Natural memory beyond the storage model: repression, trauma, and the construction of a personal past

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Naturally occurring memory processes show features which are difficult to investigate by conventional cognitive neuroscience paradigms. Distortions of memory for problematic contents are described both by psychoanalysis (internal conflicts) and research on post-traumatic stress disorder (PTSD; external traumata). Typically, declarative memory for these contents is impaired – possibly due to repression in the case of internal conflicts or due to dissociation in the case of external traumata – but they continue to exert an unconscious pathological influence: neurotic symptoms or psychosomatic disorders after repression or flashbacks and intrusions in PTSD after dissociation. Several experimental paradigms aim at investigating repression in healthy control subjects. We argue that these paradigms do not adequately operationalize the clinical process of repression, because they rely on an intentional inhibition of random stimuli (suppression). Furthermore, these paradigms ignore that memory distortions due to repression or dissociation are most accurately characterized by a lack of self-referential processing, resulting in an impaired integration of these contents into the self. This aspect of repression and dissociation cannot be captured by the concept of memory as a storage device which is usually employed in the cognitive neurosciences. It can only be assessed within the framework of a constructivist memory concept, according to which successful memory involves a reconstruction of experiences such that they fit into a representation of the self. We suggest several experimental paradigms that allow for the investigation of the neural correlates of repressed memories and trauma-induced memory distortions based on a constructivist memory concept.

Keywords: repression, memory distortions, PTSD, constructive memory, psychoanalysis, self-referential processing
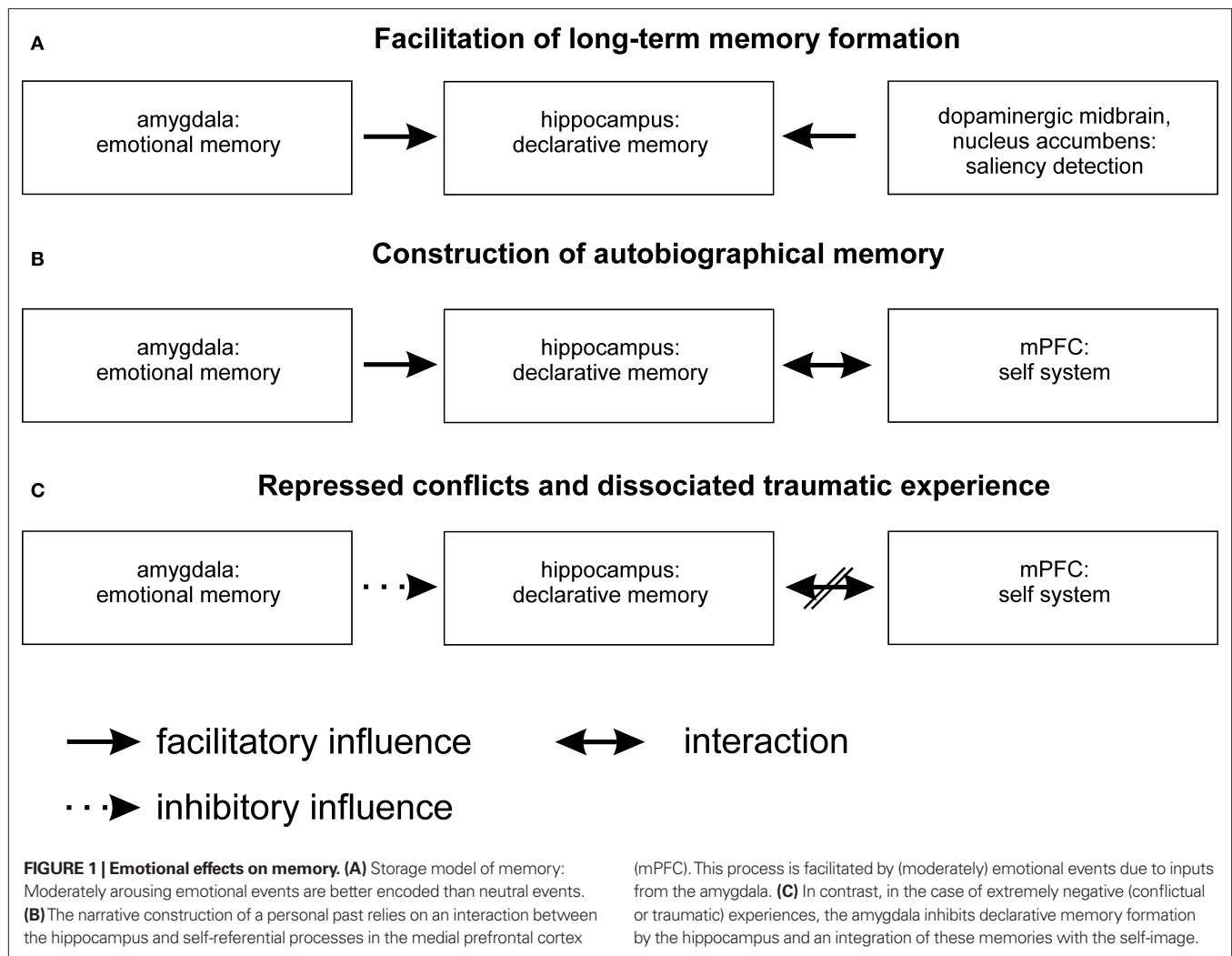
INTRODUCTION

The current cognitive neurosciences have already revealed some mechanisms underlying the modulation of memory performance. However, several phenomena occurring in natural memory like memory distortions due to repression and due to trauma-related dissociations have not been adequately addressed yet by neuro-cognitive research.

Many studies have shown convincingly that emotionally arousing stimuli are better remembered than neutral images (Heuer and Reisberg, 1990; Bradley et al., 1992; Christianson, 1992; Ochsner, 2000; Buchanan and Lovallo, 2001; Kensinger and Corkin, 2003). This effect depends on a facilitation of hippocampus-dependent memory processes by the amygdala (Seidenbecher et al., 2003; Dolcos et al., 2004; Kensinger and Corkin, 2004; Phelps, 2004; Smith et al., 2006; **Figure 1A**) and is related to the action of glucocorticoids (Kim and Diamond, 2002; Sapolsky, 2003). Such an interaction between amygdala and hippocampus may be necessary for the enhanced declarative memory of emotional events because these two structures support complementary processes, as revealed by a hippocampal-amygdala double dissociation: While integrity of the hippocampus is necessary for the conscious memory that a particular stimulus was, during conditioning, associated with a shock, the amygdala is required for the unconsciously associated vegetative reaction (Bechara et al., 1995; LaBar et al., 1995).

While these studies provide compelling evidence for an enhanced memory of stimuli which induce moderately negative emotions, this is not necessarily true for two problematic cases involving extremely negative emotions: the emergence of an unconscious conflict, which is subject to *repression*, and traumatic events that overstress a person's executive capabilities and thus lead to *dissociation*. As a result, conscious recall of these contents is impaired, but they continue to exert an unconscious effect which dramatically influences subsequent life – for example, by uncontrollably occurring intrusions and dissociative flashbacks, panic attacks, or psychosomatic symptoms (see **Box 1**). In other instances, victims of a traumatic experience may be able to recall details from the trauma, but only in a contorted manner – for example, from a detached view outside of themselves, or without the associated emotions. These symptoms of people which have suffered from real traumatic experiences are subsumed under the diagnosis of post-traumatic stress disorder (PTSD; F43.1, ICD-10, World Health Organization, 1992; DSM-IV-TR, American Psychiatric Association, 2000; Elbert and Schauer, 2002; Maercker, 2009).

Therapeutic interventions on patients suffering from symptoms due to repressed conflicts or traumatic experiences require an understanding of the mechanisms of repression and dissociation, not only on the psychological but also on the neurophysiological level (for the general benefit of cognitive neuroscience

A

Facilitation of long-term memory formation

| amygdala:
emotional memory | → | hippocampus:
declarative memory | ← | dopaminergic midbrain,
nucleus accumbens:
saliency detection |

B

Construction of autobiographical memory

| amygdala:
emotional memory | → | hippocampus:
declarative memory | ↔ | mPFC:
self system |

C

Repressed conflicts and dissociated traumatic experience

| amygdala:
emotional memory | ···▶ | hippocampus:
declarative memory | ↮ | mPFC:
self system |

→ facilitatory influence   ↔ interaction

···▶ inhibitory influence

FIGURE 1 | Emotional effects on memory. (A) Storage model of memory: Moderately arousing emotional events are better encoded than neutral events. **(B)** The narrative construction of a personal past relies on an interaction between the hippocampus and self-referential processes in the medial prefrontal cortex (mPFC). This process is facilitated by (moderately) emotional events due to inputs from the amygdala. **(C)** In contrast, in the case of extremely negative (conflictual or traumatic) experiences, the amygdala inhibits declarative memory formation by the hippocampus and an integration of these memories with the self-image.

BOX 1 | Memory distortions for problematic contents – repression and dissociation.

There are at least two distinct processes leading to memory distortions in the case of problematic contents involving extremely negative emotions: repression and dissociation. Repression is the process by which *internal* conflicts are stored in the unconscious. Dissociation, on the other hand, is the process by which parts of *external* traumatic events are stored in a non-declarative memory system (see below). *Repression* is a typical defense mechanism thoroughly described by Freud to explain clinical symptoms such as neurotic depression or psychosomatic symptoms he observed in his patients. According to Freud, the starting point is an internal conflict arising when (mostly unconscious) wishes or drives are in a strict opposition to internalized norms or standards. If this conflict cannot be solved (e.g., because opposing elements cannot be integrated with self-referential processes), it automatically produces intense anxiety signaling danger for the subject ("Signalangst"). In an effort to avoid extremely negative emotions, the entire conflict and its associated emotions and memories are pushed into the unconscious (repression). This leads to a lack of declarative memory for the conflict and often the circumstances under which it emerged. The conflictual material itself, however, continues to exist in the unconscious and,

more importantly, exerts a major influence on the subject by causing neurotic (e.g., depressed mood) or psychosomatic (e.g., paralyses) symptoms. According to Freud, the symptom is a symbolization of the internal conflict (for details, see Person et al., 2005). *Dissociation* is a process mainly investigated in the context of PTSD. When external traumata involving extremely negative emotions cannot be integrated with self-referential processes and no coherent narrative can be built, memories of this trauma become dissociated, i.e., they are stored in a system with no direct verbal access. Brewin (2001, 2003) uses the term "situationally accessible memory" to denote the memory system where such dissociated elements are stored. Verbal memories of the traumatic event are often vague and include gaps. The contents stored in the SAM, on the other hand, are the source for situationally triggered and hence not controllable intrusions and flashbacks typical for PTSD. Although distinct from the *process* of dissociation described here on a conceptual level, the clinical phenomena of "dissociations" in the traumatic situation (e.g., depersonalization, derealization) are empirically linked to the dissociation of memories in the SAM and hence the eventual development of a PTSD (Brewin and Holmes, 2003).

for understanding cognition see Henson, 2005; Axmacher et al., 2009). A number of studies investigated brain regions activated during presentation of trauma-related cues in PTSD patients by functional MRI (for a review, see Shin et al., 2005). Other studies used MEG recordings to explore the neurophysiological basis of the "trauma network" in PTSD. Elbert and colleagues found that in these patients, processing of arousing stimuli (e.g., IAPS pictures) relied more on a fast sensory processing pathway, which is uncoupled from prefrontal control, and less on elaborate processing along the ventral visual stream (Rockstroh and Elbert, 2010). This may be due to a reduced connectivity with neural assemblies representing context-related ("cold") and trauma-related ("hot") information; as a result, trauma victims are unable to locate their trauma memories in time and space and experience them as flashbacks (Elbert and Schauer, 2002). Psychotherapeutical treatment of PTSD patients (e.g., by narrative exposure therapy; Neuner et al., 2004) aims at re-integrating this network by placing the traumatic memories in a coherent context. However, despite the incontestable value of such studies directly investigating PTSD patients, they are necessarily retrospective and do not allow for an experimental control of the emotionally disturbing situation itself. Several experimental paradigms have been developed to capture the processes occurring during PTSD-*like* memory distortions in healthy control subjects.

In this article, we will first describe memory distortions due to repression of internal conflicts (Memory Distortions Due to Repression of an Internal Conflict) and due to dissociation of external traumata (Memory Distortions Due to Dissociation After an External Trauma). In the Section "Experimental Paradigms of Repression," we provide an overview of the experimental paradigms currently used in the cognitive neurosciences to study the neural correlates of repression in healthy volunteers. We will argue that these paradigms do not convincingly operationalize repression because they fall short of capturing key aspects of this clinical phenomenon. Next, we will broaden our scope and demonstrate that the concept of memory itself usually implied in cognitive neuroscience studies represents only one aspect of real-life memory, but disregards others and is therefore unable to capture several complex features of memory (Storage and Constructive Models of Memory): The criteria for successful memory retrieval – namely accurate recollections of particular events – and the corresponding measures in the cognitive neurosciences such as analyses of subsequent memory effects only capture one relevant dimension of memory but disregard its constructive aspects. This becomes most obvious in studies of autobiographical memory, which involves integration of experiences with self-referential processes (**Figure 1B**). In the Section "Trauma-Related Memory Distortions Due to Lack of Self-Referential Processing," we will argue that trauma-related memory distortions can only be adequately understood (and experimentally investigated) when they are conceptualized as a failure to construct autobiographical memories, i.e., to integrate these experiences with self-referential processes (**Figure 1C**). In other words, these memory distortions cannot be adequately understood as a failure to *store* memories, but as a failure to *integrate* them with self-referential processes. We will present a paradigm that takes these considerations into account. Finally

(Promising Approaches for Studying Memory Distortions Due to Repression), we will suggest a paradigm for the investigation of memory distortions due to repression.

MEMORY DISTORTIONS DUE TO REPRESSION OF AN INTERNAL CONFLICT

The concept of repression was originally suggested by Herbart (1824), but was introduced as a pathological process by Sigmund Freud (see **Box 1**). Most of his patients had symptoms that could not be explained by common logic or medical knowledge (e.g., paralyses of isolated limbs with no medical cause). In order to explain the etiology of such symptoms, he conceptualized the construct of repression as a mechanism being applied throughout child development. It means the storage of complete internal conflicts (mostly between drives or wishes and internalized norms or standards) and their surrounding emotions and memories in the unconscious (Freud, 1915). The developing child hence represses problematic content once an internal conflict is emergent. The classical view of repression as depicted in **Box 1** was significantly advanced by an increased consideration of the child's relationship to its parents and its developing self (Ferenczi, 1933; Balint, 1969). Internalization of a safe relationship to the parents is necessary for the development of agency and a stable self (Stern, 1985), and the infantile self is only developed through such parental feedback (Fonagy et al., 2005). In this new view, repression may occur when an internal conflict cannot be integrated with the image of the parents and/or self-referential processes. It is hence mainly this problematic integration in self-referential processes that give conflicts their true "pathological" value and trigger repression as a means to cope with them for the moment. The price to pay for the relative peace the developing self obtains by repressing internal conflicts is high, though: Clinically, it is important that the repressed material still exists in the unconscious and exerts a large influence on the subject by causing psychosomatic (e.g., paralyses) or neurotic (e.g., depressed mood) symptoms. The mechanism through which repressed conflicts gain access to the "outside" in the form of symptoms is called conversion (Breuer and Freud, 1895). By symbolizing the conflict or parts thereof in a symptomatic language, the patient can gain some relief at the price of clinical symptoms.

Although rooted in early twentieth century psychology and physiology, the concepts of repression and conversion via symbolization are still of high clinical relevance for recent models of psychotherapy (for a current clinical textbook see Person et al., 2005). Psychoanalytic therapies primarily working with the concept of repression are highly effective in treating patients with severe psychiatric problems (e.g., chronic depression, personality disorders), as reviewed in a recent meta-analysis (Leichsenring and Rabung, 2008). The recent trend that problematic integration in self-referential processes is regarded as the main virulent component of repressed conflicts is reflected in newer manualized psychodynamic treatments (e.g., Wöller and Kruse, 2010): The therapist should explicitly help the patient reorganize past experiences in a way that repressed conflicts can be integrated in self-referential processes. If successful, the patient not only gains clinical improvement on a symptomatic level (less or no need for conversion of an internal conflict in body symptoms), but also achieves a new and more coherent view of the self.
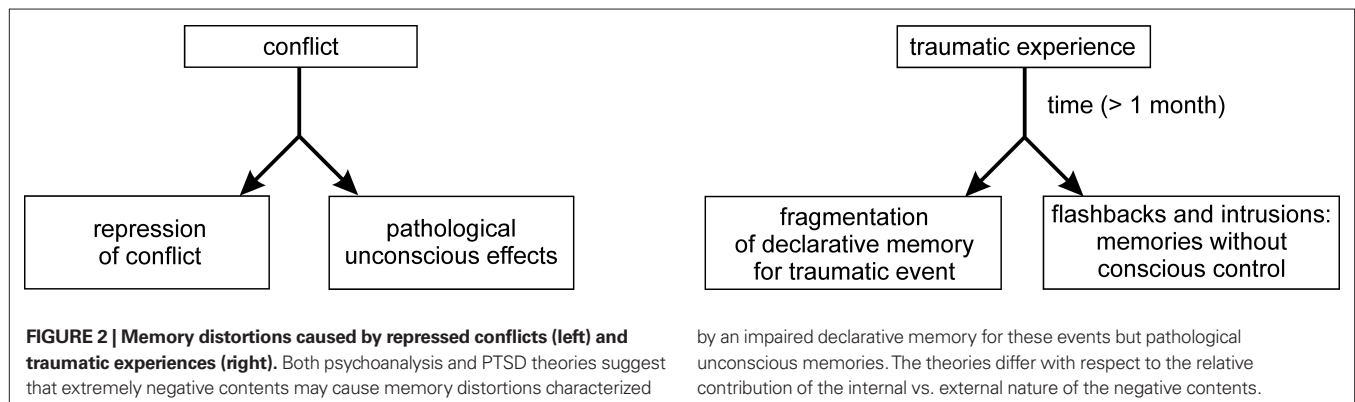
MEMORY DISTORTIONS DUE TO DISSOCIATION AFTER AN EXTERNAL TRAUMA

In contrast to the psychoanalytical focus on internal conflicts early in development, the concept of PTSD was primarily developed with regard to external later-life traumata, initially those during the Vietnam war. Memory distortions are, however, also among the main symptoms of PTSD. On the one hand, memories of the traumatic situation occur involuntarily as intrusions or even as flashbacks, in which patients do not remember the traumatic event as something past, but re-experience it as if it occurred again, similar to a dissociative state. On the other hand, declarative memory for details of the traumatic situation is often impaired (Brewin, 2007; Jones et al., 2007): A large body of studies have reported general declarative memory deficits in PTSD patients (Clancy et al., 2000; Behrendt and Moritz, 2005; Jelinek et al., 2006; for a review, see Brewin, 2007), and in particular concerning verbal declarative memory (Yehuda et al., 1995; Bremner et al., 2004). These memory impairments emphasize initial encoding and retention of new contents (Bremner, 2002), for instance, long lasting deficits in short-term memory have been shown in adults suffering from abuse during childhood (Bremner et al., 1995) as well as in Vietnam veterans diagnosed with PTSD (Bremner et al., 1993). Additionally, source memory referring to specific details of the traumatic event is often distorted in this population (Johnson et al., 1993). However, as we will elaborate below, the specific memory deformations following a trauma can be most accurately conceptualized not as failures to recall specific information, but as an impairment to integrate these experiences with self-referential processes, i.e., in the framework of constructivist memory theories (Trauma-Related Memory Distortions Due to Lack of Self-Referential Processing).

During the traumatic experience, limited time for conscious processing of accompanying sensory or vegetative perceptions inhibits an adequate integration thereof into autobiographical memory. This effect may depend on two mechanisms. First, an impaired processing of peripheral details during a traumatic situation due to a narrowing of the spotlight of attention is known as the *weapon focusing* effect (Christianson, 1992). This effect reduces the integration of all trauma-related information into a coherent representation. Second, traumatic experiences may be so overwhelming that the executive processing capabilities of trauma victims fail, leading to peri-traumatic dissociative states. In these states, subjects describe that they view themselves from a detached

standpoint (e.g., Bremner and Brett, 1997; Lanius et al., 2002). The dual representation theory (Brewin, 2003) accounts for these trauma-related memory distortions by suggesting that memory contents can be encoded either via a hippocampus-dependent mechanism, which leads to a narrative integration of these contents with other experiences and makes them accessible for declarative recall (*verbally accessible memory*, VAM), or via an amygdala-dependent process, which does not allow for a conscious control of memory retrieval; however, unconscious experiences encoded by the amygdala are automatically recalled whenever an associated cue appears. According to the dual representation theory, this latter memory system has been described as *situationally accessible memory* (SAM). This theory further suggests that amygdala and hippocampus inhibit each other in the case of extremely negative events, such that the degree to which the amygdala supports encoding of an event reduces the hippocampal contribution (Metcalfe and Jacobs, 1998; Brewin, 2001; **Figure 1C**). Indeed, functional MRI studies in PTSD patients indicate that recall of traumatic events is associated with an increased activation of the amygdala and a reduced activation of the hippocampus (Shin et al., 2005). Alternatively, it is possible that in this case the amygdala facilitates unconscious memory processes in the hippocampus (Henke et al., 2003; Degonda et al., 2005).

Although the memory distortions described in psychoanalysis (repression) and in PTSD research (memory fragmentations and intrusions due to dissociation) appear to be very different at first sight, they converge in the idea that pathological forms of unconscious memory replace declarative access to the problematic contents (**Figure 2**). In both cases, contents that are not verbally accessible (repressed conflicts or situationally accessible memories) exert a pathological influence on the subject by causing psychosomatic symptoms or intrusions and flashbacks, respectively. Thus, unconscious memories are created that do not refer to familiarity-based recognition memory, but to memories that induce intrusions and flashbacks following a trauma or neurotic symptoms following a repressed conflict. As will be elaborated below, both phenomena gain their true pathological value by a failure to integrate the problematic contents (internal conflicts or traumata) in self-referential processes. Finally, successful treatment of both includes the integration of problematic contents in a more coherent self. Therefore, we suggest that a common basis, or at least an overlap, exists for these two groups of phenomena, which might be defined in neurobiological

FIGURE 2 | Memory distortions caused by repressed conflicts (left) and traumatic experiences (right). Both psychoanalysis and PTSD theories suggest that extremely negative contents may cause memory distortions characterized by an impaired declarative memory for these events but pathological unconscious memories. The theories differ with respect to the relative contribution of the internal vs. external nature of the negative contents.

terms – possibly a modern replacement of the Freudian "metapsy-chology," which was deeply grounded in late nineteenth century neurophysiological knowledge (e.g., Stephan, 2002).

EXPERIMENTAL PARADIGMS OF REPRESSION

Cognitive neuroscience studies on repression have established two main experimental paradigms which aim at investigating repression in normal healthy subjects, the "Directed forgetting" and the "Think/No-Think" paradigm (Johnson, 1994; Anderson and Green, 2001; Erdelyi, 2006). In these paradigms, forgetting is consciously and intentionally controlled by the participants, who are explicitly asked to voluntarily inhibit randomly selected subsets of items or "not to think" of them: "On some trials they (i.e., the participants) were instructed to think of the previously learned picture; on other trials they were instructed not to let the previously associated picture enter consciousness." (Think/No-Think paradigm, Depue et al., 2007). One might wonder whether these paradigms are actually aimed at investigating the psychoanalytical process of repression. However, this is explicitly stated; for example, the article by Anderson et al. (2004) using the Think/No-Think paradigm starts with the phrases: "Over a century ago, Freud proposed that unwanted memories can be excluded from awareness, a process called repression. It is unknown, however, how repression occurs in the brain." (p. 232). In both paradigms, the instructions reliably lead to a decreased proportion of stimuli in the "voluntarily forgotten" condition which can be recalled in a subsequent declarative memory test. The functional MRI results show a reduced BOLD response in the hippocampus and an increased activity in the lateral prefrontal cortex, which was interpreted as index for a recruitment of inhibitory executive control processes. However, for three reasons we argue that these paradigms do not adequately operationalize the clinical process of repression. First, repression occurs specifically in situations which overload the executive processing capacities. During real repression, voluntary control is lacking; a person represses an experience because this experience induces an unbearable conflict. Therefore, attempting to induce repression by a recruitment of executive control processes is paradoxical. The process investigated by Anderson and colleagues can more precisely be termed "suppression," the voluntary "forgetting," or "keeping down" of unwanted content. Second, if the mechanism of repression is considered in isolation, it appears as if the contents of repression are only secondary. However, repression does not occur with regard to random situations or stimuli, but only if an intense negative emotion is evoked. Thus, repression should be automatically induced by the experimental stimuli. Third, an experimental paradigm of repression should not only reduce conscious access to "repressed" stimuli, but also exclude that these stimuli are just forgotten. In fact, it should even be shown that unconscious memory for these items is enhanced: The concept of repression was introduced to explain clinical symptoms by experiences which are not consciously accessible for the patients, but which continue to exert an unconscious influence. Thus, in a non-declarative, implicit memory test, an increased proportion of these stimuli should be "remembered," as shown in PTSD patients (e.g., McNally, 1997). For example, these stimuli may be erroneously classified as "new" during conscious recollection (because no conscious memory exists for them), but this (incorrect) response may be given with a delayed

reaction time as compared to stimuli which are in fact new, which could be interpreted as indirect evidence of an unconscious conflict during processing of these stimuli.

Alternative paradigms can take these critiques into account. In such paradigms, the process of repression should not be voluntarily controlled; instead, they should create a situation in which repression occurs automatically due to the emotional content of a stimulus. When the "repressed" stimuli are subsequently presented in a recognition memory test, it is hypothesized that they cannot be recalled consciously, but that they continue to exert an unconscious influence on the subject's behavior, as indicated by a measure of unconscious memory. In addition, however, there is a more general problem with the existing paradigms that are meant to operationalize repression, because they measure memory as an impairment of successful recall, but do not investigate whether memories are successfully integrated into the self. In other words, the constructive nature of successful memories is not taken into account. In the next two sections, we will explain such a constructivist concept of memory, which is particularly relevant for autobiographical memorizing (Storage and Constructive Models of Memory) and is impaired in trauma-related memory distortions (Trauma-Related Memory Distortions Due to Lack of Self-Referential Processing). Finally, we will describe paradigms which are suited to capture memory distortions related to repression of conflicts (Promising Approaches for Studying Memory Distortions Due to Repression).

STORAGE AND CONSTRUCTIVE MODELS OF MEMORY

In the cognitive neurosciences, memory is most often conceptualized as the process of stimulus encoding, storage, and retrieval. In this framework, memory recall involves an identical repetition of the original experiences – or, as Tulving (1983) described it in his famous definition of episodic memory, as a "mental time travel" back to the original situation. Accordingly, the neural correlates of memory are usually studied by analyzing "subsequent memory"-effects, i.e., differences in brain activation patterns associated with the initial presentation of subsequently remembered as compared to forgotten items. However, this storage model of memory only captures *one* relevant dimension of memory, which relies on the identity of encoded and remembered contents. In particular, it abstracts the specific function of memory retrieval for a subject. The cultural history of memory models has always consisted in a dichotomy of such storage models of memory on the one hand, models of constructive memory on the other hand (Assmann, 2002). Constructive concepts of memory as re-interpretation of events were, e.g., investigated experimentally by Bartlett (1932). In a number of studies, he presented his British subjects a short story, "The War of the Ghosts," which contains several seemingly illogical and irrational elements. When subjects were afterward asked to recall the story in as many details as possible, they modified it according to their own cultural schemata; illogical elements were thus replaced by more coherent narratives. These studies illustrate the constructive nature of memory retrieval and suggest that memory is not only designed to retrieve events exactly as they happened, but supports specific functions in the interaction with the (internal or external) environment.

Several current memory theories have incorporated aspects of such a constructive account on memory and also highlighted the relevance of self-referential processing. According to these views, it is not exact representations of external events that are encoded and retrieved, but the results from internal processing, evaluation, and interpretation of these events. For example, the theory of transfer-appropriate processing (TAP) interprets learning as re-performing a previous act, i.e., successful learning is an appropriate transfer of underlying structures rather than an access of a memory trace (Morris et al., 1977; Bransford et al., 1979; Baddeley, 2002). According to TAP, recall is facilitated by similarity between the encoding and the retrieval state; this effect is related to both environmental contexts (e.g., if encoding occurred in the library of the Psychology Department, recall will also be easier at that place) and internal variables such as current affective states and goals (events encoded in a sad mood will also be most likely retrieved in a sad mood). In addition, many studies investigated the effects of encoding conditions related to self-referential processing, e.g., by instructing subjects to rate the pleasantness of items (Hunt and Einstein, 1981; McDaniel and Einstein, 1993). Such effects have been described, e.g., in the framework of the levels of processing theory (Craik and Lockhardt, 1972). Furthermore, several experimental paradigms have investigated why events which have never happened are "recalled" (the false memory paradigm; see, e.g., Deese, 1959; Roediger III and McDermott, 1995), and why actual events are forgotten (e.g., retrieval-induced forgetting paradigms, Anderson et al., 1994; Macrae and MacLeod, 1999; Caroll et al., 2007). None of these theories and paradigms assumes a simple storage model of memory. Instead, they capture aspects of a constructive memory theory because they emphasize that memory encoding and retrieval depend on the construction of an integrated experience and the evaluation of its personal relevance. Furthermore, recall can be considered a "reconstruction" because it depends on the situational context during which it occurs.

However, there is a fundamental difference between these accounts and constructivist memory theories in a narrower sense, which is the criterion for successful memory: In storage models of memory, recall is successful if it recapitulates crucial aspects of a previous experience; according to constructivist memory theories, however, recall is successful if it allows the recalling person to build a coherent narrative about his/her past. Imagine that two people experience the same event, but afterward report two inconsistent versions of this event. According to the storage model of memory, there are objective criteria whether the report of the first or the second person is correct. In contrast, the constructive memory theory would assume that both reports may be correct as long as subjective coherence is achieved. This view differs considerably from paradigms such as the false memory paradigm, the retrieval-induced forgetting paradigm, or paradigms of voluntary memory suppression such as the "think/no-think" or "directed forgetting" paradigms: These paradigms investigate the conditions under which memory storage fails, but not the conditions under which a successful transformation into an acceptable narrative, and integration with self-referential processes, succeed. Similarly, even though theories such as the TAP theory or models such as the Adaptive Control of Thought model (Anderson, 1976) emphasize

the selective nature of encoding and retrieval, they do not require that experiences be integrated into a coherent and acceptable personal history for memory to be successful.

Recall of autobiographical memory is a prototypical example of a reconstructive memory process. Depending on situational requirements and personal aims, recollection of a personal experience serves specific functions. The main criterion for successful autobiographical memory recall is not whether a situation is exactly reproduced; instead, as it is one of the main functions of autobiographical memories to serve the construction of a coherent and acceptable self-image, these memories have to fit into a coherent construction of the past – for this reason, the subjects in Bartlett's studies modified the story according to their cultural expectations. Several more recent studies provide experimental evidence for this view. First, it has been shown in cross-cultural studies that autobiographical memory is influenced by the emphasis which is put in each culture on the self and on a unique life story (Nelson, 2003). Second, in each culture, autobiographical memory recall depends on an individual's current view of herself/himself, and serves the construction of a coherent and positive self (Wilson and Ross, 2003). For example, as improving selves are particularly gratifying (e.g., Frijda, 1988), subjects tend to view their own past abilities as inferior than their current abilities, and as lower than they viewed them before (Conway and Ross, 1984). Third, it was shown that the reported number of autobiographical memory recalls which aimed at creating self-continuity was higher in subjects with low degrees of self-concept clarity (corresponding to low levels of perceived self coherence), suggesting that autobiographical memory recall indeed served to strengthen self coherence (Bluck and Alea, 2008). Fourth, brain lesions which induce a loss of autobiographical memory may also lead to an impairment of the sense of one's self (Schacter, 1996).

The functions of autobiographical memory retrieval have been described in a review by Bluck (2003). First, memorizing serves the creation of a continuous identity: "[T]hough we often think of memory as a series of events, it is also a record of a series of selves, or a record of the self across time, an autobiography." (Bluck, 2003, p. 12). Second, memory is relevant for the creation and maintenance of social interactions: Often, personal statements are being justified by referring to autobiographical events, and a common past is created by evocation of situations that were experienced together. Finally, autobiographical memories serve a directive function, as they allow one to predict what will happen in the future and which actions will likely lead to the desired outcomes.

Cognitive neuroscience studies on the neuronal correlates of autobiographical memory recall support the view that this type of memory involves the construction of a self-image. These studies revealed an increased activation of both the hippocampus and the medial prefrontal cortex (mPFC) during processing of self-related autobiographical information (Cabeza et al., 2004; Summerfield et al., 2009). Activation of the mPFC was associated with self-referential processes, for example during presentation of photographs that subjects had taken themselves as compared to photographs taken by other subjects (Cabeza et al., 2004) or during evaluation whether adjectives could be attributed to oneself instead of to another person (Gutchess et al., 2007). The theory that autobiographical memory depends on an integration of declarative

memory and self-referential processes is depicted in **Figure 1B**. It should be noted, however, that reverse inference from activation of a given region during one experimental condition to mental processes occurring in this condition may be problematic because these activations are usually not unequivocal (for reviews on the validity of this inference see Henson, 2005; Axmacher et al., 2009).

While constructive concepts of memory exerted a strong influence on research in social psychology, most studies in the cognitive neurosciences (apart from autobiographical memory studies) followed the storage model. This is particularly problematic in the case of memory distortions due to repression and dissociation: Memory, conceptualized as a constructive process, serves to build personal identities. In contrast, repressed conflicts and traumatic events cannot become part of this personal identity; their subjective meaning is not re-evaluated and integrated into a narrative continuity with other events, but remains restricted to the situation when these events were experienced. Repressed conflicts and traumatic events remain permanently present in a pathological sense – they cannot be forgotten or temporarily dismissed. Thus, the case of memory distortions shows that constructive memory and storage memory are not only alternative concepts of memory, but are actually directly opposing each other in some respects. In the following two paragraphs, we describe further evidence for this view and present promising paradigms for the investigation of trauma-related and repression-related memory distortions.

TRAUMA-RELATED MEMORY DISTORTIONS DUE TO LACK OF SELF-REFERENTIAL PROCESSING

Several observations suggest that what is central for trauma-related memory distortions is not the lack of a memory for a traumatizing situation *per se*, but the lack of an integration of this memory with self-referential processes. First, during traumatic events, subjects may lose their sense of agency, i.e., they do not feel themselves as autonomous human beings but just as observers. Dissociation during the traumatic event is predictive for subsequent memory impairments and also for the development of PTSD – even more than trauma severity is (Maercker et al., 2000; Ozer et al., 2003). Second, PTSD patients often describe that the traumatic scenes are remembered from a detached view outside of themselves (Brewin and Saunders, 2001; Bohleber, 2008). Thus, they also recall themselves as lacking self-referential processing during the trauma. Third, loss of agency during traumatic events may also explain why traumatic events cannot only induce PTSD, but also a complex PTSD (Herman, 1992) or developmental trauma disorder (van der Kolk, 2005) which both involve changes to the self-image and an impaired feeling of identity. Finally, flashbacks can be understood as a dissociative re-living of the traumatic situation, i.e., re-living in a state of depersonalization and derealization (Maercker, 2009). Taken together, these considerations suggest that traumatic events mainly impair the *integration* of experiences with the internal perception and valuation of these events, and that the resulting memory distortions need to be conceptualized within a constructive memory framework (**Figure 1C**).

How can the reduced self-referential processing during traumatic experiences, with the resulting impairment in the construction of memories for these events, be assessed experimentally?

The effect of dissociation on the development of trauma-related memory distortions was studied in healthy control subjects by use of the *trauma film paradigm* (for an overview of this method, see Holmes and Bourne, 2008). This paradigm builds on observations that intrusive thoughts do not only occur in PTSD patients, but also in many situations of everyday life after strong emotional events (Berntsen, 1996; Mace, 2005). In the trauma film paradigm, intrusions are induced by a movie which contains emotionally disturbing scenes (e.g., scenes of victims from car accidents). This paradigm has already been used in a number of studies and reliably induces intrusive memories, which disappear after a few weeks (of course, ethical reasons prohibit the induction of an actual PTSD which is defined by the persistence of symptoms, after a trauma, for more than a month). In addition to intrusions, declarative memory for the contents of the trauma film is impaired (Brewin, 2007; Jones et al., 2007). Using this paradigm, it was shown that spontaneously occurring states of dissociation predicted subsequent intrusions (Holmes et al., 2004; Kindt et al., 2005). However, any attempts to increase intrusion incidence by experimentally induced dissociation failed (e.g., Holmes et al., 2007), suggesting that dissociation may affect memory distortions via an underlying psychological or physiological process, which is not triggered by the experimentally induced dissociation – e.g., via reduced activation of brain regions supporting self-referential processing.
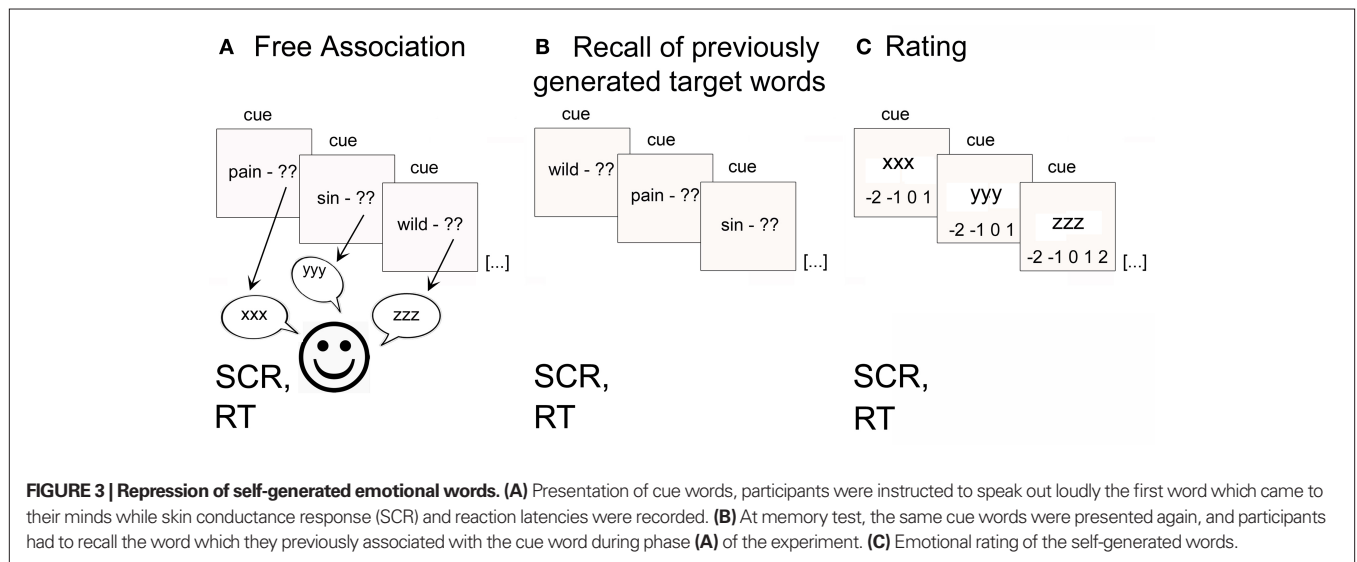
The neural basis of memory effects in the trauma film paradigm was investigated in two recent functional MRI studies (Henckens et al., 2009; van Marle et al., 2009). Physiological parameters as well as subjective reports confirmed that stress was induced by segments of a distressing movie. In the first study, IAPS pictures were presented interleaved with these segments and brain activity related to declarative encoding of IAPS pictures was analyzed (Henckens et al., 2009). In contrast to the impairment of declarative memory for traumatic events observed clinically, the authors found that stress increased subsequent recollection of pictures. However, hippocampal activity was reduced during successful encoding of images under stress, suggesting that memory formation required a hippocampal-independent mechanism. These results are therefore consistent with the dual representation theory and suggest that a high stress level shifts encoding from a hippocampus-dependent to an amygdala-dependent encoding mechanism (Brewin, 2003), although no implicit memory tests were performed, and thus the exact memory processes contributing to the stress-induced memory enhancement could not be resolved. In line with this interpretation, the second study showed increased responsiveness of the amygdala to facial stimuli presented interleaved with the movie, although memory for these items was not tested (van Marle et al., 2009). Further research using the trauma film paradigm will be extremely useful to test predictions from the dual representation theory more directly: First, it will be interesting to test memory for the movie segments themselves (instead of interleaved stimuli). Second, not only declarative memory but also intrusions should be captured using the diary method (Brewin and Saunders, 2001; Bisby et al., 2009); i.e., intrusions during the weeks following the experiment should be collected by diaries given to the participants. Finally – and maybe most importantly – the effects of dissociation during the movie should be investigated. As described above, it appears to be extremely difficult to induce dissociation by experimental

modifications. Therefore, dissociation could be measured on the neural level, by a reduced activation of regions supporting self-referential processing.

PROMISING APPROACHES FOR STUDYING MEMORY DISTORTIONS DUE TO REPRESSION

The neural signature of self-referential processing during memory recall can be used as a measure of successful reconstructive recall – or the lack thereof – not only in the trauma film paradigm, but also in paradigms investigating memory distortions due to repression. In one important paradigm (see **Figure 3**), which was initially suggested by Jung (1918), words in a list are presented consecutively and subjects are instructed to generate an associated word to each word in the list using the psychoanalytical technique of "free association" – i.e., they are asked to say the first word which comes to their mind. The idea of "free association" is rooted in Freud's psychoanalytical technique: When patients with neurotic symptoms say spontaneously what comes to their minds, they may eventually reveal material that can be linked by a skilled therapist to repressed conflicts which lead to or maintain their symptoms (Freud, 1913). The clinical usefulness of this technique has been shown many times (e.g., Person et al., 2005). According to Freud (1913), patients typically start to repress spontaneous thoughts once they may link to conflicts or memories that have to be kept unconscious. In Jung's (1918) original experiment, the process of "free association" is believed to reveal contents that are primarily unconscious but relevant for the subjects because they may be related to repressed conflicts. The

behavioral result of the hypothesized repression – resistance against revelation of these contents – can be confirmed experimentally by an increase in skin conductance response (SCR) and reaction times. The link between repression and the hypothesized increase in skin conductance is an indirect one: It is known that psychological arousal (activation) leads to increased skin conductance (Lang et al., 1995). Clinical experience suggests that patients may show increased signals of stress and arousal when repressing critical contents (Person et al., 2005). Thus, it is assumed that repression may be operationalized by increases in skin conductance. Next, the same list is presented again, but now subjects are not asked to name a new word by free association, but to recall the word they have initially generated. Finally, all initially associated words are presented again, and subjects are instructed to indicate the emotional valence and intensity of these words (as an indicator of conscious emotional content). In contrast to the often described increase in declarative memory for negative emotional material (Heuer and Reisberg, 1990; Bradley et al., 1992; Christianson, 1992; Ochsner, 2000; Buchanan and Lovallo, 2001; Kensinger and Corkin, 2003), this paradigm reliably results in an *impaired* memory for words whose initial generation is associated with physiological signs of resistance (increase in skin conductance and reaction times) and which are subsequently rated as emotionally negative (Levinger and Clark, 1961; Köhler and Wilke, 1999; Köhler et al., 2002). In particular, Levinger and Clark (1961) found that high SCRs during association predicted failure of subsequent recall. Furthermore, recall was worse for words which were afterward labeled as emotional as compared to words

FIGURE 3 | Repression of self-generated emotional words. (A) Presentation of cue words, participants were instructed to speak out loudly the first word which came to their minds while skin conductance response (SCR) and reaction latencies were recorded. **(B)** At memory test, the same cue words were presented again, and participants had to recall the word which they previously associated with the cue word during phase **(A)** of the experiment. **(C)** Emotional rating of the self-generated words.

Table 1 | Experimental paradigms for studying memory distortions.

Paradigm	Automatic stimulus effects?	Implicit memory enhanced?	Declarative memory impaired?	Self-referential processing considered?
Directed forgetting; Think/No-Think	No	? (not tested)	Yes	No
Trauma film paradigm	Yes	Yes (intrusions)	Yes	Yes (dissociation)
Levinger/Clark/Köhler (**Figure 3**)	Yes	Yes (reaction times)	Yes	Yes (subject-specific cues)

which were labeled as neutral. Several alternative explanations might account for these results. First, word frequency of the presented words may determine recall of associations. However, frequency was equilibrated between emotional and neutral words. Second, it is possible that recall depended on the number of possible associations to a word ("response entropy"). For words associated with high response entropy, the possible associations interfere with each other, making it more difficult to recall the initially associated word. In fact, Levinger and Clark found that forgotten words had higher response entropies than remembered words. However, partial correlations revealed that emotion and response entropy contributed independently to memory.

Several shortcomings of the study by Levinger and Clark (1961) should be noted. First, recall was only tested immediately after initial associations, leaving open the possibility that it does not induce sustained effects on memory. Second, reaction times as another possible measure of resistance toward revelation of repressed conflicts were not tested. In a follow-up study designed to overcome these shortcomings, Köhler and Wilke (1999) conduced a similar experiment, but (1) also measured reaction times during initial association, (2) asked subjects to recall the associated words not only directly after the association, but again after one week. They found that increased SCRs and reaction times during association as well as emotional ratings predicted both immediate forgetting and forgetting after 1 week.

To our knowledge, this paradigm has never been used for cognitive neuroscience experiments. However, the dual representation theory (Brewin, 2003) predicts that generation of subsequently forgotten words is associated with increased amygdala and decreased hippocampal activation, and a negative correlation of activity in these regions. Furthermore, based on the idea that repression is related to reduction in self-referential processing, we would expect that generation of these words leads to decreased activation of the mPFC, and to a reduced functional connectivity between this region and the hippocampus.

CONCLUSIONS

To summarize, we argued that storage models of memory as usually employed in the cognitive neurosciences are unable to capture the constructive nature of autobiographical memories and the impairment of this construction due to repression and traumatic experiences, and presented a number of experimental paradigms to study memory distortions in healthy subjects (**Table 1**). It should be noted that other lines of research have started to question the storage model of memory in cognitive neuroscience as well. First, the concept of *reconsolidation* implies that memories are not encoded for permanent storage, but that each recall involves a weakening of the memory trace and its possible re-integration with new experiences (Nader et al., 2000; Nader and Hardt, 2009). Second, studies of autobiographical memory often focused on the reconstruction of experiences rather than their exact recall. Third, the "prospective memory theory" describes that similar brain regions are activated during remembering the past and imagining the future, suggesting that both processes rely on similar constructions, or simulations, of currently absent stimulus representations (Schacter and Addis, 2007; Schacter et al., 2007). Fourth, social psychological studies exploring effects of social conformity on memory retrieval (Cialdini and Goldstein, 2004; Wright et al., 2009; Axmacher et al., 2010) could, in principle, also be adapted for neuroimaging research (Berns et al., 2005; Klucharev et al., 2009). Finally, the emerging field of "neuro-psychoanalysis" attempts to bridge the traditional gap between cognitive psychology and neuroscience on the one hand, psychoanalysis on the other hand, and might contribute relevant conceptual enhancements to cognitive neuroscience (Solms and Kaplan-Solms, 2000).

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