Arcangeli, M., Makowski, D., Wantzen, P., Zalla, T., Lemaire, S., ... Piolino, P. (2016a). The paradox of fiction: Emotional response toward fiction and the modulatory role of self-relevance. *Acta Psychologica*, 165, 53–59. doi:<https://doi.org/10.1016/j.actpsy.2016.02.003>
- Sperduti, M., Makowski, D., Arcangeli, M., Wantzen, P., Zalla, T., Lemaire, S., ... Piolino, P. (2017). The distinctive role of executive functions in implicit emotion regulation. *Acta Psychologica*, 173, 13–20. doi:<https://doi.org/10.1016/j.actpsy.2016.12.001>
- Sperduti, M., Makowski, D., & Piolino, P. (2016b). The protective role of long-term meditation on the decline of the executive component of attention in aging: A preliminary cross-sectional study. *Aging, Neuropsychology, and Cognition*, 23(6). doi:<https://doi.org/10.1080/13825585.2016.1159652>
- Szucs, D., & Ioannidis, J. P. (2016). Empirical assessment of published effect sizes and power in the recent cognitive neuroscience and psychology literature. *BioRxiv*, 071530. doi:<https://doi.org/10.1101/071530>
- Takuma, K., Hori, S., Sasaki, J., Shinozawa, Y., Yoshikawa, T., Handa, S., ... Aikawa, N. (1995). An alternative limb lead system for electrocardiographs in emergency patients. *The American Journal of Emergency Medicine*, 13(5), 514–517.
- Troy, A. S., Shallcross, A. J., & Mauss, I. B. (2013). A person-by-situation approach to emotion regulation: Cognitive reappraisal can either help or hurt, depending on the context. *Psychological Science*, 24(12), 2505–2514.
- Tugade, M. M., & Fredrickson, B. L. (2007). Regulation of positive emotions: Emotion regulation strategies that promote resilience. *Journal of Happiness Studies*, 8(3), 311–333.
- Tugade, M. M., Fredrickson, B. L., & Feldman Barrett, L. (2004). Psychological resilience and positive emotional granularity: Examining the benefits of positive emotions on coping and health. *Journal of Personality*, 72(6), 1161–1190.
- Västfjäll, D. (2003). The subjective sense of presence, emotion recognition, and experienced emotions in auditory virtual environments. *CyberPsychology & Behavior*, 6(2), 181–188.
- Vehtari, A., Gelman, A., & Gabry, J. (2017). Practical Bayesian model evaluation using leave-one-out cross-validation and WAIC. *Statistics and Computing*, 27(5), 1413–1432.
- Wagenmakers, E.-J., Marsman, M., Jamil, T., Ly, A., Verhagen, J., Love, J., ... Morey, R. D. (2018). Bayesian inference for psychology. Part I: Theoretical advantages and practical ramifications. *Psychonomic Bulletin & Review*, 25(1), 35–57.
- Watson, L. A., Dritschel, B., Obonsawin, M. C., & Jentsch, I. (2007). Seeing yourself in a positive light: Brain correlates of the self-positivity bias. *Brain Research*, 1152, 106–110.
- Webb, T. L., Miles, E., & Sheeran, P. (2012). Dealing with feeling: A meta-analysis of the effectiveness of strategies derived from the process model of emotion regulation. *Psychological Bulletin*, 138(4), 775–808. doi:<https://doi.org/10.1037/a0027600>
- Williams, L. M., Phillips, M. L., Brammer, M. J., Skerrett, D., Lagopoulos, J., Rennie, C., ... Gordon, E. (2001). Arousal dissociates amygdala and hippocampal fear responses: Evidence from simultaneous fMRI and skin conductance recording. *NeuroImage*, 14(5), 1070–1079.
- Wolgast, M., Lundh, L.-G., & Viborg, G. (2011). Cognitive reappraisal and acceptance: An experimental comparison of two emotion regulation strategies. *Behaviour Research and Therapy*, 49(12), 858–866.
- Yoshimura, S., Ueda, K., Suzuki, S. I., Onoda, K., Okamoto, Y., & Yamawaki, S. (2009). Self-referential processing of negative stimuli within the ventral anterior cingulate gyrus and right amygdala. *Brain and Cognition*, 69(1), 218–225. doi:<https://doi.org/10.1016/j.bandc.2008.07.010>



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