Cognitive, Affective, & Behavioral Neuroscience (2018) 18:1269–1282
https://doi.org/10.3758/s13415-018-0637-x

Goal-relevant situations facilitate memory of neutral faces

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Abstract

Emotional situations are typically better remembered than neutral situations, but the psychological conditions and brain mechanisms underlying this effect remain debated. Stimulus *valence* and affective *arousal* have been suggested to explain the major role of emotional stimuli in memory facilitation. However, neither valence nor arousal are sufficient affective dimensions to explain the effect of memory facilitation. Several studies showed that negative and positive details are better remembered than neutral details. However, other studies showed that neutral information encoded and coupled with arousal did not result in a memory advantage compared with neutral information not coupled with arousal. Therefore, we suggest that the fundamental affective dimension responsible for memory facilitation is *goal relevance.* To test this hypothesis at behavioral and neural levels, we conducted a functional magnetic resonance imaging study and used neutral faces embedded in goal-relevant or goal-irrelevant daily life situations. At the behavioral level, we found that neutral faces encountered in goal-relevant situations were better remembered than those encountered in goal-irrelevant situations. To explain this effect, we studied neural activations involved in goal-relevant processing at encoding and in subsequent neutral face recognition. At encoding, activation of emotional brain regions (anterior cingulate, ventral striatum, ventral tegmental area, and substantia nigra) was greater for processing of goal-relevant situations than for processing of goal-irrelevant situations. At the recognition phase, despite the presentation of neutral faces, brain activation involved in social processing (superior temporal sulcus) to successfully remember identities was greater for previously encountered faces in goal-relevant than in goal-irrelevant situations.

Keywords Goal relevance · Emotion · Memory · Reward · Social · Arousal

Accumulating evidence indicates a memory advantage for emotional as compared with neutral information (D'Argembeau, Van der Linden, Etienne, & Comblain, 2003; Hamann, Ely, Grafton, & Kilts, 1999; Mather, 2007), but the affective processes and brain mechanisms that subserve this effect remain debated. Stimulus valence, affective arousal, and appraised goal relevance (Levine & Pizarro, 2006; Montagrin, Brosch, & Sander, 2013; Montagrin & Sander, 2016), for example, have each been suggested to play an important role in emotional memory. Although valence and arousal have been largely investigated at behavioral and brain levels, the impact of goal relevance on memory has not yet been studied in a setting that allows an examination of both levels at the same time. The purpose of the current study was to use functional magnetic resonance imaging (fMRI) to test the hypothesis that goal relevance is a key determinant of memory facilitation and that this effect is subserved by key regions of the affective brain.

The valence hypothesis argued that negative stimuli are remembered in more detail than positive stimuli (Kensinger,

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2009). Other studies showed that both positive and negative stimuli are better remembered than neutral stimuli (Hamann et al., 1999), proposing an alternative account—the arousal hypothesis—according to which emotional stimuli have a privileged status in memory, because they are arousing, not because they are valenced. Yet other results suggest that a physiological response to an arousing event can occur without inducing any facilitation effect on memory (Adolphs, Tranel, & Buchanan, 2005; Christianson & Mjörndal, 1985; Montagrin & Sander, 2016; Reisberg & Heuer, 2004). For instance, participants who received a subcutaneous injection of adrenalin versus saline did no better at remembering names or occupations related to neutral faces, despite showing an increase in sympathetic system activity (Christianson & Mjörndal, 1985). Thus, the emotional significance of an episode might be necessary to facilitate memory processing (Reisberg & Heuer, 2004). The detection of a relevant event in the environment has been proposed to be a fundamental mechanism of emotion elicitation (Sander, Grandjean, & Scherer, 2005) and of the modulation of cognitive mechanisms, such as episodic memory (Montagrin et al., 2013), associative learning (Stussi, Pourtois & Sander, 2018), and attention (Pool, Brosch, Delplanque & Sander, 2016). If an event is appraised as goal conducive, it may elicit positive emotions, such as joy, hope, or interest. On the other hand, if an event is appraised as goal obstructive, it may induce negative emotions, such as frustration, fear, disgust, or anger (Ellsworth, 2009). A goal-irrelevant situation can be defined as a situation that is neither particularly goal conducive, nor particularly goal obstructive, as appraised by the protagonist. On the basis of appraisal theories of emotion, we formulated the relevance hypothesis of memory facilitation, according to which the primary reason that so-called emotional stimuli have a privileged status in a person's memory is that they are appraised as relevant for his or her goals, values, and, more generally, concerns (Montagrin et al., 2013; Montagrin & Sander, 2016). This is in line with previous studies and models reporting that cultural dimension, such as race, sexual orientation, and so forth, promote biases in memory in favor of in-group versus out-group faces because of their personal relevance (Correll, Hudson, Guillermo, & Earls, 2016; Hugenberg, Wilson, See, & Young, 2013).

Because remembering identities is essential to guide behavior in daily life situations, it is crucial to understand which emotional factors influence memory of identities. Investigators also have reported specific impacts of emotional facial expressions (D'Argembeau & Van der Linden, 2007)—social dimensions inferred from facial characteristics (e.g., trustworthy and untrustworthy vs. neutral dimensions; Mattarozzi, Todorov, & Codispoti, 2014)—on the memory of identities. However, most studies that examined memory of identity for neutral faces associated with emotional behavior compared with neutral behavior failed to reveal memory enhancement of identities (Bell & Buchner, 2010; Bell, Giang, & Buchner, 2012; Mattarozzi et al., 2014; Okada et al., 2011; Smith, Dolan, & Rugg, 2004a; Smith, Henson, Dolan, & Rugg, 2004b). For instance, participants who encountered neutral faces in unpleasant (i.e., disgusting) and pleasant compared with neutral contexts (Bell & Buchner, 2010), or those who encountered neutral faces in cheating and trustworthy compared with irrelevant contexts, showed equal memory performance for neutral face identities in the different experimental conditions (Buchner, Bell, Mehl, & Musch, 2009). However, a study in which participants were personally involved in a social dilemma game showed memory enhancement for neutral faces of cooperators and defectors rather than for neutral faces associated with behaviors that were irrelevant to the game (Bell, Buchner, & Musch, 2010). Similarly, Montagrin et al. (2013) showed that an intrinsic neutral object related to a gain was better remembered than an intrinsic neutral object related to an irrelevant event. However, these studies are limited to game-like situations and are not the most representative of our social daily life.

In terms of brain activation, emotional memory enhancement has been proposed to be underlain by the amygdala in interaction with the noradrenergic system (McGaugh, 2000, 2015). According to this framework, emotional arousal experiences initiate the release of noradrenergic neurotransmitters into the amygdala. One study, for instance, reported that patients with amygdala damage showed no memory advantage for emotional (arousing) events (Cahill et al., 1996). In addition, the activation of the amygdala was correlated with memory enhancement for negative and positive stimuli (Cahill et al., 1996; Hamann et al., 1999). However, a study of patients with a unilateral-temporal lobectomy (including the amygdala, hippocampus, and adjacent cortex) showed that, although their response to arousal stimuli at encoding was not different from that of control participants (as shown by a physiological measure, i.e., skin conductance), their memory was not enhanced for arousal stimuli as was the case for control participants (Adolphs et al., 2005). Thus, a physiological response to an arousal event can occur without influencing memory processing (Christianson & Mjörndal, 1985; Libkuman, Nichols-Whitehead, Griffith, & Thomas, 1999). The question that ensues from this result is whether arousal is sufficient to enhance emotional events in memory. At first, the meaning of the emotion episode itself, rather than the physiological response during an emotional episode (arousal), might matter in the context of memory facilitation (Montagrin & Sander, 2016; Reisberg & Heuer, 2004). For instance, a study showed that the amygdala was more activated when an individual was learning the association between object and facial emotional expression than it was for emotional facial expression alone, whereas the posterior insula was more responsive to the inverse contrast (Hooker, Germine, Knight, & D'Esposito, 2006).

The amygdala does not act alone; rather, it interacts with other brain structures, such as the hippocampus in the processing of emotional memory (Dolcos, LaBar, & Cabeza, 2004; Hamann et al., 1999; LaBar & Phelps, 1998) and with the ventral striatum in the processing of relevant stimuli (Ousdal, Reckless, Server, Andreassen, & Jensen, 2012). More specifically, the ventral striatum, with its connection to the cortex, hippocampus, and amygdala, plays an essential role in motivational information processing, which in turn influences the basal ganglia behavioral response (i.e., approach or avoidance; Haber & Knutson, 2010). Thus, these proposed regions, mediated by a learning system that leads to motivated and appropriate goal-related behaviors, might be broadly involved in goal-relevant processing.

In terms of face processing, the superior temporal sulcus (STS) and the fusiform face area (FFA) have distinct roles (Hasselmo, Rolls, & Baylis, 1989; Haxby, Hoffman, & Gobbini, 2000). Whereas the FFA plays a key role in identity processing (Haxby et al., 2000), the STS preferentially processes emotional facial expression compared with neutral facial expression (Engell & Haxby, 2007; Jiang & He, 2006), faces previously associated with laughter (Holdstock, Crane, Bachorowski, & Milner, 2010), and more broadly changeable aspects of faces (i.e., eye gaze, expression, and lip movement; Haxby et al., 2000). However, distinguishing the role of the STS in emotional facial expression from its role in identity processing might be more complex. Gobbini and Haxby (2007) proposed in their model that the posterior STS/temporoparietal junction and the anterior paracingulate are involved in the retrieval of personal traits, intentions, and so forth of familiar individuals. It is likely that the STS plays a cumulative role in face processing that is not restricted to emotional facial expressions. Thus, recognition of faces (i.e., identities) associated with, for example, emotional contexts in social interactions but that display a neutral facial expression may involve the STS.

To date, no study has investigated how goal-relevant situations have an impact on remembering of face identities at behavioral and neural levels in daily life social situations. On the basis of the relevance hypothesis, we propose that incidental memory for a face presented with a neutral facial expression encountered in a goal-relevant situation will be enhanced compared with memory for a similar face presented with a neutral facial expression encountered in a goal-irrelevant situation.

In the present study, we used descriptions depicting social goal-relevant or goal-irrelevant daily life situations wherein participants had to look at a neutral face and to imagine themselves encountering this person in this particular situation. At a behavioral level, we hypothesized that successful face recognition would be modulated by the goal relevance (i.e., emotion) of the situation. At a neural level, we focused first on encoding in order to examine how the processing of social goal-relevant daily life situations would recruit brain structures involved in the reward and aversive system (i.e., ventral striatum, ventral tegmental area, substantia nigra; Haber & Knutson, 2010; Matsumoto & Hikosaka, 2009; Metereau & Dreher, 2012; Wittmann, Schiltz, Boehler, & Düzel, 2008) and goal-directed behaviors (medial prefrontal cortex; Stawarczyk & D'Argembeau, 2015). In addition, we predicted that the amygdala, which is known to play a role in the reward circuit (Haber & Knutson, 2010) and in the processing of relevant stimuli (in co-activation with the ventral striatum; Ousdal et al., 2012), would be involved in the processing of social goal-relevant daily life situations. Indeed, these latter findings are in line with the assumption that the amygdala plays a key role as a relevance detector (Sander, Grafman, & Zalla, 2003). We also examined whether the increased memory for neutral faces presented in goal-relevant situations might increase activity in brain regions known to play a role in emotional facial and social situation processing such as the STS (Engell & Haxby, 2007; Gobbini & Haxby, 2007; Holdstock et al., 2010; Jiang & He, 2006; Tseng et al., 2014; Vrticka, Andersson, Sander, & Vuilleumier, 2009). Finally, activity in brain areas involved in memory (hippocampus) and emotional (amygdala) processing was expected at the recognition phase (Dolan et al., 2000).

Method

Participants

Twenty right-handed, healthy, native French-speaking participants were included in this fMRI study. All participants had normal or corrected-to-normal vision and no history of psychiatric or neurologic incidents. Participants gave written, informed consent for their participation in accordance with the ethical and data security guidelines of the University of Geneva. The study was approved by the Ethical Committee at the University of Geneva and conducted according to the Declaration of Helsinki.

Three participants were removed from the analysis either because of poor performance or because they did not follow the instructions for the duration of the experiment. Analyses were conducted for 17 participants (5 men) aged between 20 and 36 years old (*M* = 27.65, *SD* = 5.52).

Stimuli

Faces The stimuli were selected from two databases: Karolinska Directed Emotional Faces (Lundqvist, Flykt, & Öhman, 1998) and FERET Database (e.g., Philips, Moon, Rauss, & Rizvi, 2000). Photoshop CS3 was used to replace the background behind each face with a uniform gray and to remove all accessories (e.g., tie, jewelry). In addition, the gray T-shirt from the Karolinska database was cut and placed on each photo from both databases. We controlled for grayness, size, resolution, and contrast parameters to obtain the highest homogeneity in the set of images. A total of 182 faces (91 men) were presented in a validation study involving 53 participants (17 men) between 18 and 65 years old (*M* = 30.58, *SD* = 11.95). Participants performed the pretest on an online experimental platform. They were asked to evaluate the trustworthiness, attractiveness, dominance, and happiness of each face by using continuous scales ranging from 0 (*not at all trustworthy/attractive/dominant/happy*) to 100 (*very trustworthy/attractive/dominant/happy*). In order to obtain a homogeneous set of stimuli, we selected 120 faces (60 men) that were evaluated on a trustworthiness range from 42 to 74 (*M* = 54.98, *SD* = 7.15), an attractiveness range from 31 to 70 (*M* = 49.59, *SD* = 8.38), a dominance range from 33 to 66 (*M* = 50.63, *SD* = 7.33), and a happiness range from 43 to 57 (*M* = 49.38, *SD* = 4.17).

Everyday situations Eighty-five written scenarios of everyday situations describing goal-conducive, goal-obstructive, and goal-irrelevant behaviors were created and presented to 57 (14 men) participants who were between 17 and 58 years old (*M* = 26.92, *SD* = 8.40) in a validation study. Participants performed the pretest on a web experimental platform. Participants were asked to evaluate their indifference (to assess the goal irrelevance) and their satisfaction (to assess the goal conduciveness and obstructiveness) about these situations from 0 (*not at all indifferent/satisfied*) to 100 (*very indifferent/satisfied*). We then asked them to evaluate the probability that this situation would happen in real life on a scale from 0 (*very unlikely*) to 100 (*very likely*).

We selected 60 situations describing goal-conducive, goal-obstructive, and goal-irrelevant behaviors (60 different situations: 20 of goal-conducive, 20 of goal-obstructive, and 20 of goal-irrelevant behaviors). To ensure that participants were familiar with the situations, we selected those rated as being more likely to happen. To do so, we chose those rated with the highest values for the goal-irrelevant scenario (goal-irrelevant condition: *M* = 74.75, *SD* = 8.36; goal-obstructive condition: *M* = 75.90, *SD* = 8.42; goal-conducive condition: *M* = 78.25, *SD* = 7.74). To obtain situations that the participants felt more indifferent about, we selected the goal-irrelevant condition (*M* = 71.53, *SD* = 10.54), that is, situations that they rated above 50 on the indifference scale. In contrast, to obtain situations that participants felt less indifferent about, we chose the goal-obstructive (*M* = 50.57, *SD* = 26.45) and the goal-conducive (*M* = 52.23, *SD* = 26.27) scenarios that had lower values on the indifference scale. Finally, to select situations that were in the middle on the satisfaction scale for the goal-irrelevant condition (*M* = 51.89, *SD* = 16.29), we chose those that were rated closer to 50. For the goal-obstructive condition, we selected situations that resulted in the lowest values on the satisfaction scale (*M* = 21.51, *SD* = 8.21), and for the goal-conducive situations (*M* = 76.71, *SD* = 11.82), we selected those situations that resulted in the highest values. Because longer or more complex processing compared with shorter and less complex processing might affect memory and faces associated with it, we controlled for sentence length (i.e., number of characters without spaces) across conditions (goal conducive: *M* = 51.73, *SD* = 14.23; goal irrelevant: *M* = 51.83, *SD* = 13.18; goal obstructive: *M* = 52.17, *SD* = 13.72). An analysis of variance (ANOVA) was performed, and no significant difference was found between the different conditions (i.e., goal conducive, obstructive, and irrelevant), $F(2, 177) = 0.016$, $p = 0.984$.

From this selection, we created three lists of 60 situations counterbalanced across participants. For example, all participants saw the following situation: “You are at IKEA with your car on Saturday afternoon.” However, one participant saw this situation in relation to a goal-conducive behavior (“This person is leaving and wants to give you her parking spot”), whereas another participant saw the same situation in relation to a goal-obstructive behavior (“This person came from the other side of the lot to take the parking spot you were waiting for”) or a goal-irrelevant behavior (“This employee is walking in the direction of the shop”). The length of the sentences was controlled to create a similar number of words across the different conditions.

To disentangle the effect on memory of goal relevance from arousal and valence (2 frequently described affective dimensions), we conducted a post hoc evaluation with 30 independent raters (9 men and 21 women; *M* = 32.6, *SD* = 9.54). The raters assessed the dimensions of goal relevance (from 0, not goal relevant, to 100, very goal relevant), arousal (from 0, not at all intense, to 100, very intense), and valence (from −50, very negative, to 50, very positive) for 60 situations. We created three lists to have one situation in relation to a goal-conducive, one in relation to a goal-obstructive, and one in relation to a goal-irrelevant behavior. The goal-conducive, goal-obstructive, and goal-irrelevant behaviors were counterbalanced across the different lists.

Procedure

Encoding task During the first session, participants read 60 different descriptions of everyday situations corresponding to 40 goal-relevant behaviors (20 goal conducive, 20 goal obstructive) and to 20 goal-irrelevant behaviors. Participants were asked to imagine as much as possible being in these different situations and to link each situation and the related goal with the identity of the person presented with a neutral expression (Fig. 1).

The duration of the presentation of the everyday situation was self-paced. The 60 identities presented with neutral expressions were seen twice by each participant for 1,500 ms each time: first, after the reading of the everyday situation, and second, after the reading of the description of the person’s

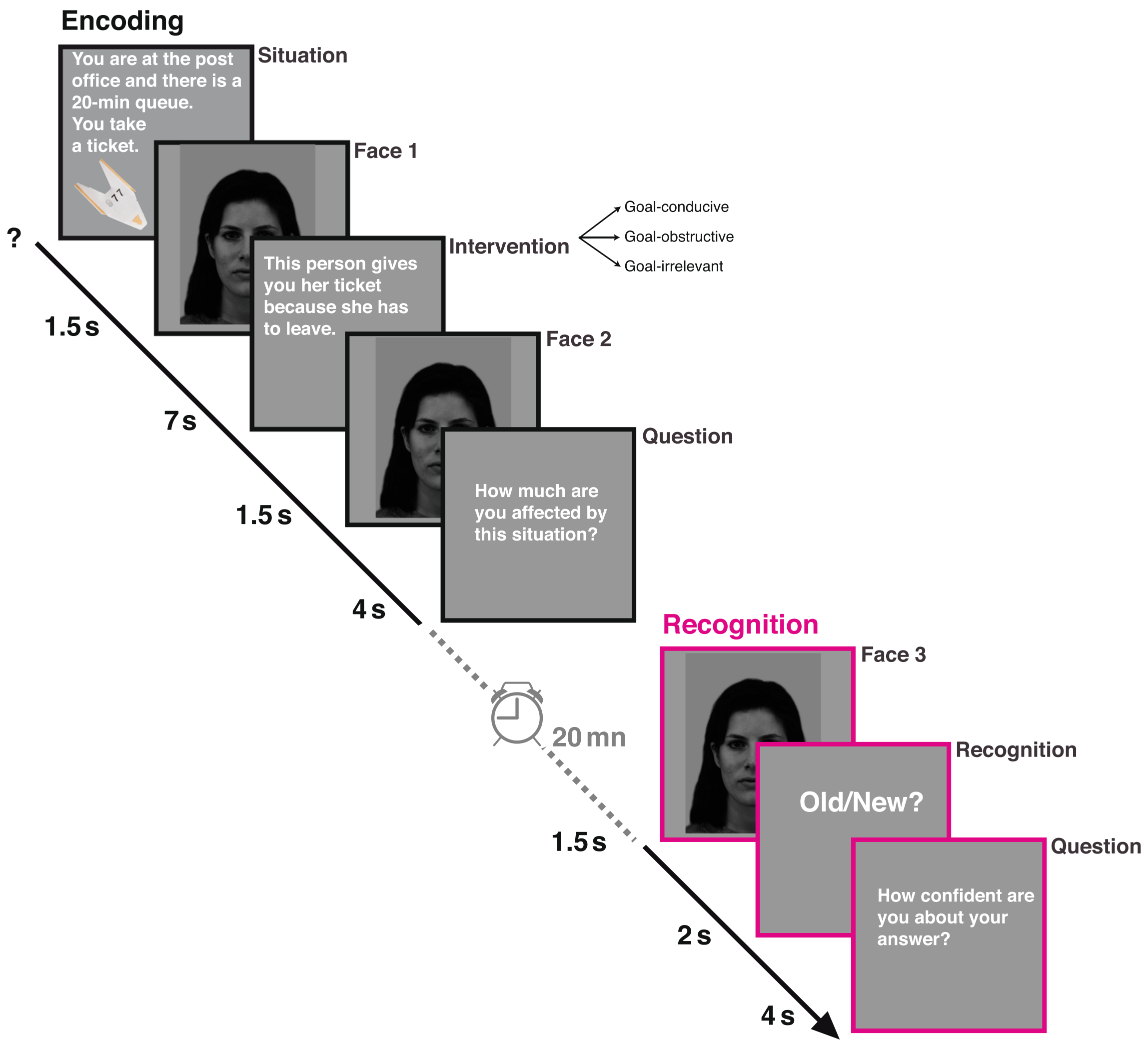

Fig. 1 Sequence of the functional magnetic resonance imaging experiment

behavior that was goal conducive, goal obstructive, or goal irrelevant. For each trial, after the repetition of the presentation of the identity, participants had 4,000 ms to report how much they were affected by the behavior of *this particular individual* (the identity presented) on a scale from 1 (*not affected at all*) to 3 (*extremely affected*). Across participants, behaviors and identities were randomized.

To allow time for consolidation of information in memory and to ensure a clear memory buffer in the participants, we included 20 min between the encoding and the recognition tasks. During this break, participants stayed in the scanner and watched a documentary film produced by the BBC (*Planet Earth*).

Recognition task During the recognition phase, 60 novel neutral faces were intermixed with the 60 neutral faces presented during encoding. For each item, participants made a judgment about whether the identity was "old" or "new." Participants also were asked to report the confidence they had about their memory from 1 (*not at all*) to 3 (*very confident*). In the end, we decided not to take into account the confidence ratings so as to avoid removing too many trials from the brain imaging analysis.

Image acquisition Data were acquired with a 3-T head-only magnetic resonance (MR) scanner (Siemens Trio, Erlangen, Germany) by using an echo-planar imaging sequence (35 slides, voxel size: 3 × 3 × 3.6 mm, repetition time (TR): 2,000 ms, echo time (TE): 30 ms, flip angle: 80°, field of view (FOV): 205 × 205 mm^2).

A structural MR scan was acquired at the beginning of the experimental session (T1-weighted 3D MP-RAGE sequence, TR: 1,960 ms, TE: 4.43 ms, inversion time: 1,100 ms, FOV: 230 × 173 mm^2, matrix size: 256 × 192 × 176, voxel size: 0.9 × 0.9 × 0.9 mm). Stimuli were displayed on a screen positioned at the rear of the scanner, which the participant could comfortably see through a mirror mounted on the standard head coil.

Image analysis Preprocessing and data analyses were performed by using SPM8 software implemented in MatLab

R2010b (www.fil.ion.ucl.ac.uk/spm/). Preprocessing was performed by using standard procedures, including realignment, slice timing, normalization, and smoothing (8-mm FWHM Gaussian kernel). The first-level analyses were then conducted with the general linear model approach by convolving each event or epoch of each condition. During encoding, the epochs were modeled with the boxcar function convolved with the hemodynamic response function (HRF). More specifically, the epoch started at the beginning of the presentation of the behavior (i.e., goal conducive, goal obstructive, or goal irrelevant) and lasted for the entire story presentation (7 s). Three event types were modeled, representing the conditions of goal relevance (goal conducive, goal obstructive, and goal irrelevant) so that we could compute linear contrast vectors. During recognition, events were modeled by convolving each trial onset with an HRF. The events started at the beginning of the presentation of the face and the duration was zero. For these two sessions, we separately modeled responses to old faces correctly identified as old (hits), responses to old faces identified as new (miss), responses to new faces correctly identified as new (correct rejection), and responses to new faces identified as old (false alarms) for the three goal-related conditions, as well as responses identified as non-valid (i.e., a value of 1, instead of 2 or 3, as the subjective impact of arousal attributed to the goal-conducive or goal-obstructive conditions). Realignment parameters were also entered in the design matrix. Finally, our contrasts were taken to a second level (random effects) and two separate group analyses (i.e., encoding and recognition) were performed by using ANOVAs. To examine the emotional processing of behaviors related to faces subsequently recognized, we contrasted brain activations of goal-conducive and goal-obstructive versus goal-irrelevant behaviors. During the recognition phase, our main contrasts compared faces that were subsequently recognized as being related to goal-conducive, goal-obstructive, or goal-irrelevant behaviors. We added to the model the forgotten faces, but we did not take this into account because of the small number of "miss" trials.

To account for the tendency of each subject to be potentially more affected by positive or negative situations, we controlled for a positive or a negative bias in a second whole brain analysis. Indeed, interindividual differences have been shown to influence affective intensity (Lazarus, 1991), and the amygdala has been proposed to play a role in social preference encoding (Haruno, Kimura, & Frith, 2014). To determine a positive or negative bias, we calculated from the subjective goal-obstructive and goal-conducive ratings a *negativity score* and a *positivity score.* First, we computed a score based on the sum of all goal-conducive trials and the sum of all goal-obstructive trials for each participant (e.g., if participant x rated that he was affected moderately by the goal-obstructive situation y [rated as 2/3] and that he was extremely affected by the goal-obstructive situation z [rated as 3/3], the score for the goal-obstructive condition would be 2 + 3 points = 5 points). To calculate the negativity bias, we subtracted the sum obtained for the goal-conducive situations from the sum obtained for the goal-obstructive situations for each participant. To calculate the positivity bias, we subtracted the negative bias from the sum obtained for the goal-conducive situations. These two scores were added as a covariate in two separate models.

Finally, we created a new model aiming at testing whether the effect of goal relevance on memory facilitation was particularly linked to goal-relevance rather than confounded with other affective dimensions, such as arousal and valence. For the encoding, the first column of the matrix contained all subsequently recognized trials (independent of the affected score given during the task) and the second contained all subsequently forgotten trials. For the recognition, the first column contained all the recognized trials and the second all the missed trials. Moreover, the scores for goal-relevance, arousal, and valence dimensions obtained by independent raters were added as three parametric modulators of each condition. We were then able to measure brain responses related to each of the three affective dimensions.

All neuroimaging activations were thresholded at a combined voxel level of $p < 0.001$ and a cluster extent of $k > 50$ voxels at the encoding phase and $k > 39$ voxels at the recognition phase. These combined voxel and cluster thresholds correspond to $p < 0.05$ corrected at the cluster level and were determined by the 3DClustSim algorithm implemented in AFNI software (http://afni.nimh.nih.gov/afni) according to the estimated smoothness of the data. Activations below this threshold were corrected for small volume. To perform small-volume correction (SVC), we chose coordinates selected from articles showing similar contrast analyses. All coordinates are reported according to Montreal Neurological Institute space.

Results

Behavioral Data

Subjective arousal The rating for how much participants were affected by the situations was computed to give a score of *subjective impact of emotion* (i.e., not at all affected = 1 point, moderately affected = 2 points, extremely affected = 3 points). From these scores, we performed an ANOVA to ensure that the situations affected participants as expected. Analyses indeed showed a main effect of goal relevance, $F(2, 32) = 179.13$, $p < 0.001$ (Fig. 2). Goal-conducive and goal-obstructive situations were rated as more arousing than goal-irrelevant situations, $F(1, 16) = 220.98$, $p < 0.001$, and $F(1, 16) = 250.35$, $p < 0.001$, respectively. Goal-conducive and goal-obstructive situations did not differ in terms of subjective arousal, $F(1, 16) = 1.70$, $p = 0.21$.

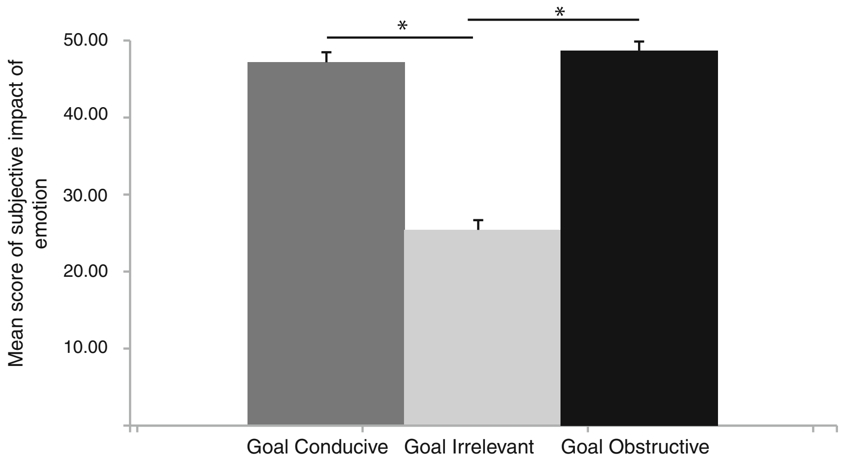

Fig. 2 Mean score of subjective emotional impact in percentage for goal-conducive, goal-irrelevant, and goal-obstructive situations. *$p < 0.001$

Memory task To test our hypothesis that neutral faces associated with goal-conducive and goal-obstructive behaviors were better remembered than neutral faces associated with goal-irrelevant behaviors, we conducted a repeated measure ANOVA on the percentage of correctly recognized neutral faces, in which we considered goal relevance (goal conducive, goal obstructive, and goal irrelevant) as a within-subject factor. We computed the accuracy by grouping the subjective impact of emotional stimuli given by the participants (i.e., assessed by the question, "How much are you affected by the situation?"). For the goal-irrelevant condition, we took into account the correct responses corresponding to *not at all affected* by the situation experienced, whereas for the goal-conducive and goal-obstructive conditions, we kept the responses corresponding to *moderately* and *extremely affected* by the situation experienced.

We found a significant main effect of goal relevance, $F(2, 32) = 3.51$, $p < 0.05$. Identities presented with a neutral facial expression and associated with goal-conducive behaviors ($M = 81.66$, $SE = 3.41$) were better remembered than identities presented with a neutral facial expression and associated with goal-irrelevant behaviors ($M = 74.90$, $SE = 3.67$), $F(1, 16) = 4.74$, $p < 0.05$, $d = 0.46$ (Fig. 3). Identities presented with a neutral facial expression and associated with goal-obstructive behaviors ($M = 81.10$, $SE = 3.20$) were better remembered than identities presented with a neutral facial expression and associated with goal-irrelevant behaviors, $F(1, 16) = 8.35$, $p = 0.01$, $d = 0.43$. Identities presented with a neutral facial expression and associated with goal-obstructive and goal-conducive behaviors were not significantly differently remembered, $F < 1$. Finally, the mean for the performance of false alarms (new faces identified as old) was 23.73 ($SE = 2.51$; a sensitive index such as d-prime cannot be analyzed with our specific experimental design because new faces cannot be specified as goal conducive, goal obstructive, or goal irrelevant).

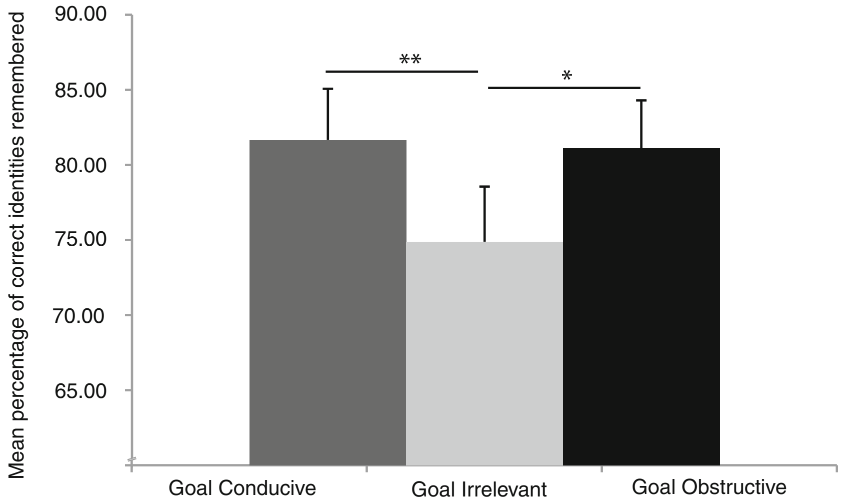

Fig. 3 Mean score in percentage of correct identities remembered and embedded in goal-conducive, goal-irrelevant, and goal-obstructive contexts. *$p < 0.001$, **$p < 0.05$

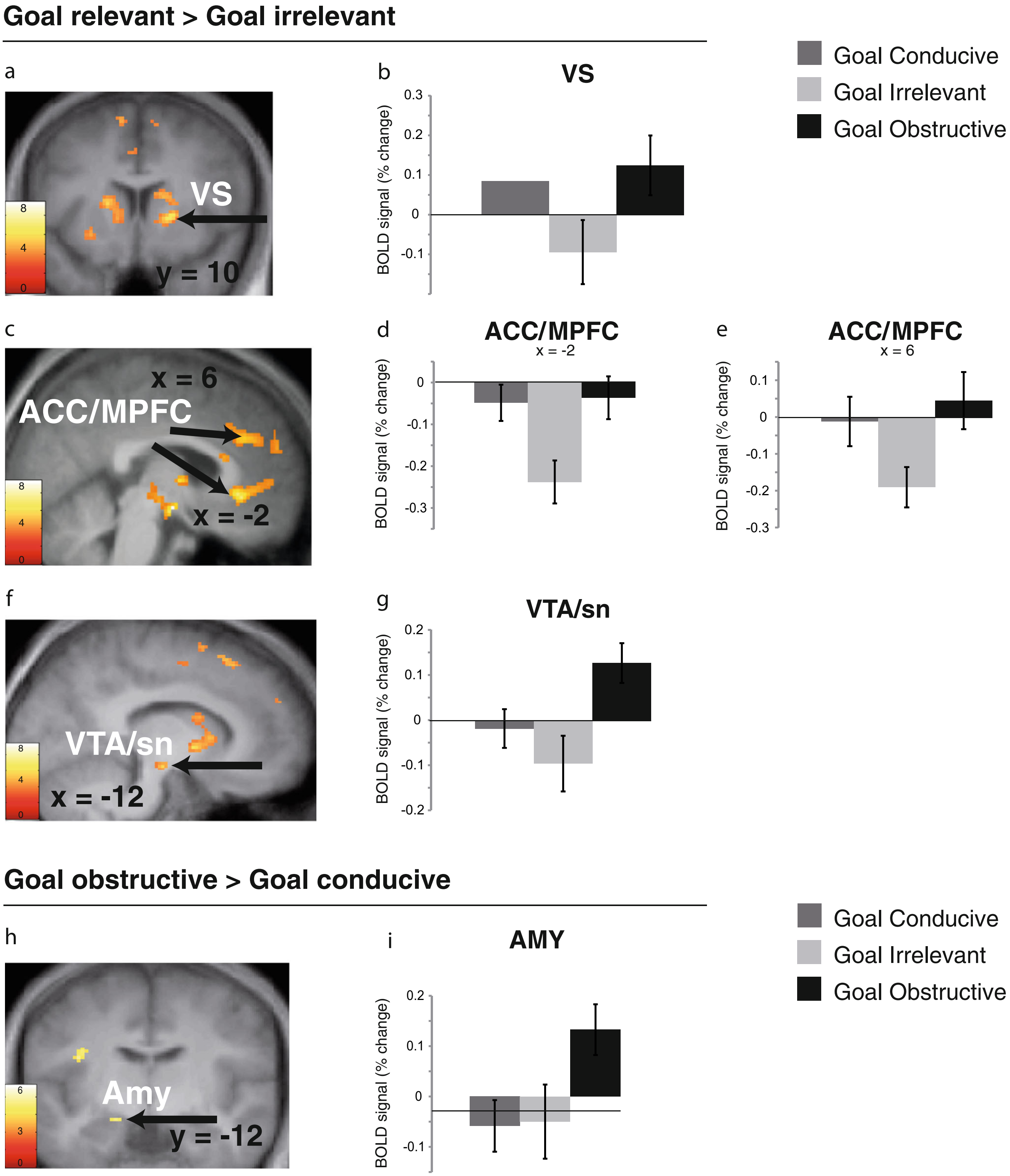

Fig. 4 Enhanced activity during encoding for the contrast goal-relevant > goal-irrelevant behaviors for subsequently successfully recognized identities. (**a**) Greater activation of the bilateral ventral striatum. (**b**) Percentage of signal change in the right ventral striatum. (**c**) Greater anterior cingulate cortex/medial prefrontal cortex. (**d-e**) Percentage of signal change in the anterior cingulate cortex/medial prefrontal cortex. (**f**) Greater ventral tegmental area/substantia nigra. (**g**) Percentage of signal change in the right ventral tegmental area and substantia nigra. Enhanced activity during encoding for the contrast goal-obstructive > goal-conducive behaviors for subsequently successfully recognized identities. (**h**) Greater activation of the amygdala. (**i**) Percentage of signal change in the left amygdala. VS = ventral striatum; ACC = anterior cingulate cortex; MPFC = medial prefrontal cortex; VTA= the ventral tegmental area; sn= substantia nigra; AMY = amygdala. Note. (**a-f**) Corresponds to $p < 0.05$ corrected at the cluster level (see *Methods*); (**h**) Corrected for small volume using a sphere of 10-mm radius

Neuroimaging Data

Our first objective was to test whether, at encoding, the brain responses reading goal-conducive and goal-obstructive versus goal-irrelevant behaviors, in particular those that would subsequently be correctly retrieved, showed more activation in key brain regions typically considered as being critical for emotional processing (e.g., amygdala, ventral striatum, anterior cingulate cortex, ventral tegmental area). Our second objective was to examine whether, in addition to these areas that could be reactivated, the STS, which is known to be involved in familiarity for faces and, more generally, social processing, was activated during the correct recognition of identities previously associated with goal-relevant versus goal-irrelevant behaviors. In addition, we were expected to find greater hippocampus and amygdala activation for the recognition of faces encountered in goal-relevant as compared in goal-irrelevant situations.

Encoding task The contrasts comparing goal-relevant to goal-irrelevant behaviors showed that goal-relevant behaviors elicited greater activation within the bilateral ventral striatum (bilateral caudate, putamen, and nucleus accumbens), substantia nigra, ventral tegmental area, bilateral insula, anterior cingulate cortex/medial prefrontal cortex (Fig. 4 and Table 1).

Goal-conducive compared with goal-obstructive behaviors showed greater activation in the right caudate. On the other hand, goal-obstructive compared with goal-conducive behaviors showed greater activation in the amygdala and the hippocampus (Fig. 4 and Table 1).

To test whether the effect of goal relevance of memory facilitation is particularly linked to goal-relevance rather than

Table 1 Encoding phase

Region	Hemisphere	Cluster size in voxels	MNI coordinates (*x, y, z*)	Z	References with SVC (reporting coordinates)
Goal relevant vs. goal irrelevant for subsequently corrected recognized items					
Nucleus accumbens	R	273	18, 10, 0	4.53	
	L		-14, 2, -2	4.39	
Caudate	R		22, 12, 10	4.31	
	L		-18, 10, 10	4.10	
ACC/MPFC	L-R	522	0, 36, 26	4.63	
			0, 22, 32	4.07	
			8, 28, 32	3.95	
ACC/MPFC	L	355	-2, 30, -4	5.21	
VTA/sn	R	274	4, -8, -14	5.40	
	L		-12, -16, -14	4.10	
			-2, -12, -8	3.96	
Insula	L	81	-26, 14, -20	4.08	
Insula	R	59	28, 20, -14	4.57	
Postcentral gyrus	L	86	-42, -30, 48	3.80	
Dorsolateral PFC	L	89	-22, 52, 30	3.80	
	L	80	-6, 20, 60	3.51	
Thalamus	L	358	-2, -2, -2	4.82	
Goal conducive vs. goal obstructive for subsequently corrected recognized items					
Caudate[a]	R	6	20, 20, 6	3.34	Liu et al., 2007 [18 16 4]
Superior frontal gyrus	L	57	-18, -6, 66	3.71	
Precentral gyrus	L		-22, -12, 62	3.22	
Goal obstructive vs. goal conducive for subsequently corrected recognized items					
Hippocampus[a]	L	12	-28, -20, -16	3.79	Ford, Morris, & Kensinger, 2014 [-32 -28 -18]
Amygdala[a]	L	7	-18, -12, -18	3.76	Okada et al., 2011 [-24 -8 -16]

Note. Corresponds to $p < 0.05$ corrected at the cluster level (see *Methods*).

[a] Corrected for small volume using a sphere of 10-mm radius. L = left; R = right; ACC = anterior cingulate cortex; MPFC = medial prefrontal cortex; Sn = substantia nigra; VTA = ventral tegmental area; SVC = small volume correction. Spatial coordinates are for the maximum voxel activation(s) in a cluster of suprathreshold voxels that covers one or several brain regions. Coordinates are in millimeters and correspond to the Montreal Neurological Institute (MNI) space.

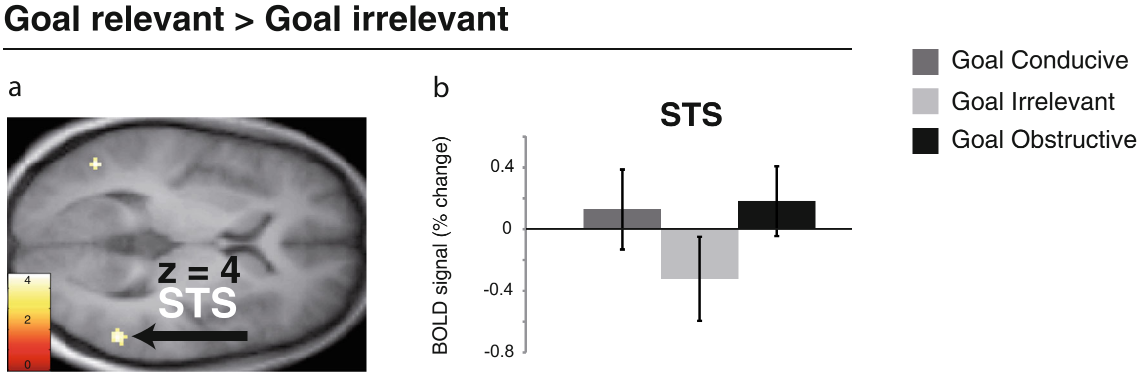

Fig. 5 Enhanced activity for identities successfully recognized and initially embedded in goal-relevant > goal-irrelevant behaviors. (**a**) Greater activity in the superior temporal sulcus. (**b**) Percentage of signal change in the right superior temporal sulcus. STS = superior temporal sulcus. Note. Corrected for small volume using a sphere of 10-mm radius

other affective dimensions, such as arousal and valence, we built a new model that included all correct trials regardless of the initial manipulation of goal relevance. We then took into account as covariates the scores obtained by independent raters on goal-relevance, valence, and arousal dimensions. We observed that behaviors subsequently recognized and rated as goal relevant were associated with activity in the VTA/sn areas [z-score = 4.81 (−12x, −16y, −10z), *p* = 0.010, small-volume corrected for familywise error with a sphere of 10-mm radius (Wittmann et al. 2008; Talairach Coordinate −9x, −18y, −7z)]. The reverse contrast that revealed brain regions related to behaviors subsequently recognized and rated as goal irrelevant showed significant activation in the left FFA [z-score = −3.72 (−34x, −34y, −18z), *p* = 0.027, small-volume corrected for familywise error with a sphere of 10-mm radius (Jiang & He, 2006; Talairach coordinate −38x, −35y, −11z)] and in the right FFA [z score = −3.81 (30x, −36y, −16z), *p* = 0.016, small-volume corrected for familywise error with a sphere of 10-mm radius (Jiang & He, 2006; Talairach coordinate; 35x, −39y, −14z)]. The same contrasts, using arousal and valence parametric modulators, did not show any significant results.

Recognition task At the recognition phase, we characterized the main effect of goals on correctly recognized items (the responses to successfully remembered identities with a neutral facial expression previously associated with goal-relevant > goal-irrelevant behaviors; Fig. 5; Table 2). This contrast showed a greater activation in the STS. To test whether the effect of goal relevance of memory facilitation is particularly linked to goal-relevance rather than other affective dimensions, such as arousal and valence, we built a new model with all correct trials regardless of the initial manipulation of goal relevance. We then took into account as covariates the scores obtained by independent raters on goal-relevance, valence, and arousal dimensions. We observed that neutral faces that were correctly recognized and rated as highly goal relevant were associated with activity in the left STS [*z*-score = 4.06, (−56x, −16y, −2z), *p* < 0.05, small-volume corrected for familywise error with a sphere of 10-mm radius (Holdstock et al., 2010; −64x, −26y, 2z)]. The contrast modulated by valence and arousal did not show any significant activation. To control for an effect of emotion modulated by negativity bias, we took it into account as a covariate (i.e., the brain regions that are more activated for goal-relevant than for goal-irrelevant faces and are more activated for participants affected by negative situations than for those affected by positive situations), and we observed that the amygdala was significantly more activated.

Table 2 Recognition phase

Region	Hemisphere	Cluster size in voxels	MNI coordinates (*x, y, z*)	Z-value	References with SVC (reporting coordinates)
Goal relevant vs. goal irrelevant for correctly recognized items					
STS^a	R	11	56, -54, 4	3.53	Tseng et al., 2014 [52 -48 12] NB: Talairach Coordinate
Goal relevant vs. goal irrelevant for correctly recognized items, taking into account negativity bias					
Amygdala^a	R	13	34, -4, -18	4.16	Haruno et al., 2014 [34 -4 -24]

Note. ^{a} Corrected for small volume using a sphere of 10-mm radius. R = right; STS = superior temporal sulcus; SVC = small volume correction. Spatial coordinates are for the maximum voxel activation(s) in a cluster of suprathreshold voxels that covers one or several brain regions. Coordinates are in millimeters and correspond to the Montreal Neurological Institute (MNI) space (except when mentioned "Talairach Coordinate" when reported from other studies).

The contrast for identities correctly recognized and previously associated with goal-conducive > goal-obstructive behaviors showed activations in the right insula. Identities successfully recognized and previously associated with goal-obstructive behaviors compared with goal-conducive behaviors showed greater activation in the right medial prefrontal cortex.

Discussion

The purpose of this study was to investigate incidental memory processing for identities presented with neutral facial expressions embedded in goal-relevant situations compared with goal-irrelevant situations. We expected that identities embedded in goal-relevant situations would be better remembered and that this would involve the reward and punishment system in particular. This system is known to play a key role in the mediation of different aspects of learning, leading to adaptive behaviors. In addition, we expected the amygdala to be involved in the detection of goal-relevant situations and in the recognition of identities embedded in such situations. We also hypothesized that the STS might be more activated for faces correctly recognized that were encountered in a goal-relevant as compared with a goal-irrelevant situation because of the emotional value acquired and incorporated in the multimodal representation.

Behavioral results showed that identities presented with a neutral facial expression embedded in goal-relevant situations—either related to the achievement of a goal (i.e., goal conducive) or to the obstruction of a goal (i.e., goal obstructive)—were advantaged in memory as compared with identities presented with a neutral facial expression embedded in goal-irrelevant situations. Memory performance enhancement was found for identities encountered in goal-relevant situations, which is consistent with the relevance hypothesis, according to which appraised goal obstructiveness and appraised goal conduciveness are key determinants of memory facilitation (Levine & Pizarro, 2006; Montagrin et al., 2013; Montagrin & Sander, 2016).

Brain imaging results revealed activations underlying the encoding of goal-relevant contexts in which identities were subsequently correctly remembered. Regions with a key role in the learning of rewarding and aversive situations were found to be more activated in the goal-relevant than in the goal-irrelevant situations (ventral striatum, ventral tegmental area, substantia nigra, cingulate cortex; Haber & Knutson, 2010; Matsumoto & Hikosaka, 2009; Metereau & Dreher, 2012). Consistent with our relevance hypothesis, we also found other regions that were involved in self-related information processing, such as goals for goal-relevant compared with goal-irrelevant situations (anterior cingulate cortex/medial prefrontal cortex; Stawarczyk and D'Argembeau, 2015).

During the recognition phase, despite the presence of a neutral facial expression, we found greater STS activation for successful remembering of identities previously encountered in goal-relevant compared with goal-irrelevant contexts. This activation is particularly interesting, because the STS has been shown to be involved in the processing of familiar faces or faces previously associated with laughter (Engell & Haxby, 2007; Holdstock et al., 2010; Jiang & Hu, 2006; Tseng et al., 2014; Vrticka et al., 2009) and has been proposed more broadly to play a key role in the retrieval of, for instance, intentions of familiar individuals (Gobbini & Haxby, 2007). Thus, in the current study, it is likely that at the encoding phase, people attribute a social value (e.g., intentions) to the face when they bind the behavior to the identity. Different features of an episode (i.e., target stimulus and context) are bound to ensure a coherent representation of the episode in memory (Van der Linden, 2014). This latter assumption is consistent with several models suggesting that the STS is responsible in multimodal representations and in recognizing a person's identity (Gobbini & Haxby, 2007; Yovel & O'Toole, 2016. Interestingly, although the behaviors rated as highly goal relevant were associated with regions involved in reward processing (VTA/sn; Wittmann et al., 2008), the irrelevant behaviors activated the bilateral FFA, a region that has a key role in identity processing (Haxby et al., 2000). It is interesting that FFA activation took place during the encoding of the behaviors, because the onset occurred just after the presentation of the face. It is possible that when behaviors were less relevant, people focused longer on the face (presented previously), whereas the highly goal-relevant behaviors captured the emotional response (sn/VTA activations). Thus, goal-relevant behaviors might be bound with neutral faces via the dopaminergic system, whereas at the recognition phase, STS activation reflects the successful retrieval of initially neutral stimuli, which became goal relevant.

We did not find, as expected, greater amygdala activation responsible for the emotional memory enhancement of goal-relevant versus goal-irrelevant information. We did, however, find that people who were more sensitive to negative situations revealed greater amygdala activation for memory of goal-relevant—compared with goal-irrelevant—identities, highlighting the importance of considering individual differences in the appraisal of situations. New studies should include autonomic measures of emotion, such as pupil dilation or skin conductance (Bradley, Miccoli, Escrig, & Lang, 2008; Lang, Greenwald, Bradley, & Hamm, 1993). Pupil dilation, for instance, has been shown to be a reliable measure of the arousal response (Bradley et al., 2008). The release of noradrenaline induced by an emotionally arousing event is suggested to play a key role in the effect of memory facilitation in interaction with the amygdala (McGaugh, 2000, 2015). The fact that we found more amygdala activation in people who are more sensitive to negative situations might be explained directly by the fact that such situations are more relevant or by an increased physiological response to these events because of their greater self-relevance. A particular role of relevance is in line with our second analysis showing that goal relevance used as a parametric modulator of subsequently recognized items is the only factor that has shown activation in emotion-related areas (in contrast to valence and arousal). Indeed, behaviors rated as goal relevant at encoding elicited greater activation of the reward system (i.e., VTA/sn regions), which is crucial to the success of memory formation (Wittmann et al., 2008). Our study tested the effect of goal relevance on memory. The construct of "goal" is conceptually considered in its broad sense (Austin & Vancouver, 1996), and goal relevance corresponds to the notion of concern-relevance (Montagrin & Sander, 2016; Pool et al., 2016; Stussi et al., 2018), which also includes the notion of self-relevance (Cristinzio, N'Diaye, Seeck, Vuilleumier & Sander, 2010; N'Diaye, Sander & Vuilleumier, 2009). Hence, in our study, we operationalized this construct specifically with respect to particular goals (rather than values, needs, or other concerns). Further research should address whether other relevant events also cause memory facilitation. A previous study, for instance, showed effects of in-group/out-group on memory depending on factors, such as race and sexual orientation (Correll et al., 2016; Hugenberg et al., 2013). Appraisal theories of emotion suggest that events that are appraised as relevant for the current concerns of an individual, such as goals, values, or needs, elicit an emotional response and modulate various cognitive mechanisms (Sander, Grandjean, & Scherer, in press). Thus, in line with appraisal theories of emotion, such events that are appraised as relevant should be facilitated in memory (Montagrin et al., 2013; Montagrin & Sander, 2016; Stussi et al., 2018). Because the interpretation of gaze direction can differ in relevance depending on context (e.g., fear/anger and direct or averted gaze; Adams & Kleck, 2005; Sander, Grandjean, Kaiser, Wehrle, & Scherer, 2007), it would be interesting, for instance, to examine whether identities that are most relevant, depending on context (i.e., interpretation given to the gaze direction and the emotional facial expression displayed), can be privileged in memory. In addition, further studies should examine a similar question by examining nonsocial faces and/or nonsocial context processing. Although we expect similar brain activations (i.e., ventral striatum, ventral tegmental area, substantia nigra, cingulate cortex/medial prefrontal cortex) for the encoding of relevant—but not specifically social-related stimuli—that are subsequently better remembered, we do not expect to find STS activation for nonsocial stimuli or a nonsocial context at recognition. Indeed, in addition to visual identity, the STS has been revealed to have a role in auditory representations (within and across modalities) in person identity processing (Anzelloti & Caramazza, 2017) but has not responded to nonsocial content, such as places, objects, or people who are not interacting (Lahnakoski et al., 2012). Thus, part of the findings of the current study might be specific to social stimuli.

In conclusion, we observed that identities encountered in goal-relevant daily life situations were better remembered than those encountered in goal-irrelevant daily life situations. This effect may be subserved by a learning and memory circuit involved in the processing of aversive and rewarding situations to automate adapted responses to future social situations. Finally, despite the fact that only neutral facial expressions were displayed by the different identities presented, we demonstrated increased brain activations in regions typically involved in the processing of emotional events, facial expressions, and multimodal representation. Identities may have been bound in memory with the relevant social value in which they were encountered.

The present study suggests that goal relevance plays a key role, at both behavioral and neural levels, in the emotional modulation of memory processing. These results, consistent with recent findings on emotional attention (Pool et al., 2016) and emotional learning (Stussi et al., 2018) support the relevance hypothesis of memory facilitation according to which emotional stimuli are facilitated in memory, because they are primary appraised as relevant for one's goals (Montagrin et al., 2013; Montagrin & Sander, 2016). However, because of the small sample size of the study, the generalizability of the results should be interpreted with caution and the study should be replicated for greater validity.

Acknowledgments The authors thank Dr. Julie Péron, Dr. Daniela Schiller and Dr. Sophie Schwartz for helpful comments and discussions. Dr. Ben Meuleman for his assistance with statistics.

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