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Episodic Memory, Perceptual Memory, and their Interaction:

Foundations for a Theory of Posttraumatic Stress Disorder

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Abstract

A number of autobiographical memory theories and clinical theories of posttraumatic stress disorder (PTSD) make claims that are different from standard views of memory, and have been the subject of controversy. These claims include: The existence of a long-term perceptual memory system supporting conscious experience separate to episodic memory; greater involvement of perceptual memory in the response to emotion-laden and personally meaningful events; increased perceptual memory intrusions accompanied by impaired episodic memory for the traumatic event among PTSD patients; and a lack of association, or inverse association, between indices of voluntary recall and involuntary images relating to the same traumatic materials. In this article I review current research on perceptual memory, which supports the presence of long-term representations that are selective or incomplete reflections of sensory input. The functional independence of perceptual and episodic memory is illustrated by research on verbal overshadowing but is most clearly exemplified by the strong evidence in favor of enhanced perceptual memory and impaired episodic memory in PTSD. Theoretical predictions concerning the relation between perceptual priming and the development of intrusive images, the effect of verbal versus visuospatial secondary tasks on intrusive trauma images, and the independence of voluntary and involuntary memory for the same materials, have garnered widespread support. Reasons for the continuing controversy over traumatic memory are discussed, and some implications of the review for general theories of recall and recognition, clinical theories of PTSD, and "special mechanism" views of memory, are set out.

One of the most characteristic features of posttraumatic stress disorder (PTSD) is the involuntary intrusion of vivid and detailed images in which the traumatic scenes are re-experienced as though they were occurring in the present (flashbacks). This has led to PTSD being viewed as a disorder of memory (Brewin, 2003; McNally, 2003; van der Kolk, 2007), a proposal supported by recent research (Brewin, 2011a; Bryant, O'Donnell, Creamer, McFarlane, & Silove, 2011; Gootzeit & Markon, 2011). These frequent involuntary images are claimed to co-exist with impairments in the ability to retrieve ordinary episodic memories of the trauma. Drawing in part on some existing accounts of memory (R. Brown & Kulik, 1977; Johnson & Multhaup, 1992; Pillemer & White, 1989) as well as observations of patients (Janet, 1904), clinical theories of PTSD have proposed that flashbacks are the result of enhanced perceptual priming (Ehlers & Clark, 2000), are the product of a separate, image-based memory system (Brewin, Dalgleish, & Joseph, 1996), or arise because of a disconnection between such a memory system and episodic memories supported by medial temporal lobe structures (Brewin, Gregory, Lipton, & Burgess, 2010). All these theories therefore require the existence of a specialized long-term perceptual memory system that is functionally independent of episodic memory. The purpose of this article is to review the evidence for these claims, to establish their relevance to PTSD, and to bring out more general implications for the study of memory.

There has been a long-standing debate over whether visual information is stored in a depictive form (Kosslyn, Thompson, & Ganis, 2006; Paivio, 1971, 1991), corresponding to a distinct, specialized system retaining the spatial configuration of the sensory input, or in a more abstract propositional form in which perceptual information is just one feature among many within a single memory system (Pylyshyn, 2002). Whereas neuroimaging studies comparing visual imagery and perceptual tasks have supported the case for depictive representations (Borst & Kosslyn, 2008), studies of change blindness have strengthened the view that visual information may be retained in gist form rather than as a detailed pictorial representation (Simons & Levin, 1997). There has also been disagreement over whether a long-term perceptual memory store, if such exists, does (R. Brown & Kulik, 1977; Chun & Johnson, 2011; Goodman, 1980; Janet, 1904; Johnson & Multhaup, 1992; Pillemer, 1998) or does not (M. A. Conway, 2001, 2005; Tulving & Schacter, 1990) support conscious experience.

Other areas of controversy concern the functional relations between this hypothetical perceptual memory store and ordinary episodic memory. Clinical theories (Brewin, Dalgleish, et al., 1996; Ehlers & Clark, 2000; Foa & Rothbaum, 1998) take their cue in part from experimental research suggesting that the hormonal effects of acute trauma may simultaneously diminish neural activity in anatomical structures serving conscious processing and enhance activity in structures serving perception (Jacobs & Nadel, 1985; Metcalfe & Jacobs, 1998). This research implies that under some circumstances the strength of involuntary image-based trauma memories is unrelated to, or inversely related to, the strength of voluntary memory for the trauma as measured using indices of recall or recognition. In contrast, other researchers have asserted that all forms of traumatic memory are invariably clearer and better remembered than non-traumatic memories (McNally, 2003; Porter & Birt, 2001; Rubin, Berntsen, & Bohni, 2008; Shobe & Kihlstrom, 1997). More specifically, some have argued that increased involuntary memories of an emotional event would be expected to strengthen voluntary recall and recognition, leading to a positive correlation between the two types of remembering (Ferree & Cahill, 2009). These different views make this one of the most contentious issues in the study of memory for trauma.

The claims put forward concerning the relations between perceptual and episodic memory also have significant implications for our understanding of memory more generally. For example, there is an important paradox concerning the psychological treatment of PTSD. One of the most effective treatments is based on exposure, in which patients are required to deliberately and repeatedly rehearse their trauma memories in extreme detail, taking audio recordings to enable them to practice at home (S. P. Cahill, Rothbaum, Resick, & Follette, 2009). According to most standard theories of memory this kind of rehearsal would be expected to strengthen the trauma memory representation (Crowder, 1976) and, by extension, to exacerbate the disorder, but the opposite is observed (Hackmann, Ehlers, Speckens, & Clark, 2004; Speckens, Ehlers, Hackmann, & Clark, 2006). Although there are a few examples of rehearsal apparently weakening rather than strengthening memory, such as massed repetition decrements (Kuhl & Anderson, 2011), semantic satiation effects (L. C. Smith, 1984), and unpriming (Sparrow & Wegner, 2006), such effects have never been demonstrated for autobiographical memory. There does therefore appear to be a prima facie contradiction between standard memory theory and clinical practice that invites deeper understanding.

This article first considers the different ways in which perceptual memory for non-autobiographical material has been studied, including brief and longer-lasting representations, in a section titled Types of Perceptual Memory. The second section (Long-Term Perceptual Memory for Autobiographical Events) describes work on autobiographical memory, including the proposal that a type of perceptual memory is involved in the phenomenon of flashbulb memory. The third section (Interaction Between Perceptual and Episodic Memory) reviews research on situations characterized by independence between perceptual memory and episodic memory. Presentation of theories of PTSD in a fourth section (Perceptual and Episodic Memory in PTSD) is followed by reviews of the evidence that the disorder is accompanied simultaneously by a strengthening of involuntary perceptual memory and an impairment of voluntary episodic memory. A fifth section (Trauma-Related Research on Interactions Involving Perceptual and Episodic Memory) then examines the evidence that in the presence of traumatic stimuli these systems may demonstrate functional independence. A variety of reasons for the continuing controversy over the nature of traumatic memory are put forward in a sixth section (Reflections on the Controversy Concerning Memory Impairment in PTSD), followed by the implications of this review for the study of memory (Conclusions and Recommendations), both in healthy participants and in those suffering from PTSD.

Types of Perceptual Memory

The idea of a perceptual memory system has been most often associated with the notion of a very short-term ‘sensory’ or ‘iconic’ store, but it has also been considered in relation to representations that are able to endure over longer periods. Studies have suggested that a tripartite division into sensory memory, short-term memory, and long-term memory is a useful way of summarizing current knowledge (Luck & Hollingworth, 2008).

Sensory Memory

The term ‘sensory memory’ or ‘iconic memory’ generally refers to a short-term memory store that briefly retains sensory traces in the form of a rapidly decaying image following the brief presentation of a visual stimulus (Long, 1980). Typically the impressions last for up to one second, are pre-categorical (i.e., relatively unprocessed), have high capacity, and are sensitive to spatial position (Phillips, 1974; Sperling, 1963). There is also evidence for a corresponding pre-categorical acoustic store that holds perceptual representations of sounds in a relatively unprocessed form (Crowder & Morton, 1969; Frankish, 2008). Research has supported the existence of several types of early visual memory, all with a duration of the order of several hundred milliseconds, available for recoding into short-term and long-term memory (Irwin & Thomas, 2008). Emotional stimuli receive more prolonged processing in sensory memory than do neutral stimuli (Kuhbandner, Spitzer, & Pekrun, 2011).

Short-Term Perceptual Memory

A long-held view is that short-term perceptual memory representations are created rapidly either from external sensory input or from stored representations, have to be actively maintained, are resource-demanding, and are very limited in the information they can contain at one time (Luck, 2008). Typically the continuing representation of not more than five or six relatively simple objects can be maintained for many seconds. These representations are coded in relatively abstract formats that permit their maintenance across delay and subsequent perceptual processing (Luck, 2008), in contrast to the detailed but much more fleeting perceptual information that is maintained in sensory memory. Recent research has found evidence for another type of visual short-term memory (VSTM) representation known as “fragile VSTM” (Sligte, Vandenbroucke, Scholte, & Lamme, 2010) which is midway between sensory memory and conventional short-term memory in terms of the number of high-resolution objects that can be maintained and the lifetime of the representations.

Among their functions, short-term representations are thought to be involved in binding together individual sensory features to form a stable object, episodic memory, or action sequence. According to one prominent theory, this binding is brought about by focusing attention on an object or scene, so that the individual features are integrated by virtue of sharing the same location in space (Treisman & Gelade, 1980). This form of memory also permits rehearsal and the creation of more enduring representations in long-term memory.

Within the working memory framework (Baddeley, 1986) separate short-term memory stores exist in the visual (visuospatial sketchpad) and auditory (phonological loop) modalities. These stores retain information for limited periods of time so that cognitive operations (e.g., selection, manipulation, rehearsal) can be performed on their contents, under the control of the central executive. The vividness of recollections is determined in part by the availability of modality-specific working memory resources for maintaining information from long-term memory (Andrade, Kavanagh, & Baddeley, 1997; Baddeley & Andrade, 2000).

The working memory framework has also been applied to autobiographical memories. The emotionality and vividness of visual images corresponding to autobiographical events were selectively reduced by side-to-side eye movements, a task involving both visual and spatial interference, relative to a verbal (articulatory suppression) task (Kemps & Tiggemann, 2007). The opposite effect was obtained with auditory images of autobiographical events. This finding has since been extended to traumatic events experienced by patients with PTSD, for whom the vividness and emotionality of their visual images were reduced more by eye movements than by counting aloud (Lilley, Andrade, Turpin, Sabin-Farrell, & Holmes, 2009).

An influential conceptualization of the attentional processes that support visual short-term memory (Kosslyn, et al., 2006) proposed the existence of a buffer that contains information from the entire visual field. Only some of this information can be processed in detail, and an *attention window* selects some of the information in the buffer for further processing. Information in the attention window is sent to an object-properties processing system, where an abstract structural description is created on the basis of features such as shape and color, and can be compared with previously stored representations. This attention window has many similarities with conventional ideas about short-term memory, whereas the contents of the visual buffer may correspond to fragile VSTM.

Long-Term Perceptual Memory

Studies conducted within the working memory framework determined that attended information can be stored out of consciousness during gaps between operations, suggesting the need for a longer-term memory store, sometimes referred to as a visual cache (Quinn, 2008), that is able to support explicit memory operations. Reflecting the fact that most research has been conducted on experimental stimuli of low intrinsic memorability, there has been a correspondingly larger focus on priming and recognition as indices of memory.

Priming. Priming refers to the increased ease or speed of identification of a stimulus that the person has previously seen relative to one that was not previously seen. Priming is a form of implicit memory, in that it does not involve explicit recall of the previous stimulus exposure, and has been noted for words, shapes, pictures, and objects. Tulving and Schacter (1990) argued that the independence of priming and explicit memory performance made it highly unlikely that priming was the product of the kind of focal and abstract representations thought to support explicit recognition and recall. Rather, the data implied the existence of multiple distributed representations of features, including perceptual features, that could only be accessed by very specific cues. They therefore proposed the existence of a pre-semantic perceptual representation system (PRS), its operations being disconnected from consciousness and its products not providing a basis for awareness of previous experience.

From the outset priming studies indicated that even using relatively simple stimuli such as words there was greater informational persistence than was suggested by sensory memory studies, with effects regularly observed up to 24 hours post-stimulus presentation (Cave, 1997). Even more persistent priming was demonstrated when participants were shown fragmented pictures and had to name the object they contained. After having seen the pictures once, savings were found when participants were reshown the pictures as long as 48 weeks later. These effects appeared to be independent of recognition memory (Cave, 1997). Using these methods perceptual priming has been observed over periods as long as 17 years (Kennedy, Rodrigue, & Raz, 2007; Mitchell, 2006).

Spatial priming and memory. Recalling the spatial location of objects can rely on coding the information in relation to the perceiver (egocentric perspective) or in relation to the external world (allocentric perspective). It has been proposed that egocentric information derived from the dorsal visual stream is used in the service of visuomotor control whereas allocentric information derived from the ventral visual stream supports perception and object recognition (Milner & Goodale, 1993). According to Milner and Goodale, egocentric information cannot support perception and is only stored for a very brief period of time. In contrast, other theorists have provided evidence for parallel representational stores that capture both egocentric and allocentric information (Byrne, Becker, & Burgess, 2007). Byrne et al. proposed that the dorsal visual stream processes relatively raw, sensation-near information from the entire visual field whereas the ventral stream is involved in the extraction of abstract features and the detailed classification of attended information.

Both egocentric and allocentric information appear to be used in spatial memory tasks (Burgess, Spiers, & Paleologou, 2004). The length of time egocentric information remains available has beeen addressed by studies of spatial priming, the tendency for objects to be more readily located in positions where they have previously been seen. This research indicates that egocentric information for simple stimuli encountered in the laboratory is stored for at least two minutes (K. Ball, Smith, Ellison, & Schenk, 2009, 2010).

Recognition memory. A series of experiments has established that the brain has an enormous capacity to store information about briefly presented complex visual material over long periods. Recognition of 200 photographs presented for five seconds each was well above chance after a delay of nearly a year (Nickerson, 1968), and in another study participants were very accurate at recognizing which of 10,000 briefly glimpsed photographs they had been shown five days earlier (Standing, 1973). Importantly, perceptual information appears to be retained, not just the gist of objects or scenes. One study found long-term memory for details of observed actions (Urgolites & Wood, 2013), and in another participants were able to detect that a single object had changed orientation after having viewed 48 different scenes and hundreds of individual objects 24 hours earlier (Hollingworth, 2005). Individuals briefly shown thousands of scenes over several hours were later able to distinguish these scenes from similar examples with high accuracy (Konkle, Brady, Alvarez, & Oliva, 2010).

These striking results are consistent with evidence that in visual search tasks detailed information is encoded automatically leading to above-chance object discrimination

(Williams, Henderson, & Zacks, 2005). The features of events that are thought to be automatically encoded include spatial location, time, and frequency of occurrence (Hasher & Zacks, 1979). Of particular relevance to this article is the automatic encoding of spatial information, which has now been shown using a variety of paradigms (Treisman & Zhang, 2006; Zhang, Xuan, Fu, & Pylyshyn, 2010).

This degree of memory for briefly presented stimuli clearly cannot depend on the very limited capacity offered by short-term memory stores, and implies that either a visual buffer (Kosslyn, et al., 2006) or sensory memory provide an alternative access route to long-term visual memory. The brief duration of sensory memory means that such long-term representations are very unlikely to contain complete and detailed pictorial information that maps directly onto the perceptual experience. Rather, perceptual experience would have to be recoded in a way that captures a significant amount of information about form, color etc. and that then permits later recognition. Kosslyn et al.'s visual buffer, which is not dependent on the current focus of attention but maintains information about the wider visual field, may provide this recoding. Entry to the buffer is likely to depend on visual fixation, however brief (Nelson & Loftus, 1980; Williams, et al., 2005).

Studies of incidental memory for voices have found weaker recognition effects than for visual stimuli, but indicate an above chance ability for delayed recognition of individual voices that declines over the first few weeks (Clifford, 1980). Similarly, studies of memory for words indicate that participants can remember details of the voice reading the words for one day when given an explicit recognition test, and for one week when given an implicit perceptual identification test (Goldinger, 1996), supporting the idea that some perceptual information related to the specific learning episode is routinely encoded. Although rarely studied, evidence for long-term olfactory memory lasting as long as several years has also been reported (Goldman & Seamon, 1992; Lehrner, 1993).

Summary

As proposed by a number of theorists (R. Brown & Kulik, 1977; Chun & Johnson, 2011; Johnson & Multhaup, 1992; Paivio, 1971; Pillemer, 1998), a distinction between memory systems specialized for verbal and perceptual (visual, spatial, auditory, olfactory) material has emerged from studies of both short-term and long-term memory for non-autobiographical material. In the case of visual material, information that has been only briefly fixated appears to be encoded automatically and to form a relatively stable representation in long-term memory that then supports both priming and conscious forms of memory such as recognition. The form of this representation is thought to be a higher-level abstraction of the original input that preserves many perceptual features of it while not corresponding to a detailed and complete sensory image. This automatic encoding co-exists with the facility for more deliberate encoding based on a prolonged holding of material in focal attention, rehearsal, etc. One implication is that there may be a variety of visual representations of a particular event, differing in their content (visual, spatial, etc.) and in the extent of feature integration that has taken place. Further evidence for long-term perceptual representations comes from the literature on autobiographical memory.

Long-Term Perceptual Memory for Autobiographical Events

Perceptual details have invariably featured strongly in accounts of the recall of personal memories (Brewer, 1986, 1996), and this has been particularly true of events that are significant for the individual or include traumatic elements. The 19th century French physician and psychologist Pierre Janet, who studied the recall of traumatic events, was one of the first to propose the existence of an image-based memory system that captured sensory and perceptual details of significant scenes and was distinct from a verbally based narrative memory system (Janet, 1904). A number of other theorists (Johnson & Multhaup, 1992; Pillemer & White, 1989) have similarly proposed the existence of a separate long-term perceptual memory store that can support conscious experience. This system, they argued, is present from birth with its contents expressed through images, whereas the episodic system, developing in early childhood, is dependent on language with its contents expressed through narrative. Consistent with Janet's observations, it has been noted that people describing frightening experiences from the past often shift spontaneously into the present tense without realizing what they are doing (Pillemer, Desrochers, & Ebanks, 1998). Pillemer and colleagues suggested that in describing terrifying events there is an upswell of perceptual imagery, so that people are no longer simply recounting an episode but are effectively reliving some salient aspect of it, causing them to spontaneously fall into the present tense.

Perceptual information has been identified as belonging to the lowest or most specific level in an influential model of autobiographical knowledge that incorporates a hierarchy of specificity: lifetime periods, general events, and event-specific knowledge (M. A. Conway & Pleydell-Pearce, 2000). Later versions of the theory proposed a separate memory system that retains detailed sensory and perceptual knowledge over relatively brief retention intervals measured in minutes and hours (M. A. Conway, 2001, 2005), but then suggested that its contents, although hard to access without the necessary retrieval cues, may be permanent (M. A. Conway, 2009). Retrieval from this perceptual memory system is proposed to be involuntary rather than deliberate and corresponds to a recollective experience or reliving.

Flashbulb Memories

A focus of interest for those studying emotion and memory has been the level of recall for the circumstances in which individuals learned of shocking events such as the assassination of a prominent public figure. These were termed ‘flashbulb memories’ (R. Brown & Kulik, 1977) on the basis that they possessed “a primary, ‘live’ quality that is almost perceptual. Indeed, it is very like a photograph that indiscriminately preserves the scene in which each of us found himself when the flashbulb was fired” (p. 74). This account of flashbulb memory followed an existing notion (Livingston, 1967) that a surprising or emotion-arousing event triggered a “Now Print” mechanism that indiscriminately recorded any ongoing neural activity in the form of an enduring image. Brown and Kulik were clear, however, that this was an imperfect analogy: They commented perspicaciously that flashbulb memories did not record all details indiscriminately and were usually far from complete.

There is general acceptance that flashbulb memories of how a very significant event was learned about may endure over long periods (Berntsen & Thomsen, 2005). In addition such memories are sometimes more vivid and detailed than ordinary memories and better recalled than information about the event that triggered the flashbulb (Bohannon, 1988; Kvavilashvili, Mirani, Schlagman, Erskine, & Kornbrot, 2010; Kvavilashvili, Mirani, Schlagman, & Kornbrot, 2003; Rubin & Kozin, 1984; Talarico & Rubin, 2003; Talarico & Rubin, 2007; Weaver & Krug, 2004; Yarmey & Bull, 1978). Flashbulbs are also associated with more intense emotional responses (Holland & Kensinger, 2010; Talarico, LaBar, & Rubin, 2004; Talarico & Rubin, 2007).

In contrast, there has been controversy over whether flashbulb memories involve a special mechanism such as “Now Print” for preserving perceptual detail. This claim has primarily been evaluated by asking whether flashbulb memories are more accurate than non-flashbulb memories. Some studies have certainly indicated that flashbulb memories are often remarkably consistent. Over 85% of a UK sample reported flashbulb memories following the resignation of British prime minister Margaret Thatcher in 1990, and their reports collected 11 months after the event corresponded exactly to their descriptions given two weeks after the resignation (M. A. Conway et al., 1994). The authors noted that the actual words participants used were not the same, suggesting that they were not recalling their previous description but rather an image or memory of the actual reception event. Similarly, studies of the September 11 2001 attacks on the U.S. reveal that the majority of questions used to assess flashbulb memory were answered consistently over delays of 1-2 years (A. R. A. Conway, Skitka, Hemmerich, & Kershaw, 2009; Kvavilashvili, Mirani, Schlagman, Foley, & Kornbrot, 2009).

Other articles, however, have emphasized that flashbulb memories may show evidence of inconsistency and are not always more consistent than non-flashbulb memories (Larsen, 1992; Neisser & Harsch, 1992; Talarico & Rubin, 2003; Talarico & Rubin, 2007). For example, Neisser and Harsch reported high degrees of inconsistency for memories of hearing about the Challenger explosion three years previously. They concluded that flashbulb memories did not have special qualities but were likely ordinary memories that had been subject to additional rehearsal. Other authors have come to the same conclusion (McCloskey, Wible, & Cohen, 1988).

As has previously been noted (Kvavilashvili, et al., 2009), the focus on consistency has thrown up awkward questions concerning what features should be measured, how they should be measured, and what degree of consistency over what time period should characterize a flashbulb memory. But it is now clear that the issue of whether flashbulb memories involve a more detailed perceptual record of an experience than ordinary memories, and whether they are more consistent, are logically distinct questions. Once past the stage of sensory or iconic memory, perceptual memory involves synthesis and selection (see section on Types of Perceptual Memory). Likewise, amygdala activation prompted by arousing experiences leads to the subjective experience of a vivid memory and to the registration of more event details, but not to the registration of *all* event details (Holland & Kensinger, 2010; Kensinger, Garoff-Eaton, & Schacter, 2006). Thus, the appropriate question may not be whether a narrative of the circumstances in which the person learned of the flashbulb-eliciting event is consistent or inconsistent, but whether specific images are prompted by questions or reminders about the event and whether their contents are consistent or inconsistent.

At recall individuals must make a selection from available perceptual details, and this selection may vary across recall occasions. Nor does hearing of an event necessarily consist of a single experience but it may be protracted, with new and more shocking information coming to light over a period of time. It is quite possible, therefore, that multiple perceptual records are encoded so that, even if each one of them were perfectly accurate, inconsistency could arise from retrieving some of them and not others (Kvavilashvili, et al., 2009; Neisser & Harsch, 1992). The implication is that just because a memory is strongly perceptual does not mean it is necessarily more accurate in every respect.

Among other ways of identifying the presence of ‘special mechanisms’ is to conduct taxometric analyses on flashbulb memory data to test whether scores fall onto a continuum (suggesting they are simply a vivid form of ordinary memory) or into two separate categories (suggesting they represent a different form of memory). A recent study of memories for the Pope's death (Lanciano & Curci, 2012) found clear evidence for a latent categorical structure. The authors concluded that their findings supported the idea of flashbulb memories as recollections of event-specific sensory-perceptual details, different from ordinary autobiographical memory. Other studies have found that the correlates of flashbulb and event memories for the same incident are different (Curci & Luminet, 2006; Hirst et al., 2009), also supporting the fact they may have a different underlying basis.

Summary

Unlike studies of experimental materials, which have mainly relied on measures of priming or recognition, research using personally meaningful autobiographical memories has placed a much greater emphasis on recall, both voluntary and involuntary. These studies are consistent with investigations using experimental stimuli in suggesting that visual memories are not simply gist-based and that high levels of perceptual detail concerning scenes and events can be preserved over long periods. Although studies of autobiographical memory have emphasized the important role played by perceptual information, this information is mostly embedded within the context of the episodic memory. Such studies cannot speak convincingly to the claim that such information is supported by a distinct memory system.

Interaction Between Perceptual and Episodic Memory

Of particular theoretical interest is the relation between episodic and perceptual memory. Under normal conditions, for example the conscious recall of significant autobiographical events, both are likely to be enhanced. The flashbulb memory literature showing increased perceptual memory for notable events is consistent with there being corresponding improvements in memory for non-perceptual details. Although there is some limited evidence that emotions may selectively strengthen perceptual over other types of memory (Arntz, de Groot, & Kindt, 2005; Kensinger, Addis, & Atapattu, 2011; Kensinger & Schacter, 2007), what are of value are demonstrations that under certain conditions there is a dissociation between episodic and perceptual memory, with one functioning more effectively and the other less effectively. Two areas of the literature, concerned with verbal over-shadowing and the use of automatic cameras to prompt recall, are relevant to this question.

Verbal Overshadowing

A demonstration that verbally-influenced and perceptual representations of the same stimulus event may sometimes compete comes from work on verbal overshadowing. In an initial study, participants watched a video of a robbery carried out by a salient individual whom those assigned to the verbalization condition subsequently described (Schooler & Engstler-Schooler, 1990). Participants who described the robber were subsequently poorer at picking him out of a lineup, compared with control participants who read an unrelated text for the same amount of time. Detrimental effects of verbal descriptions have since been found for other visual stimuli such as abstract shapes (Brandimonte, Schooler, & Gabbino, 1997) and perceptual events (Huff & Schwan, 2008), as well as for other aspects of perceptual memory including recognition of colors, music, and voices (Chin & Schooler, 2008).

Although verbal overshadowing can be reliably demonstrated for face recognition (Meissner & Brigham, 2001), the effect is not large and is now known to be reliant on particular features of the experiment. Under conditions that vary from those of the classical overshadowing paradigm (e.g., use of multiple faces rather than a single face, immediate rather than delayed verbal description), verbalization can have the opposite effect of facilitating memory for faces (C. Brown & Lloyd-Jones, 2005; Meissner, Sporer, & Susa, 2008). These varied effects of verbalization are discussed in detail in a special issue of the European Journal of Cognitive Psychology (Lloyd-Jones, Brandimonte, & Bäuml, 2008).

For the purposes of this review, however, the main interest concerns those situations where verbally-influenced representations impair perceptual memory for the same stimulus. Two main explanations of this effect have been discussed (Chin & Schooler, 2008). The content or retrieval-process explanation proposes that the information generated by the verbal description is a poor match to the perceptual experience, and produces a deficient, verbally-biased representation. This new representation interferes with retrieval of the perceptual representation required for accurate recognition but does not eradicate the original visual memory. Consistent with this, there is a small but significant association between the quality of the verbal description and subsequent recognition accuracy (Meissner, et al., 2008). Supporting the idea that the original memory retains intact, overshadowing effects can be attenuated by re-introducing visual cues present at encoding (Brandimonte, et al., 1997).

In some cases, however, verbalization of one stimulus has had detrimental effects on the recognition of other, non-described stimuli. This finding has led to an alternative explanation that contrasts a global/holistic/configural processing orientation, with a focus on the entire stimulus array and the relations between them, with a local/analytic/featural processing orientation in which the focus is on individual features. According to one version of this account, verbalization may under certain circumstances produce a switch to local/analytic processing, which then impedes performance on tasks, such as the recognition of complex perceptual events, that require more global processing (Chin & Schooler, 2008).

This explanation, known as the transfer-inappropriate processing shift account, has been supported by evidence that manipulations requiring participants to focus on the local features of unrelated stimuli tend to impair face recognition whereas a more global focus on the same stimuli improves recognition (Macrae & Lewis, 2002).

Although no one explanation is likely to account for all verbal overshadowing effects, the retrieval process account emphasizing competing representations in memory is of particular interest for this article. The account has been applied not only to perceptual memory but to visuospatial memory. Investigators have studied how verbal overshadowing affects route finding versus configural knowledge applied to the same map (Fiore & Schooler, 2002). Whereas route memory involves recalling a specific series of consecutive locations and can be based on egocentric spatial representations, configural knowledge involves recalling the relationship between elements in the whole scene and hence depends heavily on allocentric spatial representations (see previous section on Spatial priming and memory). Fiore and Schooler reported that, compared to controls, participants who were required to verbalize their knowledge of a route involving 16 landmarks were significantly impaired on a task involving configural knowledge.

In a related study (Brandimonte & Collina, 2008), participants memorized line drawings which they were subsequently required to mentally rotate, enabling them to identify the letters that made up the drawing. Naming the line drawings at encoding led to a verbal overshadowing effect, but only when the names were provided by someone else. Names generated by participants themselves improved performance. Because performance depended on the specific nature of the verbal label, rather than on verbalization *per se*, the authors concluded that their findings supported a retrieval process over a transfer-inappropriate processing account. A similar study (Walker, Blake, & Bremner, 2008) investigated the impact of naming on alternative visual object representations. Participants were briefly shown a novel object that they were asked to draw. Half were provided with a name (‘riff’ or ‘dax’) for the object and the other half were not given a name. The results showed that after a delay participants given a name for the object tended to draw it from an alternative viewpoint to the one they had originally seen, whereas without a name participants showed no such tendency. As in Brandimonte and Collina’s study where a name provided by someone else favored configural over featural representations, Walker et al. argued that naming favored access to the allocentric representation and reduced the accessibility of the egocentric representation.

SenseCam Studies

Recent work using new image capture technology has suggested that perceptual information can be stored for long periods in the absence of episodic recall. SenseCam is a small camera with sensors that is typically worn high on the chest and automatically takes pictures of the environment immediately in front of the wearer (i.e., from an egocentric viewpoint) (Hodges, Berry, & Wood, 2011). When pictures are taken is determined by a timing device and by change detected by the sensors, not by the intervention of the wearer. A fish-eye lens results in nearly everything in front of the camera being photographed. During the course of a day SenseCam may record several hundred images. In an early study it was found that a patient with severe episodic memory impairment consequent on limbic encephalitis was, after viewing the corresponding SenseCam images, able to report apparently normal recall of 80% of recently experienced events, significantly more than when using a written diary. The images were reported to trigger occurrences, thoughts, and feelings associated with the episode but not contained in the images. The patient retained a high level of recall over 11 months, despite not having reviewed the images in the final three months (Berry et al., 2007). Similar improvements in recall have been reported in another patient with severe memory problems (Loveday & Conway, 2011).

A subsequent neuroimaging study with the patient studied by Berry et al. investigated neural responses to SenseCam images of an event that had been rehearsed by repeated viewing of the images versus another event that had been rehearsed using a written diary (Berry et al., 2009). Repeated image viewing led to superior recognition relative to the written condition and in the fMRI scanner the corresponding images were accompanied by increased activation in prefrontal, posterior temporal, parietal, and occipital areas, but not the hippocampus. The authors concluded that SenseCam may aid memory by providing a bottom-up replacement for the medial temporal lobes, and suggested that the images constitute such a powerful retrieval cue that reviewing them is sufficient to consolidate the events in a long-term memory store.

Preliminary data suggest that healthy participants are very successful at discriminating their own SenseCam images from those of others over periods as long as four months, and that a proportion of them can lead to full recollection of the original situation (Sellen et al., 2007). Interestingly, images automatically recorded by SenseCam provided better cues to subsequent recall than images participants had taken deliberately using the same camera. The results support previous evidence for the existence of a long-term, consciously accessible memory store that provides a repository for automatically encoded perceptual information.

Summary

It is now clear that verbalization can have a variety of effects depending on the experimental design and the nature of the verbalization. Under some conditions, however, verbalization does consistently lead to impairment of perceptual memory for the same stimulus. Although there is unlikely to be a single explanation for this effect, both the main theoretical approaches to verbal overshadowing are compatible with the idea of competition between multiple memory systems and representations (Meissner, et al., 2008). Furthermore, under conditions in which access to episodic memories is compromised, studies using SenseCam support the proposal that there is an alternative long-term store of consciously experienced visual memories (M. A. Conway, 2009). To date, however, the evidence that long-lasting perceptual representations may be automatically encoded and be functionally distinct from verbal representations is limited. The claims made by clinical theories of PTSD and other trauma-related disorders, namely that these two forms of representation are differentially affected by extreme stress, are therefore of considerable importance for general theories of memory. If correct, they have implications that go beyond the understanding of one particular clinical disorder.

Perceptual and Episodic Memory in PTSD

Psychological Theories of PTSD

According to several clinical accounts of PTSD (Brewin, Dalgleish, et al., 1996; Ehlers & Clark, 2000; Foa & Rothbaum, 1998; Freyd, 1996; Terr, 1991) the disorder is characterized by two very distinct effects relating to memory for the traumatic event, both part of current diagnostic criteria in the Diagnostic and Statistical Manual of the American Psychiatric

Association (DSM-IV-TR: American Psychiatric Association, 2000). On the one hand there are frequent and intense involuntary memories consisting of trauma-related images (symptom B3: "acting or feeling as if the traumatic event were recurring") that are experienced in the present (so-called "flashbacks"). On the other hand voluntary recall of the traumatic memory tends to be effortful, fragmented, and disorganized (symptom C3: "inability to recall an important aspect of the trauma"). This symptom refers to patients' experience of gaps or discontinuities in their memory of the event and does not imply amnesia for the fact of the event having occurred. The theories all imply that a dissociation between perceptual and episodic memory for the trauma is at the heart of the condition.

Although most posttraumatic symptoms are common to a number of disorders, flashbacks are only mentioned in the context of PTSD and a closely related condition, acute stress disorder (ASD) (American Psychiatric Association, 2000). Flashbacks are part of the PTSD re-experiencing symptom cluster within DSM-IV-TR and typically consist of a vivid, detailed multi-sensory image, usually visual but not necessarily so. For example, they may include somatosensory re-experiencing of heat, cold, or pain that accompanied the trauma (Whalley, Farmer, & Brewin, 2007). They tend to consist of fragmented snapshots or series of images, come to mind involuntarily, and are experienced as happening again in the present (Brewin, 2007; Ehlers, Hackmann, & Michael, 2004). Although there are no official or generally accepted definitions of a flashback, the description introduced in DSM-5 (American Psychiatric Association, 2013) offers clarification by stating that they can vary from relatively mild (there is a transient sense of the event reoccurring in the present) to extreme (the person loses all connection with their current autobiographical self and present surroundings while reexperiencing the memory).

A detailed theoretical account of flashbacks is provided by the dual representation theory of PTSD. According to the initial version of the theory (Brewin, Dalgleish, et al., 1996), flashbacks are the product of long-term image-based (perceptual) representations that were rapidly captured during the trauma, required minimal conscious attention to encode, and can subsequently only be accessed automatically ('situationally accessible memory' or SAM). These co-exist with other trauma representations that reflect more conscious attention at encoding, resulting in them being voluntarily accessible, verbalizable, and able to interact with other information in autobiographical memory ('verbally accessible memory' or VAM). The capture of sensory images by the SAM system is seen as a functional response to the down-regulation of the episodic memory system under extreme stress (Jacobs & Nadel, 1985; Metcalfe & Jacobs, 1998), allowing a large quantity of survival-related information to be encoded and stored for long periods even though conscious attention may be more narrowly focused on the source of threat.

According to this approach flashbacks initially reflect an adaptive response that is part of the recovery process; when automatically triggered by trauma reminders such as sensory cues, the allocation of conscious attention to the content of these images allows detailed perceptual information to be re-encoded into episodic memory where it can be made verbally accessible and assigned a temporal and spatial context. Once provided with this context, sensory cues no longer signal a current source of danger and as a result flashbacks become progressively weaker and less frequent. The theory proposed that the involuntary retrieval and reliving of threat-related images is more likely under two conditions: when encoding of the event into the SAM system is unimpeded or enhanced, and when encoding or re-encoding into the VAM system is in some way degraded or reduced. PTSD results when individuals cannot tolerate reexperiencing of the traumatic images, such that re-encoding into episodic memory is never achieved and flashbacks remain intense and persistent.

Three main claims differentiate dual representation theory from other standard models of memory. The first is that involuntary memories of a trauma scene can be weakened by carrying out a secondary task at the same time as the images are encoded, but that this can only be accomplished by a task that competes for perceptual resources. In contrast, a task that competes for verbal resources will strengthen subsequent involuntary memories of the trauma scene. The second claim, shared with Ehlers and Clark (2000), is that the degree of voluntary explicit memory (recall and recognition) for a trauma scene should be unrelated, or if anything inversely related, to the degree of involuntary memory for that scene, supporting their functional independence. The third claim is that the determinants and characteristics of involuntary trauma images (perceptual experiences) are different to those of involuntary thoughts (verbal experiences such as "Why did this event happen to me?") for the same material.

According to Ehlers and Clark (2000), during a trauma strong associations are formed that result in perceptual priming and help the person to make (sometimes preconscious) predictions about future sources of danger. Using a distinction that has been influential in cognitive psychology (Roediger & McDermott, 1993), they proposed that this process is enhanced by relatively strong data-driven processing focused on sensory impressions, and by relatively weak conceptual processing focused on the meaning of the situation, organizing the information, and placing it in context. Ehlers and Clark also noted that the retrieval of flashbacks from associative memory is cue-driven and unintentional, so that the person may be unaware of the triggers for reexperiencing.

Difficulty in recalling important aspects of the trauma is a separate symptom that forms part of the avoidance and numbing cluster in DSM-IV-TR. According to Foa and Rothbaum (1998), the emotional intensity of the event disrupts the cognitive processes of attention and memory at the time of encoding, leading to the formation of a disjointed and fragmented representation in memory and to trauma narratives that are relatively brief, simplistic, and poorly articulated. Repeated reliving in therapy generates a more organized memory record that is easier to integrate with the rest of the memory system. Similarly, Ehlers and Clark (2000) proposed that the memory of the trauma is poorly elaborated and inadequately integrated into the general database of autobiographical knowledge, partly as a result of the difficulty in conceptually processing the events. The absence of clearly specified retrieval routes is one factor that accounts for the difficulty in intentional recall.

Despite general acceptance that high levels of emotion can impair eyewitness testimony (Kassin, Ellsworth, & Smith, 1989) and that the effects of emotion on memory are complex (Christianson, 1992; Reisberg & Heuer, 1992), the claim that voluntary memory is fragmented and disorganized in PTSD has been frequently disputed (Berntsen & Rubin, 2006; McNally, 2003, 2005; Porter & Birt, 2001; Rubin, Berntsen, et al., 2008; Shobe & Kihlstrom, 1997) and remains controversial. For example, Berntsen and Rubin (2006, p. 222) stated: “Clinical case studies and observations have indicated that traumatic memories are fragmented and lack narrative coherence as compared to other memories both with respect to the narrative coherence of the trauma memory when viewed in isolation and with respect to the integration of the trauma memory into the overall life story and self-schema of the person…However, both claims have found little support when subjected to more systematic experimental examination".

One issue is that the initial clinical observations (Foa, Molnar, & Cashman, 1995; van Minnen, Wessel, Dijkstra, & Roelofs, 2002) were unsupported by proper controlled comparisons with similar individuals not suffering from PTSD. Further, it was pointed out that PTSD might be associated with similar deficits in neutral or even in positive memories and hence be unrelated specifically to trauma (McNally, 2003). The accretion of empirical data has now yielded a substantial evidence base that addresses this issue (see *Voluntary Episodic Memory in PTSD*). In contrast, there has been much more widespread agreement that PTSD is associated with the involuntary intrusion of vivid memories containing large quantities of sensory detail, and these studies are more briefly reviewed.

Involuntary Perceptual Memory in PTSD

Phenomenological descriptions of involuntary memories reported by PTSD patients have consistently described them as being brief and perceptually detailed (Ehlers & Steil, 1995; Mellman & Davis, 1985; van der Kolk & Fisler, 1995), with visual details predominating (Ehlers et al., 2002; Ehlers & Steil, 1995; Hackmann, et al., 2004). Although involuntary memories are an essentially normal phenomenon (Brewin, Christodoulides, & Hutchinson, 1996), what distinguishes those occurring in PTSD is that they typically involve a small number of traumatic scenes that are repeatedly reexperienced (Brewin, et al., 2010). They are also distinct from ruminative thoughts in being briefer and containing more sensory elements (Speckens, Ehlers, Hackmann, Ruths, & Clark, 2007). Individuals with PTSD describe more sensory details in their trauma memories than in their non-trauma memories (Rubin, Feldman, & Beckham, 2004). One exception to the above was the finding that Croatian war veterans did not report more sensory features in their trauma memories than in a neutral memory (Geraerts et al., 2007). In this case, however, the opportunity to indicate these sensory features was limited to a Yes or No answer, a format which may have been insufficiently sensitive to detect differences.

In one study flashbacks and ordinary episodic memories of trauma reported by PTSD patients were directly compared. Patients were required to write a detailed trauma narrative and indicate which words and sentences had spontaneously elicited flashbacks. Those sections that were associated with flashbacks were found to contain more perceptual details and mentions of motion (Hellawell & Brewin, 2004). Writing sections that elicited flashbacks also produced more interference with a subsequent visuospatial task than did writing non-flashback sections, supporting the prediction that they would involve more use of perceptual processing resources. In contrast, there was no differential interference with a subsequent verbal task (Hellawell & Brewin, 2002).

Another characteristic of involuntary memories in PTSD is the sense of 'nowness' whereby they are experienced as though they are occurring in the present. This subjective lack of past temporal context (Ehlers, et al., 2004) decreases with successful treatment (Hackmann, et al., 2004; Speckens, et al., 2006). The trauma memories of individuals with PTSD are more strongly characterized by this feature than their non-trauma memories (Rubin, et al., 2004), and the sense of 'nowness' also distinguishes involuntary memories in PTSD from the involuntary memories reported by depressed patients or individuals who were exposed to trauma without developing PTSD (Berntsen, Willert, & Rubin, 2003; Birrer, Michael, & Munsch, 2007; Reynolds & Brewin, 1998).

Memories with these same qualities of enhanced perceptual features and sense of ‘nowness’ also characterize children with posttraumatic conditions (McKinnon, Nixon, & Brewer, 2008; Meiser-Stedman, Dalgleish, Smith, Yule, & Glucksman, 2007). Importantly, empirical studies confirm that flashbacks appear to be a specific indicator of PTSD (Bryant, et al., 2011), and the sense of ‘nowness’ is predictive of the course of the disorder over and above the effects of initial symptom levels (Kleim, Ehlers, & Glucksman, 2007; Michael, Ehlers, Halligan, & Clark, 2005).

Perceptual Priming and Involuntary Images

Earlier evidence that perceptual priming for trauma-related words is enhanced for people with PTSD compared to those without PTSD was mixed (Amir, McNally, & Wiegartz, 1996; Golier, Yehuda, Lupien, & Harvey, 2003; McNally & Amir, 1996). However, two recent studies employing a word-stem completion task found that the degree of priming for trauma-related words assessed in survivors post-trauma predicted the subsequent development of symptoms (Ehring & Ehlers, 2011; Michael, Ehlers, & Halligan, 2005). Michael et al. showed that at eight weeks post-trauma the degree of priming was significantly greater in assault survivors with PTSD than those without PTSD. In the study by Ehring and Ehlers the degree of priming at two weeks post-trauma predicted PTSD symptoms in motor vehicle accident victims six months later, even when levels of initial symptoms and priming for other words were controlled. Although the word-stem completion task is usually regarded as a measure of perceptual priming, Ehring and Ehlers noted that a contribution to the overall effect made by conceptual priming could not be ruled out. A recent study is of particular interest in this regard, as it employed both the word-stem completion test and an unambiguous measure of conceptual priming, a word-cue association task (Lyttle, Dorahy, Hanna, & Huntjens, 2010). Relative to healthy controls exposed to trauma, PTSD patients showed significantly greater priming to trauma-related words on the word-stem completion task but significantly less conceptual priming. Perceptual priming was additionally correlated with reporting higher levels of state dissociation.

Among the limitations noted by these authors are that the type of post-trauma priming assessed here is different from the perceptual priming that is hypothesized to take place during exposure to the traumatic event. In a series of studies with healthy volunteers, however, Ehlers, Michael, and their colleagues have studied priming for neutral objects that are embedded within traumatic versus neutral picture stories. Consistent with research by Arntz et al. (2005), they showed that objects that preceded traumatic pictures were more strongly primed than those preceding neutral pictures, as assessed by a blurred picture identification task (Ehlers, Michael, Chen, Payne, & Shan, 2006). Moreover, stronger perceptual priming predicted more involuntary intrusion of viewed pictures over the next three months.

These results were subsequently replicated (Michael & Ehlers, 2007; Sündermann, Hauschildt, & Ehlers, 2013), Sündermann et al. finding that the effects of priming could not be accounted for by explicit memory for the primed objects. Michael and Ehlers, but not Sündermann et al., additionally showed that greater state dissociation (e.g., feeling the world was unreal, alterations in the experience of self, speeding or slowing of subjective time) during exposure to the traumatic stories was related to stronger perceptual priming for those stories. In a second experiment Michael and Ehlers had some of their participants elaborate their memory for their stories by asking them a series of questions about their experience of the study and about the story materials they had viewed. A control group conducted verbal tasks that were not related to the story content. Michael and Ehlers found that the elaboration group demonstrated significantly less perceptual priming for the trauma stories and fewer subsequent intrusions of images from the stories than did the group performing unrelated verbal tasks, a result that may be related to the phenomenon of unpriming (Sparrow & Wegner, 2006).

In the absence of a third group who were not given any task, however, it is not possible to determine whether Michael and Ehlers's results reflected a reduction in intrusions caused by verbal elaboration, an increase in intrusions caused by the unrelated verbal task, or both. Subsequent research (Ehlers, Mauchnik, & Handley, 2012) has confirmed that memory elaboration has an effect on priming and is associated with a reduction in subsequent intrusive memories, although in this investigation elaboration increased priming of stimuli associated with neutral material rather than decreasing priming of stimuli associated with traumatic material.

Although these striking findings are supportive of an alteration in perceptual processing associated with PTSD, and suggest this may be related to the development of some symptoms of the disorder, it has not yet been possible to show that there is enhanced priming for stimuli present during an actual traumatic exposure.

Voluntary Episodic Memory in PTSD

In view of the controversy over this question a search was conducted of all controlled studies of memory disorganization or fragmentation in ASD or PTSD. The inclusion criteria were as follows: Studies were required either to report data from clinical (PTSD, ASD) and non-clinical samples on indices of fragmentation or disorganization of a voluntarily recalled traumatic memory, or to report data from a clinical sample on indices of fragmentation or disorganization of voluntarily recalled traumatic and non-traumatic memories. Studies using computerized methods designed for other purposes to assess disorganization (e.g., Flesch reading formulas designed to gauge narrative complexity and articulation) were excluded as their validity in this context is highly questionable (Gray & Lombardo, 2001). Details of the resulting nine studies reported in eight articles are shown in Table 1. The table reports the following information: sample size and gender composition; the nature of the groups studied; the material used; the way in which fragmentation or disorganization were measured; and the main findings. Findings are expressed as the presence or absence of group differences, stimulus differences, or interactions between group and stimulus, accompanied by the level of statistical significance.

The studies can be divided into those that required participants to produce a detailed narrative that was then rated by independent judges, and those that used questionnaire measures. The table shows that all six studies using judge ratings of narratives were consistent in showing greater disorganization or fragmentation in the trauma memories of adults and children with ASD or PTSD than in healthy controls, some of these differences being highly significant (Halligan, Michael, Clark, & Ehlers, 2003; Harvey & Bryant, 1999; Jelinek, Randjbar, Seifert, Kellner, & Moritz, 2009; Jones, Harvey, & Brewin, 2007; Kenardy et al., 2007; Salmond et al., 2011).

In contrast, the results using self-reported questionnaire ratings were more variable with two studies (Halligan et al., 2003, studies 1 and 2) showing similar significant effects and two studies (Berntsen, et al., 2003; Jelinek, et al., 2009) showing no significant group differences. Of note, no study using any measure showed a healthy control group with significantly greater disorganization in their trauma memories. The only study not to show any evidence for a group difference in fragmentation or disorganization on any measure (Berntsen et al., 2003) relied on a single item. Berntsen et al. asked “When you recall the traumatic event, do you then think of it as a continuous series of episodes or as some isolated incoherent fragments?” In addition to the problems of low reliability with single-item measures that address complex concepts such as fragmentation or disorganization, the item does not distinguish between voluntary and involuntary recall of the trauma. Salmond et al. (2011) further noted that use of self-report measures to characterize memory quality has been criticised because responses may be influenced by demand characteristics (Pasupathi, 2007) and may not correspond with actual memory performance (Kindt & van den Hout, 2003).

Four studies, three in adults and one in children, have addressed the question of whether individuals with ASD or PTSD have greater disorganization in their trauma memories but not in unpleasant, nontraumatic memories. As shown in Table 1, two studies using independent judge ratings (Jelinek, et al., 2009; Salmond, et al., 2011) and one using self–ratings (Halligan et al., 2003, study 2) found that disorganization was significantly more marked in the trauma memories; similarly, one study found no evidence of impaired sequence memory for non-autobiographical material (Jelinek, et al., 2009). In a similar pattern to that shown for the between-group differences, the single study to show equivalent levels of disorganization within a PTSD sample for traumatic and non-traumatic events (Rubin, et al., 2004) used two single-item measures.

In other studies PTSD patients have been found to take longer to retrieve autobiographical memories when listening to a script of their traumatic event than to a script of another very distressing but non-traumatic event, suggesting that the traumatic event memory was less well integrated with other autobiographical material (Kleim, Wallott, & Ehlers, 2008). Finally, these impairments in voluntary trauma memory have frequently been found to predict the course of PTSD (Buck, Kindt, van den Hout, Steens, & Linders, 2007; Ehring, Ehlers, & Glucksman, 2008; Engelhard, van den Hout, Kindt, Arntz, & Schouten, 2003), in some cases over and above the effects of initial symptom levels (Halligan, et al., 2003; Jones, et al., 2007).

Shobe and Kihlstrom (1997) explicitly rejected the proposal that “memories of trauma, or at least of certain forms of trauma, are encoded by processes, such as repression and dissociation, that make them difficult to retrieve as coherent, verbal narratives” (p. 74). In contrast, Foa and Rothbaum (1998) proposed that higher levels of fragmentation and disorganization in trauma narratives are related to the occurrence of dissociative responses. Subsequent research has consistently found that higher levels of fragmentation in trauma narratives are related to self-reported dissociation either during or after the traumatic event (Engelhard, et al., 2003; Giesbrecht, Merckelbach, van Oorsouw, & Simeon, 2010; Halligan, et al., 2003; Harvey & Bryant, 1999; Murray, Ehlers, & Mayou, 2002; Rubin, et al., 2004). Two studies failed to find any correlation between dissociation and objective indices of fragmentation but in both, unlike the previous investigations, exposure was to a trauma video in the laboratory and not to a personally experienced event (Kindt & van den Hout, 2003; Kindt, van den Hout, & Buck, 2005). More recent experimental studies have confirmed that inducing dissociation in the laboratory does appear to impair several aspects of memory (Brewin, Ma, & Colson, 2013; Brewin & Mersaditabari, 2013).

Summary

A considerable amount of evidence now strongly favors the claims that in samples suffering from ASD or PTSD trauma memories are affected in two separate ways, with enhanced perceptual features and a sense of 'nowness' accompanying involuntary recall, and fragmentation or disorganization accompanying voluntary recall. Although these qualities of involuntary memory in PTSD are generally accepted, recent evidence has specifically implicated perceptual priming in the development of this symptom. Controversy over the presence of disorganization appears likely to be attributable to the use of different types of measurement, with more rigorous, independent measures yielding consistent findings and briefer, self-report measures yielding less consistent findings. Importantly, both of these distinct effects on memory are predictive of the course of the disorder, suggesting a possible causal role in psychopathology. Further, in agreement with clinical models, fragmentation and disorganization are related to reports of dissociative reactions occurring at the time of the trauma. Studies have yet to properly identify the exact nature of the disorganization, however, for example distinguishing between narrative cohesion (the connectedness of the elements) and narrative coherence (its overall conceptual organization) (O'Kearney & Perrott, 2006).

Trauma-Related Research on Interactions Involving Perceptual and Episodic Memory

Involuntary Recall and the Modality of Competing Tasks at or after Encoding

Consistent with the hypothesis of functional independence between perceptual and episodic memory systems, a number of studies have tested the claim made by dual representation theory (Brewin, Dalgleish, et al., 1996) that concurrent visuospatial tasks at trauma exposure would reduce subsequent intrusions whereas concurrent verbal tasks would increase subsequent intrusions (see *Psychological Theories of PTSD*). The assumption has been that visuospatial tasks are particularly likely to interfere with perceptual, image-based representations. In order to test this it has been necessary to utilize an analogue design in which healthy volunteers are shown a film containing traumatic scenes. To replicate traumatic conditions and engage participants as fully as possible, most studies have used real-life footage together with a brief commentary about the individuals involved. While watching the film participants either perform a concurrent visuospatial task such as pattern tapping or a verbal task such as counting backwards in threes. They subsequently record images of the film that come unbidden into their minds over the next 1-2 weeks. A search was therefore conducted to identify controlled studies meeting the following inclusion criteria: Participants were shown a trauma film and carried out either a verbal or a perceptual concurrent task; there was a control no-task condition; involuntary memories were assessed over a period of at least 48 hours. The studies previously located for the review of memory quality in PTSD were screened, along with studies identified in a previous review (Holmes & Bourne, 2008), yielding a total of 18 studies described in 13 separate articles.

Table 2 presents the following information concerning the 18 studies: the number of participants and their gender composition; the film content (real-life or fiction), structure, length, and modality; the secondary tasks employed; the timing of the tasks; voluntary memory for the film in the different conditions (mean cued recall or recognition scores, standard deviations); and involuntary memory for the film in the different conditions (time period, mean number of occasions memories were reported, standard deviations). The voluntary recall data are relevant to the next section (*Relation of Voluntary Episodic Recall to Involuntary Intrusion of Images*). Significant differences between means are indicated by the presence of different subscripts. As shown in Table 2, the studies used several perceptual concurrent tasks that primarily involved a visuospatial component, including pattern tapping, making shapes out of plasticine, and the computer game Tetris. The most common task involved tapping a memorized sequence of keys on a keyboard. Verbal tasks included counting backwards and the computer game Pub Quiz. Some studies included a verbal enhancement condition, designed to reduce intrusions, in which participants attempted to describe the trauma film in words as they watched it.

The results consistently demonstrated that a concurrent visuospatial task reduced the subsequent involuntary recall of images of the film over the following week, relative to a no-task condition (Bourne, Frasquilho, Roth, & Holmes, 2010; Brewin & Saunders, 2001; Holmes, Brewin, & Hennessy, 2004; Krans, Näring, Holmes, & Becker, 2010a, 2010b; Stuart, Holmes, & Brewin, 2006). In a single study the effect was in the same direction but nonsignificant, although the visuospatial task did significantly reduce intrusions during the day of the film for high-anxious participants (Logan & O'Kearney, 2012). The effects of pattern tapping on reducing intrusions do not appear to be solely due to the movement component of the task, as a comparable task involving movement without a visuospatial element (a complex gum-chewing task in which the gum had to be moved systematically round the mouth) did not reduce intrusions (Krans, et al., 2010b). Later studies indicated that visuospatial tasks still reduce involuntary images when administered up to four hours post-encoding (Holmes, James, Coode-Bate, & Deeprose, 2009; Holmes, James, Kilford, & Deeprose, 2010). Overall, 13 out of 13 studies demonstrated a numerical group difference in the predicted direction ($p < .001$ by sign test).

The effects of concurrent verbal tasks were more varied. In the first study Holmes et al. (2004, exp. 3) showed that counting backwards in 3s while watching the trauma film led to a significant increase in intrusive images relative to a control condition. Several authors have attempted to directly replicate this finding employing as their task counting backwards in threes or sevens (Bourne, et al., 2010; Deeprose, Zhang, DeJong, Dalgleish, & Holmes, 2012; Krans, Näring, & Becker, 2009; Logan & O'Kearney, 2012). This procedure significantly increased intrusions of a trauma film relative to a no-task control condition in one study (Bourne et al., 2010, exp. 2), showed a nonsignificant trend in the same direction in three studies (Bourne et al., 2010, exp. 1; Deeprose et al., 2012, exps. 1 and 2), and showed a nonsignificant trend in the opposite direction in two studies (Krans et al., 2009; Logan & O'Kearney, 2012). Bourne et al. (2010, exp. 1) found that the better participants performed the counting task, the more intrusions they developed. Combining the results of these seven studies on 207 participants meta-analytically (Bax, Yu, Ikeda, Tsuruta, & Moons, 2006), employing Hedges' g as a measure of effect size and applying a random effects model, yielded a highly significant effect, $z = 8.08$, $p < .001$.

Five other studies carried out conceptual replications employing alternative verbal concurrent tasks, including remembering a 9-digit number (Nixon, Cain, Nehmy, & Seymour, 2009; Nixon, Nehmy, & Seymour, 2007), simple counting from 1 to 6 (Krans et al., 2010a), or the computer game Pub Quiz (Holmes et al., 2010, exps. 1 and 2). The verbal tasks significantly increased intrusions of a trauma film relative to a no-task control condition in one study (Holmes et al., 2010, exp. 1), were not significantly different in three studies (Holmes et al., 2010, exp. 2; Nixon et al., 2007, 2009), and showed a significant effect in the opposite direction in one study (Krans et al., 2010a). A similar meta-analysis of the results of these five studies on 232 participants yielded a nonsignificant effect, $z = 0.42$, $p > .60$.

Unlike the consistent results with spatial tasks, the findings with verbal tasks suggest that the nature of the task is critical. Counting backwards continuously in 3s or 7s appears to reliably increase intrusions relative to a control condition, but the task parameters driving this effect remain to be determined. Among the possibilities why alternative tasks were ineffective are that they were not continuous (e.g., remembering a 9-digit number), that they were insufficiently demanding (e.g., simple counting from 1 to 6), or that the effects are hard to obtain when they are administered several hours after the trauma film (e.g., Pub Quiz).

As shown in Table 2, there have been several attempts to enhance verbal processing during exposure to a trauma film, for example by having participants attempt to put into words what they were seeing on the screen. In two experiments using this method the number of subsequent intrusions did not differ from those reported by participants in a no-task control condition (Holmes, et al., 2004; Krans, Näring, & Becker, 2009). One of the problems with this method is that participants are often unable to fully comply with the task and verbalization is interrupted when unexpected or shocking images are shown.

Relation of Voluntary Episodic Recall to Involuntary Intrusion of Images

Several studies have reported data that permit an assessment of the claim (Brewin, Dalgleish, et al., 1996; Ehlers & Clark, 2000) that voluntary episodic memory and involuntary perceptual memory for the same traumatic materials are unrelated, or even negatively associated (see *Psychological Theories of PTSD*). Other studies reported similar data on negative but not necessarily traumatic materials. A further search was therefore conducted to identify controlled studies meeting the following inclusion criteria: Participants were shown stimulus materials at least some of which were negatively valenced; recall or recognition was tested for the materials; the occurrence of involuntary images was assessed over a period of at least 48 hours; the data reported allowed for a quantitative estimate of the association between voluntary recall and the intrusion of images. Two sorts of study were found: Correlational studies, summarized in Table 3, and experimental studies, summarized in Table 4. The studies previously located for the review of memory quality in PTSD were screened, yielding a total of 25 studies described in 21 separate articles. Tables 3 and 4 present the following information concerning those studies not already described in Table 2: The number of participants and their gender composition; the experimental stimuli employed; the measures of voluntary and involuntary recall; the design of the study; and the association between voluntary and involuntary recall.

Eleven of the studies showing traumatic material to healthy volunteers correlated the number of images involuntarily recalled over the succeeding week with measures of explicit recall and recognition of the same material. As shown in Table 3, the majority of studies failed to find any significant association between them (Brewin & Saunders, 2001;

Hagenaars, van Minnen, Holmes, Brewin, & Hoogduin, 2008; Holmes, et al., 2004; Krans, et al., 2010b; Nixon, et al., 2009; Sündermann, et al., 2013), with one study reporting a significant negative correlation (Michael & Ehlers, 2007, Expt. 2) and two reporting significant positive correlations (Ferree & Cahill, 2009; Ferree, Kamat, & Cahill, 2011). Eight studies in Table 3 involving a total of 444 participants reported actual correlation sizes and these were combined meta-analytically (Field, 2001; Hunter & Schmidt, 1990). Where more than one effect was reported separately within a single study, their average was used. This yielded an average $r = .02$, which did not differ significantly from zero, $z = .29$, $p > .70$.

As already noted, two of the studies in Table 3 carried out by the same research group reported that more intrusions of brief emotional film clips were significantly associated with greater voluntary recall of details (Ferree & Cahill, 2009; Ferree, et al., 2011). These investigations used a short time period (48 hours), and were the only ones to have relied on an overall retrospective rating of involuntary memory rather than the contemporaneous diary method used by the other studies reviewed. The procedure involved participants voluntarily recalling some details, such as what films they remembered seeing, how well they remembered them, and in what order they were shown. Only then did they indicate how many involuntary intrusions they had experienced. As such, although Ferree and colleagues tried to reduce demand effects by randomizing the order in which participants rated the intrusiveness of each film, there may have been more scope for the subjective estimates to be influenced by prior voluntary memory activity.

The estimates generated by meta-analytically combining the correlation coefficients in Table 3 should be treated with caution given the small number of studies. However, the results are consistent with other studies that after an experimental manipulation reported group differences in involuntary and voluntary memory separately but did not correlate them. The great majority of those studies that found significant group differences in involuntary memory did not report any corresponding significant differences in measures of recall or recognition. Some of these studies appear in Table 2 (Bourne et al., 2010, exp. 1; Holmes et al., 2009; Holmes et al., 2010, exps. 1 and 2; Krans et al., 2010a) with additional studies being shown in Table 4 (Ehlers, et al., 2012; Pearson, 2012; Pearson, Ross, & Webster, 2012).

Of particular interest are studies that included an intervention successfully producing significant changes in the strength of voluntary memory and that also investigated the effect on subsequent intrusions. In addition to one study shown in Table 2 (Bourne et al., 2010, exp. 2), four additional studies are included in Table 4. For example, after watching a traumatic film participants were given a recognition test for details contained in some scenes but not others (Krans, Näring, Holmes, & Becker, 2009). The authors found that the recognition procedure led to significantly better recall on a final test, but to significantly decreased involuntary memories from those scenes over the next week. In another study imaginal rescripting of a trauma film, relative to employing positive imagery unrelated to the film, led to significantly better cued recall but to significantly fewer intrusive images (Hagenaars & Arntz, 2012). Two other studies reported that increasing levels of alcohol reduced voluntary memory in a linear fashion, whereas the relationship with involuntary memory was U-shaped, low levels of alcohol being associated with increased intrusions relative to no alcohol and high levels of alcohol (Bisby, Brewin, Leitz, & Curran, 2009; Bisby, King, Brewin, Burgess, & Curran, 2010). Thus all five studies that successfully manipulated the strength of voluntary memory found a significantly different type of effect on the frequency of involuntary images.

Independence of Involuntary Images and Involuntary Thoughts

The third claim made by dual representation theory is that the determinants and characteristics of involuntary images and involuntary thoughts are different (see *Psychological Theories of PTSD*). Few studies have separately analyzed the occurrence of involuntary images and thoughts for the same material within the same study, however. In the investigation (see *Perceptual Priming and Involuntary Images*) by Michael and Ehlers (2007, Expt. 2), the authors found a significant interaction between condition and intrusion content: The elaboration condition was associated with significantly fewer involuntary images from the picture stories than the control condition, but there was no corresponding effect on involuntary thoughts. Further analyses on the study by Hagenaars et al. (2008) described in Table 3 revealed a similar condition by intrusion content interaction (Hagenaars, Brewin, van Minnen, Holmes, & Hoogduin, 2010): Participants in a condition where they were not free to move reported significantly more involuntary images from the trauma film than the control condition, but a reduction in the frequency of involuntary thoughts. Greater anxiety, horror, and anger while watching the film were positively related to the frequency of involuntary images but not to involuntary thoughts. This finding is consistent with evidence that imagery is more strongly related to emotion than is verbal material (Holmes & Mathews, 2005). In a second experiment, Hagenaars et al. (2010) demonstrated that a traumatic film, relative to a neutral film, was associated with an increased frequency of involuntary images but not of involuntary thoughts. Once again levels of anxiety and horror while watching the films were related to the number of subsequent involuntary images but not to involuntary thoughts.

Summary

There is now a rapidly growing body of knowledge which allows a number of perhaps surprising conclusions to be drawn: Engaging in visuospatial tasks at or shortly after trauma encoding appears to block the development of involuntary images, whereas engaging in a verbal task that specifically involves counting backwards leads to more involuntary images; the extent of voluntary recall and the number of involuntary images of the same traumatic materials appear to be functionally independent; and involuntary images and thoughts about the same traumatic stimuli appear to have distinct characteristics. These data are very largely based on viewing of trauma films and the effects may not be observed with other stimuli such as briefly-presented affective pictures. For example, both a visuospatial and a verbal secondary task were found to reduce the intrusion of positively and negatively valenced pictures that had been presented to participants for one second each (Pearson & Sawyer, 2011). Although this study did not use the counting backwards task that is associated with more numerous intrusions of trauma films, their finding raises the possibility that more prolonged exposure to traumatic materials is needed to engage the processes that underlie the differential effects of visuospatial and verbal interference. For example, the rapid presentation of stimuli that have no specific personal meaning may make it unlikely that dissociation, a typical response to traumatic situations, will occur. Just as verbalization was found to have a variety of effects on verbal overshadowing, verbal tasks other than counting backwards have had variable effects on intrusive memory development. With this caveat, the findings reviewed in this section are broadly supportive of clinical theories of PTSD but are inconsistent with many standard memory theories that do not discriminate perceptual and episodic memory.

Reflections on the Controversy Concerning Memory Impairment in PTSD

Given what is the now very substantial empirical evidence for both enhanced involuntary perceptual memory and impaired voluntary episodic memory in PTSD, it is important to understand why the area has attracted such an extreme degree of controversy, and how even very recently researchers could state (Peace, Porter, & ten Brinke, 2008): "A range of perspectives have been applied to understanding the impact of trauma on memory, from the traditional clinical argument that trauma impairs memory for the event to the increasingly supported scientific view that memory is facilitated by trauma" (p. 10). Four possible explanations are discussed for the controversy in this area: First, the equating of processes in clinical and non-clinical samples; second, the influence of the recovered memory controversy; third, the equating of the semantic and episodic components of voluntary memory for the trauma; and fourth, the partial application of biological findings concerning emotion and memory.

Equating Clinical and Non-clinical Samples

A much-cited article in the debate has been that of Shobe and Kihlstrom (1997) who identified what they termed a 'trauma-memory argument'. They identified clinical theorists who supposedly argued that traumatic memories had 'special properties' that distinguished them from memories routinely studied in the laboratory. Shobe and Kihlstrom rejected the idea that narrative memories of trauma might be impaired, citing evidence that they were more likely to be distinctive, long-lasting, and easily retrieved. The article did not distinguish, however, between the memories of individuals with disorders such as PTSD, who were the focus of the clinical theorists, and the trauma memories of healthy or trauma-resilient individuals, who were not explicitly considered by these theorists.

This use of the ‘trauma-memory argument’ with its extrapolation of the clinical theories’ claims to all trauma memories, even in healthy samples, has been widely promulgated (Geraerts, et al., 2007; Porter & Birt, 2001; Rubin, Berntsen, et al., 2008), and is clearly manifest in the immediately preceding quotation from Peace et al. (2008). Of course, clinical and nonclinical groups do share a number of characteristics. For example, as shown by the trauma film studies both groups tend to respond to traumatic events with increased involuntary memories. On the other hand there is little evidence that the qualities of voluntary trauma and non-trauma memories differ in healthy samples (Brewin, 2007).

This indicates that considerable caution is needed when testing claims developed in the context of clinical samples by doing studies with healthy samples: For example, it may be inadvisable to conclude that clinical theories are mistaken because no evidence is found for greater fragmentation in the trauma than the non-trauma memories of healthy or mildly symptomatic participants (Porter & Birt, 2001; Rubin, Boals, & Berntsen, 2008). Rather, the extent to which effects associated with traumatic stimuli are or are not present in both groups is something to be established empirically.

The Recovered Memory Controversy

The article by Shobe and Kihlstrom (1997) devoted space to what they believed were erroneous claims concerning the possibility that the occurrence of traumatic events could be completely forgotten and then subsequently recalled essentially accurately. One of the main foundations of their critique of recovered memories of trauma was the position that traumatic events were inherently extremely memorable, and therefore to claim that they could be forgotten or repressed ran counter to scientific knowledge concerning memory. A similar argument has been made by McNally (2003). From this perspective observations or findings concerning impairment in the voluntary recall of traumatic events may appear counter-intuitive.

It has now become clear that although traumatic events are in general more memorable than non-traumatic events, they are not invariably well-remembered (Brewin, 2011b). Memorability is not conferred by meeting the DSM-IV-TR PTSD stressor criterion that defines a traumatic event but by the same criteria of personal significance and consequentiality that apply to other events discussed in the autobiographical memory literature (M. A. Conway, et al., 1994; Pillemer, 1998). If such events (e.g., happening to witness another person being seriously injured in an automobile accident) have little relevance to the person's identity, or if that sense of identity is fragmented by exposure to significant adversity in childhood (Harter, 1998; Harter, Bresnick, Bouchey, & Whitesell, 1997), even events that are generally regarded as "traumatic" may be forgotten (Brewin, 2011b). Consistent with this, recent research supports the position adopted by most professional bodies that some recovered memories of trauma, particularly those that do not occur in the context of suggestive therapeutic practices, may be essentially accurate (Geraerts et al., 2009). The impairments in voluntary memory reviewed in this article may help to explain why some traumatic events are forgotten despite this outcome appearing unlikely to outside observers. Other factors that may assist forgetting are specific individual cognitive characteristics (Brewin, 2011b; Geraerts, et al., 2009) and the ability to deliberately suppress unwanted mental content (Anderson & Huddleston, 2011), including autobiographical memories (Noreen & MacLeod, 2013; Stephens, Braid, & Hertel, 2013). Recent research has further shown that deliberate suppression reduces the occurrence of unwanted intrusions (Levy & Anderson, 2012).

Equating Semantic and Episodic Memory

Some authors have asserted that the claim that traumatic memories are fragmented and lack narrative coherence, as specified in clinical theories of PTSD, is contradicted by the fact that in this group the trauma memory tends to be central to the person's overall life story (Berntsen & Rubin, 2006; Rubin, Berntsen, et al., 2008). The Centrality of Event Scale, which is typically used in these studies, includes such items such as "I feel that this event has become a central part of my life story" and "This event is making my life different from the life of most other people" (Berntsen & Rubin, 2006). These questions clearly differ markedly from the independent judge ratings of fragmentation described in the earlier section *Voluntary Episodic Memory in PTSD*.

The assertion of a contradiction between these two bodies of research appears to equate conceptual knowledge concerning the fact that the event has occurred and its relative prominence in autobiographical memory, with the representation of the event in specific episodic memory records. Trauma clinicians and researchers have been aware for many years of the impact of trauma on the person's sense of themselves and have proposed that traumatic events can form turning points in people's construction of their own identity (Herman, 1992; C. S. Myers, 1940; Pillemer, 1998; Sutherland & Bryant, 2005). According to one highly influential theory, the centrality of the event is a direct result of a general motivation to integrate new experience into past schemas (the 'completion tendency'), and of the difficulty in so doing due to the shocking content of the experience (Horowitz, 1976).

Contrary to the claims made by Berntsen and Rubin (2006), there seems to be no inherent contradiction between the fact of the trauma having happened dominating much of the person's mental life, while at the same time avoidance of memories of specific distressing scenes may leave these fragmented and disconnected. Likewise, there seems to be no prima facie contradiction with observations that the implications of the event are hard to assimilate within pre-existing knowledge structures. None of these more episodic aspects of memory are assessed by the Centrality of Event Scale.

Biological Findings on Emotional Memory

Shobe and Kihlstrom (1997) noted: "research with both humans and animals indicates that high levels of stress enhance rather than impair memory – perhaps by virtue of hormones that are released in response to stress and in turn regulate memory storage, or perhaps by virtue of activating the amygdala, a subcortical brain structure known to be involved in fear and other emotions" (p. 71). Classic research that emotionally arousing events lead to stronger rather than weaker memory (L. Cahill & McGaugh, 1998) is frequently adduced to contest claims that trauma memories may be impaired (Berntsen & Rubin, 2006; McNally, 2003; Porter & Birt, 2001).

The orienting response of increased surprise or interest typically produced in a healthy person by emotional materials is completely different, however, from the effects on memory produced by high levels of anxiety. Meta-analytic review has shown that individuals' levels of stress or anxiety correlated with poorer performance on eyewitness identification of a perpetrator or target person and on eyewitness recall of details associated with the crime (Deffenbacher, Bornstein, Penrod, & McGorty, 2004). More anxious people also tend to remember the central details of a witnessed scene as well as less anxious people do, but their recognition of background information is poorer, suggesting that anxiety may inhibit the formation of complete mental representations of complex emotional scenes (Waring, Payne, Schacter, & Kensinger, 2010).

It is also well established that high levels of glucocorticoids, an important class of stress hormone, adversely affect memory for facts and events (McEwen & Sapolsky, 1995), facilitating the encoding of events into memory but impairing their retrieval (de Quervain, Aerni, Schelling, & Roozendaal, 2009). These findings are consistent with evidence in individuals with PTSD that memory for emotionally neutral material is impaired (Brewin, Kleiner, Vasterling, & Field, 2007), and that areas of the brain centrally involved in the processing of declarative memory, such as the hippocampus, are decreased in volume (M. E. Smith, 2005). They are also consistent with the conclusion that impairments in voluntary memory for trauma are present in people with disorders such as PTSD, but not in healthy samples.

Summary

The existence of controversy over whether impairment in the trauma memory is part of PTSD may be related to four factors that have figured in the literature: A failure to distinguish clinical and healthy samples, the conviction that traumatic events are always well-remembered, a blurring of the distinction between semantic and episodic aspects of the trauma memory, and a partial application of relevant biological evidence. When these are taken into account, the data on trauma and memory impairment reviewed above do not appear to contradict any established cognitive or neurobiological findings.

Conclusions and Recommendations

Memory in Healthy Participants

Previous research does provide some examples of the importance of considering the role of a separate perceptual memory system. For example, in the "reversed eye-witness suggestibility design" (Lindsay & Johnson, 1989) participants are provided with verbal suggestions about a visual scene before witnessing it. The scene contains some items that had been referred to in the verbal narrative and some that had not. In addition, some items referred to in the narrative do not appear in the visual scene (the misinformation items). Participants subsequently tested on their memory for items present in the visual scene by means of a written checklist demonstrate a misinformation effect, recalling items that were in the narrative but not in the picture. However, if the test is pictorial rather than verbal, the effect is no longer present, presumably because the test provides participants with improved access to their perceptual memory of the picture rather than their episodic memory of the narrative (Abeles & Morton, 1999).

There has also been acknowledgment of the role of "involuntary conscious memory" in understanding the phenomenon of priming (Richardson-Klavehn & Gardiner, 1995). This refers to the possibility that in carrying out a stem completion task (e.g., "Complete the stem Har…with the first word that comes to mind") previously viewed words such as “Harass” will be consciously remembered as well as being able to unconsciously affect the choice of word. More recently evidence has accumulated that a wide variety of tasks such as generating word associations (C. T. Ball, 2007; Brewin & Soni, 2011), passively viewing words and phrases (Schlagman & Kvavilashvili, 2008), or deliberately recalling the past (Mace, 2006), are likely to lead to the spontaneous retrieval of autobiographical memories complete with visual scene details.

These results strongly suggest that investigators should routinely assess the occurrence of involuntary perceptual memories within voluntary memory tasks such as recall of shocking events or of emotional scenes or pictures. For example, debates about the consistency or inconsistency of recall may be illuminated by looking separately at the consistency across time of voluntary and involuntary components. Whether or not involuntary memories are experienced in a particular context is likely to depend on the extent to which available cues are uniquely associated with them (Berntsen, Staugaard, & Sørensen, 2012). A recent investigation of the cued recall of valenced pictures found that presenting cues was more likely to lead to involuntary perceptual memories when pictures were negative than when they were positive. Perceptual cues prompted these involuntary memories more often than verbal cues, and the occurrence of the involuntary memories was strongly related to recall performance (Brewin & Langley, 2012). Just as in the trauma film studies reviewed above, involuntary memories of some of the picture stimuli continued sporadically over the succeeding week.

The presence of these striking phenomenological accounts indicates that a complete account of recall and recognition, whether dealing with verbal or pictorial stimuli, needs to consider the interaction of episodic and perceptual memory. Our current understanding is that perceptual memory should not be expected to be necessarily veridical or consistent but rather show partial or selective accuracy. The occurrence of a perceptual intrusion nevertheless may contribute to memorial judgement, decision-making, and control processes in ways we are only beginning to understand. For example, a recent neuroimaging study of the suppression of emotional memories found evidence for a two-stage process in which initial suppression of sensory components of the memory representation was followed by suppression of the multimodal and emotional aspects of the representation (Depue, Curran, & Banich, 2007).

Memory in Posttraumatic Stress Disorder

The literature reviewed indicates that the long-held view that under extreme stress there are differential effects on multiple memory systems (Jacobs & Nadel, 1985; Janet, 1904; Metcalfe & Jacobs, 1998; Terr, 1991; van der Kolk & Fisler, 1995) is scientifically plausible. This view is supported by recent evidence that individual brain regions are affected by stress in very different ways. For example, a study of neuronal morphology showed that the same stress experience produced dendritic atrophy and debranching in the hippocampus at the same time as producing enhanced dendritic arborization in the amygdala (Vyas, Mitra, Rao, & Chattarji, 2002).

The increased functioning of the amygdala under stress has generally been seen as consistent with the formation of overly strong implicit memories related to autonomic conditioning and fear, including priming (Metcalfe & Jacobs, 1998; Pitman, Shalev, & Orr, 2000). Potentially, however, the amygdala could also contribute to the encoding and consolidation of long-term perceptual memories that remain consciously accessible. The latest version of the dual representation theory of PTSD (Brewin, et al., 2010) specifies in more detail the original description of an image-based memory system (‘situationally accessible memory’ or SAM) in terms of a contemporary model of spatial memory and imagery (Byrne, et al., 2007). The authors suggest that these perceptual memories consist of ‘sensation-near’ representations (‘S-reps’) which are the product of processing in the dorsal visual stream, insula, and amygdala, and which are specialized for action on the environment. S-reps capture the entire visual field, are egocentric (rely on the person’s own viewpoint), are automatically activated by related cues, and are relatively inflexible.

The updated theory also replaces the concept of ‘verbally accessible memories’ (VAM) described by Brewin et al. (1996) by proposing parallel contextualized representations (‘C-reps’) that are the product of processing in the ventral visual stream and medial temporal lobe. C-reps are selective, correspond to the focus of conscious attention, are allocentric (permit the adoption of alternative viewpoints), and can be strategically or automatically retrieved. C-reps support episodic memories and verbal accounts of a traumatic event, whereas S-reps support involuntary flashbacks. The theory suggests that during a traumatic event the encoding of S-reps (perceptual memories) is strengthened, whereas the encoding of C-reps (contextualized episodic memories), and the connections between S-reps and C-reps, are weakened. This leaves individuals able to retrieve C-reps of the event when they want to deliberately think or communicate about the trauma, although these are likely to be fragmented and disorganized. Reminders of the trauma are likely to lead to the automatic retrieval of S-reps, with vivid, decontextualized images being experienced as the event happening again in the present.

In tests of the theory it was shown that individuals who had lesser contextual (allocentric) memory abilities were, as predicted, more vulnerable to developing involuntary memories of a traumatic film over the following week (Bisby, et al., 2010). The naturally occurring intrusive memories of such individuals are also more strongly characterized by a lack of temporal context (increased “nowness”) (Glazer, Mason, King, & Brewin, 2013). These findings are consistent with previous work showing an association between PTSD and a specific deficit in allocentric spatial processing that appeared to function as a preexisting risk factor (Gilbertson et al., 2007), as well as with the finding that greater efficiency of temporal-lobe-based spatial configuration learning predicts fewer intrusive trauma memories of a trauma film (Meyer et al., 2013).

It has also been proposed that the kind of contextual-encoding deficit described by dual representation and other theories may lead to subsequent inappropriate generalization of past learning to novel situations in the form of either over- or undergeneralization (C. E. Myers et al., 2003). The prediction that PTSD patients should therefore be equivalent to controls in learning initial stimulus-outcome associations but show a selective deficit in generalizing this learning to novel situations was recently confirmed (Levy-Gigi et al., 2012).

At a neural level it has been found that PTSD patients reporting more frequent flashbacks have reduced brain volume in bilateral inferior temporal cortex, an area of the brain that is part of the ventral visual stream and is involved in processing the context of visual objects and scenes (Kroes, Whalley, Rugg, & Brewin, 2011). A parallel functional MRI study investigated neural responses to the recognition or words and phrases from the trauma narratives of the same patients, contrasting those that elicited or did not elicit flashbacks (Whalley et al., 2013). Flashbacks were associated with increased activation in sensory and motor areas, and with decreased activation in the parahippocampal gyrus, part of the medial temporal lobe.

It is important to note that within dual representation theory contextualization refers to a *process* whereby selective attention leads to a recoding of the sensory input into an abstract structural description. This recoding then permits interaction with other knowledge, better organized consciously accessible memories, and reduced involuntary intrusions. Contrary to recent suggestions (Pearson, 2012; Pearson, et al., 2012), the process does not bear any straightforward relationship to the amount of contextual or explanatory *information* present in the input. Different contextual or explanatory content could facilitate either the formation of C-reps (for example, by encouraging alternative visual perspectives), or S-reps (for example, by increasing emotional engagement or dissociation). Studies which show that providing more explanatory information at encoding increases subsequent intrusions (Pearson, 2012; Pearson, et al., 2012) are quite consistent with dual representation theory (Brewin & Burgess, in press).

The distinction between perceptual and episodic memory also provides an account of the apparently paradoxical effect, alluded to at the beginning of this article, whereby repeatedly rehearsing a trauma memory in therapy leads to a reliable reduction in symptoms including the involuntary recall of that memory. According to dual representation theory, by retrieving the distressing images and holding them in conscious attention, stronger C-reps are formed that provide a context for the memory in time and place. Further, associations between corresponding C-reps and S-reps are strengthened. Now, when reminders are encountered, the memories retrieved are contextualized and are experienced as belonging to the past rather than being a source of danger in the present. This account is compatible with many contemporary theories of human and animal cognition (Gold, 2004; Kesner & Rogers, 2004; Poldrack & Packard, 2003) which favor the idea that learning produces a variety of new representations that can collaborate or compete with existing memories for control of behavior. The concept of retrieval competition between alternative representations features strongly in the literature on verbal overshadowing (Schooler & Engstler-Schooler, 1990; Brandimonte & Collina, 2008), and has similarly been incorporated into several models of therapeutic change (Bjork & Bjork, 2006; Brewin, 2006).

This account is primarily applicable to psychological treatment for established PTSD. There is controversy over whether rehearsing the trauma memory is effective as a measure to prevent PTSD in populations very recently exposed to trauma (e.g., as part of psychological debriefing). Reviews have suggested that at this time the procedure is ineffective and may even be harmful (McNally, Bryant, & Ehlers, 2003; van Emmerik, Kamphuis, Hulsbosch, & Emmelkamp, 2002). It should be noted, however, that studies of psychological debriefing have not typically sought to identify high-risk samples, to rehearse the trauma memory in a particular way, or to do it more than once. There is some preliminary evidence that methods involving more guided or structured rehearsal may prove to have preventive value in selected samples (Gidron et al., 2001; Gidron et al., 2007), but the issue remains controversial.

The distinction between perceptual and episodic representations may assist in explaining a variety of phenomena including some instances of false memory creation. In a recent study (Brewin, Huntley, & Whalley, 2012) participants with PTSD wrote a trauma narrative and reported during what parts of the narrative they experienced flashbacks. They were later presented with stimuli from flashback and non-flashback parts of their narrative, mixed with foil stimuli, and judged whether they belonged to their own narrative. They also reported whether stimuli elicited a flashback during this recognition test. Overall reporting a flashback at test was associated with significantly better recognition performance. However, flashbacks were occasionally reported to foil stimuli, which were then significantly more likely to be wrongly attributed to the person's own narrative. These findings illustrate how perceptual and episodic memory systems may under some conditions collaborate to improve recall but under other conditions compete, potentially accounting for some cases of false trauma memories.

Three areas for future research would especially benefit the understanding of trauma-related psychological disorders. The first concerns the voluntary memories produced by individuals with PTSD. It is still unclear whether the underlying representation in memory is indeed disorganized or whether the disorganization occurs during the production of the trauma narrative. On the one hand the positive correlations between dissociation reported to have occurred during the trauma and indices of memory fragmentation suggest that there is a disturbance at the stage of encoding. But it is also possible that there is a disturbance during retrieval, caused for example by the spontaneous emergence of emotion-laden images that disrupt conscious attempts at recall. As previously noted (see section on Long-Term Perceptual Memory for Autobiographical Events), the intrusion of such images has been linked to spontaneous shifts into the present tense (Pillemer, et al., 1998), although with a few exceptions (Hellawell & Brewin, 2004; Jelinek et al., 2010) this has rarely been studied in PTSD samples.

Another phenomenon described by trauma researchers is that recall and reliving of voluntary memories within PTSD therapy often produces hypermnesia for details of the traumatic event. Hypermnesia is a well-established experimental phenomenon (Erdelyi, 2010), particularly in respect of pictorial material (Erdelyi & Becker, 1974), and there are demonstrations of a variety of interventions leading to recall of additional details of a briefly perceived stimulus (Haber & Erdelyi, 1967; Thompson, Kosslyn, Hoffman, & van der Kooij, 2008). There are obvious parallels between the repeated attempts at recall characteristic of hypermnesia experiments and the repeated reliving that occurs in trauma therapy. It would be informative to know whether the clinical observations of hypermnesia are related to the processes identified in these experimental findings.

Finally, although the functional independence of perceptual and episodic memories is becoming increasingly clear, research is needed on the way in which they interact to produce the involuntary memories that characterize PTSD. For example, most of the demonstrations of the independence of involuntary and voluntary memory within the trauma film paradigm are confounded with this perceptual/episodic distinction. It would be valuable to conduct more studies measuring both involuntary images and involuntary thoughts derived from the same sensory input, and to test whether they are differentially related to indices of voluntary recall and recognition. It is also important to bear in mind that to date much of this research has been based on healthy volunteers, utilizing different kinds of secondary task with the intention of strengthening or weakening different competing representations (Holmes, et al., 2004; Holmes, et al., 2010). These studies have been extremely valuable in providing evidence for key theoretical predictions arising from clinical theories of PTSD, but much remains to be done to establish their validity in clinical settings and clinical samples.

Coda: "Special Mechanisms" in Memory

A final implication of the review is for the series of debates that have revolved around the idea of "special mechanisms" in memory. In presenting their ground-breaking work on vivid flashbulb memories, Brown and Kulik (1977) speculated on the existence of a special mechanism to explain their data, "Now Print", leading to the publication of numerous articles that attempted to decide whether flashbulb memories were any more accurate or reliable than other memories rather than directly addressing individuals' phenomenological experience. Subsequently Shobe and Kihlstrom (1997) criticized the idea that traumatic events could be subject to special memory mechanisms such as repression or dissociation, leading to a glut of articles questioning these hypothetical mechanisms at the expense of studying the actual phenomenon, i.e. the forgetting of traumatic events.

More recently, Rubin and colleagues (Rubin, Boals, et al., 2008) contrasted "special mechanism" accounts of memory in PTSD, in which they included the clinical theories described in this article, with "basic mechanism" accounts such as that of Rubin, Berntsen et al. (2008). They suggested that "special mechanism" accounts derived from clinical research into PTSD whereas basic mechanism accounts derived from "naturalistic and experimental research on memory, with the aim of providing a broad understanding of memory in diverse contexts, including, but not limited to, traumatic events" (p. 592).

It should be evident from this review that there is no such clear-cut distinction; rather, both 'special mechanism' and 'basic mechanism' accounts of memory in PTSD are equally grounded in a broad appreciation of human memory phenomena and in a variety of different methodological approaches utilizing clinical and healthy samples. The theories do, however, make differing predictions and some of these have been addressed in this review (e.g., clinical theories predict an impairment of voluntary memory for the traumatic event whereas Rubin, Berntsen et al., 2008, predict enhanced voluntary memory). Where differing conclusions rest on different methodologies, e.g., the use of observer ratings versus single self-report items to assess the quality of traumatic memory (see *Voluntary Episodic Memory in PTSD*), these should be addressed empirically.

To invoke "special mechanisms" implies that we have a good scientific understanding of how memory behaves under normative conditions. But it is increasingly clear that the search for generally applicable laws of memory has failed (Roediger, 2008). Instead of framing questions in terms of a "special mechanism", therefore, it will likely be more fruitful to consider how ordinary memory mechanisms may operate under usual and unusual circumstances. The existence of long-term perceptual memory representations, and the differing relations they have with episodic memory, open up a range of empirical questions and techniques that can be exploited to investigate the richness and variety of memory phenomena in both clinical and nonclinical arenas.

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Table 1
Studies of quality of voluntary memory for traumatic events in acute stress disorder and posttraumatic stress disorder

Study	N	Groups	Material	Measure	Findings
Harvey & Bryant (1999)	29 MVA survivors (14M)	ASD/No ASD	Trauma narrative	Judges' ratings: Disorganization of individual narrative elements	ASD more disorganized than non-ASD (*p*<.05)
Halligan et al. (2003) study 1	81 assault survivors (48M)	Current PTSD Recovered PTSD No PTSD	Trauma narrative	Judges' ratings: Disorganization of individual narrative elements	Current PTSD ($p < .01$) and recovered PTSD ($p < .05$) more disorganized than no PTSD
				Overall coherence	Current PTSD ($p < .001$) and recovered PTSD ($p < .01$) more disorganized than no PTSD
			Trauma Memory Questionnaire	Self-rating of disorganization (5 items)	Current PTSD more disorganized than no PTSD ($p < .01$)
Halligan et al. (2003) study 2	73 assault survivors (41M)	PTSD/No PTSD	Trauma Memory Questionnaire	Self-rating of disorganization (5 items) of the assault and a negative, non-traumatic event	Significant group x memory type interaction ($p < .01$): Disorganization greater for assault than non-traumatic event, this effect strongest in PTSD group
Berntsen et al. (2003)	113 trauma survivors[1]	PTSD/No PTSD	Memory Questionnaire	Coherence of memory (1 item)	No group differences (p < .05)
Rubin et al. (2004)	50 military veterans (50M)	PTSD	Autobiographical Memory Questionnaire in respect of 4 types of memory	Coherence of story (1 item)	Trend for traumatic memory to be more coherent than non-traumatic memories
				Fragmentation (1 item)	No differences between memories ($p < .05$)
Jones et al. (2007)	131 MVA survivors (52M)	ASD/No ASD 1 week post-trauma PTSD/No PTSD 6 weeks post-trauma PTSD/No PTSD 3 months post-trauma	Trauma narrative	Judges' ratings: Repetition	No significant differences at 1 or 6 weeks. PTSD at 3 months more repetition than no PTSD ($p < .01$)
				Non-consecutive chunks	No significant differences at 1 or 6 weeks. PTSD at 3 months more non-

					consecutive than no PTSD ($p < .001$)
				Overall coherence	ASD less coherent than no ASD ($p < .001$); PTSD at 6 weeks less coherent than no PTSD ($p < .01$); PTSD at 3 months less coherent than no PTSD ($p < .001$)
Jelinek et al. (2009)	81 survivors of a single trauma (38M) 30 non-traumatized (11M)	PTSD/No PTSD/ non-traumatized	Trauma and non-trauma narratives	Judges' ratings: Disorganization of individual narrative elements	Significant group x memory type interaction ($p < .01$): Disorganization greater for assault than non-traumatic event, this effect strongest in PTSD
				Overall coherence	Marginal group x memory type interaction ($p < .07$): Disorganization greater for assault than non-traumatic event, this effect strongest in PTSD
			Trauma Memory Questionnaire: trauma and non-trauma memory	Self-rating of disorganization (5 items)	No significant interaction ($p < .05$)
Kenardy et al. (2007)	87 child survivors of a trauma aged 7-15 (59M)	Subsyndromal PTSD by parent report/no PTSD	Verbal trauma narrative	Judges' ratings: Temporal disorganization	PTSD more disorganized than non-PTSD ($p<.05$)
Salmond et al. (2011)	50 child survivors of a trauma aged 8-17 (25M)	ASD/no ASD	Verbal trauma and non-trauma narratives	Judges' ratings: Disorganization of individual narrative elements	Significant group x memory type interaction ($p < .01$): Disorganization greater for trauma than non-trauma narrative in ASD only
				Overall coherence	Significant group x memory type interaction ($p < .05$): Disorganization greater for trauma than non-trauma narrative in ASD only

Footnote. [1] Gender breakdown for sample not provided.
M = males; ASD = Acute Stress Disorder; PTSD = Posttraumatic Stress Disorder; MVA = motor vehicle accident.

Table 2
Effects of secondary tasks on voluntary and involuntary memory of a traumatic film

Study	N	Film modality (clips; time)	Secondary tasks	Timing of tasks	Voluntary memory results[1]	Involuntary memory results[1]
Brewin & Saunders (2001)	39 (19M)	Visual real-life 5 clips (12:30)	Spatial tapping (S) No-task control (C)	During film	Cued recall: S=4.53a (1.54) C=4.95a (2.16)	Intrusive images over 2 weeks: S=1.95a (2.21) C=5.32b (4.24)
Holmes et al. (2004) exp. 1	51[2]	Visual real-life 5 clips (12:30)	Spatial tapping (S) No-task control (C)	During film	Cued recall: S=8.32a (1.98) C=8.06a (2.83)	Intrusive images over 1 week: S=2.23a (2.92) C=4.94b (4.29)
Holmes et al. (2004) exp. 2	80 (41M)	Visual real-life 5 clips (12:30)	Complex tapping (S3) Overpractised tapping (S2) Simple tapping (S1) No-task control (C)	During film	Cued recall: S3=6.52a (2.38) S2=6.88a (2.19) S1=7.58a (2.28) C=7.10a (2.79) Recognition: S3=10.10a (2.79) S2=9.35a (2.46) S1=10.50ab (2.24) C=11.85b (2.78)	Intrusive images over 1 week: S3=3.25a (3.55) S2=3.70a (3.28) S1=5.50ab (5.11) C=6.65b (8.36)
Holmes et al. (2004) exp. 3	60 (27M)	Visual real-life 5 clips (12:30)	Describing out loud (VE) No-task control (C) Counting backwards in 3s (V)	During film	Cued recall: VE=8.16a (2.32) C=7.44a (1.95) V=7.63a (2.11) Recognition: VE=10.58a (2.41) C=9.63a (2.73) V=9.05a (2.70)	Intrusive images over 1 week: VE=5.10ab (3.40) C=3.10a (3.60) V=9.70b (10.47)
Stuart et al. (2006)	20 (7 M)	Visual real-life 5 clips	Making shapes (S)[3] No-task control (C) [3]	During film	Not measured	Intrusive images over 1 week: S=0.95a (1.10)

		(12:30)				C=2.40b (1.93)
Nixon et al. (2007)	43	Visual fiction 1 clip (5:00)	Remembering 9-digit number (V) No-task control (C)	During film	Recall sequence: V=2.05a (1.61) C=3.10b (1.41) Recall performance: V=4.45a (1.84) C=5.19a (1.75) Recognition (d'): V=0.23a (0.65) C=0.46a (0.56)	Impact of Event Scale Intrusion score over 1 week: V=1.03a (0.50) C=1.01a (0.58)
Nixon et al. (2009)	40	Visual fiction 1 clip (5:00)	Remembering 9-digit number (V) No-task control (C)	Immediately after film	Recall sequence: V=4.35a (1.23) C=4.30a (1.26) Recall performance: V=5.35a (1.73) C=5.70a (1.72) Recognition (d'): V=0.25a (0.88) C=-0.01a (0.78)	Intrusive images over 1 week: V=10.50a (10.63) C=7.20a (4.55)
Krans et al. (2009)	76 (11 M)	Visual real-life 3 clips (6:48)	Describing out loud (VE) No-task control (C) Counting backwards in 3s (V)	During film	Cued recall: VE=4.38a (1.86) C=5.48a (1.59) V=2.97b (2.15) Recognition: VE=5.63a (1.21) C=5.78a (1.31) V=5.17a (1.34)	Intrusive images over 1 week: VE=3.75a (2.41) C=3.53a (3.26) V=2.07a (2.02)
Holmes et al. (2009) [4]	40 (22 M)	Visual real-life 11 clips (12:00)	Tetris (S) No-task control (C)	30 mins post-film	Recognition: S=20.10a (3.44) C=20.20a (2.93)	Intrusive images over 1 week: S=2.80a (0.59) C=6.70b (1.22)
Bourne et al. (2010) exp. 1[4]	40 (23 M)	Visual real-life 5 clips (13.00)	Spatial tapping (S) No-task control (C) Counting backwards in 3s (V)	During film	Cued recall: S=9.81a (2.23) C=9.07a (2.81) V=6.20b (2.24) Recognition: S=11.00a (3.90)	Intrusive images over 1 week: S=1.45a; (1.86) C=3.79b (2.91) V=6.33b (4.97)

					C=10.29a (2.23) V=8.73a (2.63)	
Bourne et al. (2010) exp. 2[4]	38 (12 M)	Visual real-life 10 clips (21:30)	No-task control (C) Counting backwards in 7s (V)	During film	Recognition: C=19.53a (1.90) V=18.11b (2.35)	Intrusive images over 1 week: C=2.84a (1.61) V=5.32b (4.10)
Krans et al. (2010a)	86 (26M)	Auditory real-life 5 clips (11:42)	Making shapes (S) No-task control (C) Simple counting 1-6 (V)	During narrative	Cued recall: S=5.56a (2.29) C=5.86a (2.10) V=5.61a (2.23) Recognition: S=7.07a (1.77) C=8.00a (1.63) V=7.56a (1.43)	Intrusive images over 1 week: S=2.48a (2.23) C=4.57b (3.69) V=2.52a (2.55)
Krans et al. (2010b)	54 (20M)	Visual real-life 4 clips	Spatial tapping (S) No-task control (C) Gum-chewing (P)	During film	Cued recall: S=5.19a (2.34) C=7.00b (1.56) P=6.21ab (1.47) Recognition: S=10.81a (1.60) C=11.47a (1.90) P=11.00a (1.86)	Intrusive images over 1 week: S=1.64a (1.86) C=4.28b (4.79) P=2.63b (1.61)
Holmes et al. (2010) exp. 1[4]	60 (30M)	Visual real-life 15 clips (21:00)	Tetris (S) No-task control (C) Pub Quiz (V)	30 mins post-film	Recognition: S=20.65a (2.87) C=20.95a (7.13) V=19.65a (4.68)	Intrusive images over 1 week: S=2.90a (1.61) C=5.10b (3.80) V=7.70c (4.20)
Holmes et al. (2010) exp. 2[4]	78 (36M)	Visual real-life 11 clips (12:00)	Tetris (S) No-task control (C) Pub Quiz (V)	4 hours post-film	Recognition: S=19.46a (3.33) C=20.61a (2.57) V=20.50a (2.45)	Intrusive images over 1 week: S=3.50a (2.96) C=6.65b (6.24) V=7.53b (6.99)
Deeprose et al. (2012) exp. 1[4]	60 (21M)	Visual real-life 13 clips (9:00)	Spatial tapping (S) No-task control (C) Counting backwards in 3s (V)	Immediately post-film	Not measured	Intrusive images over 1 week: S=2.00a (2.49) C=4.50b (4.76) V=4.70b (1.65)

Deeprose et al. (2012) exp. 2[4]	75 (38M)	Visual real-life 14 clips (22:00)	Spatial tapping (S) No-task control (C) Counting backwards in 7s (V)	30 mins post-film	Recognition: S=17.68a (3.16) C=17.92a (2.89) V=17.76a (2.95)	Intrusive images over 1 week: S=2.96a (3.16) C=4.92b (3.55) V=6.76b (5.41)
Logan & O'Kearney (2012)	105 (52M)	Visual real-life 1 clip (9:00)	Making shapes (S) No-task control (C) Counting backwards in 3s (V)	During film	Not measured	Intrusive images over 1 week: S=8.11a (9.83) C=8.83a (9.88) V=7.15a (5.04)

Footnote. [1] Data are means (standard deviations). Different subscripts (a, b, c) indicate significant differences (*p* < .05); [2] Gender breakdown for sample not provided; [3] Within-subject design; [4] Data supplied by the authors.
M = males; C = no-task control; P = propriospatial imagery; S = visuospatial imagery; V = verbal interference; VE = verbal enhancement.

Table 3
Relation between voluntary episodic recall and involuntary intrusion of same stimuli: Correlational studies

Study	N	Stimulus	Voluntary memory measure	Involuntary memory measure	Relation of voluntary to involuntary measures
Brewin & Saunders (2001)	39 (19M)	Trauma film	Cued recall	Intrusive images over 2 weeks	Correlation not significant (*p*<.05)
Holmes et al. (2004) exp. 1	51[1]	Trauma film	Cued recall	Intrusive images over 1 week	*r* = -.06
Holmes et al. (2004) exp. 2	80 (41M)	Trauma film	Cued recall Recognition	Intrusive images over 1 week	*r* = .01 *r* = -.08
Holmes et al. (2004) exp. 3	60 (27M)	Trauma film	Cued recall Recognition	Intrusive images over 1 week	*r* = .04 *r* = .08
Michael & Ehlers (2007) exp. 2	35[1]	Traumatic and neutral picture stories	Recognition	Reexperiencing over 1 month	*r* = -.40
Hagenaars et al. (2008)	79 (11M)	Trauma film	Cued recall	Intrusive images over 1 week	*r* = -.06
Nixon et al. (2009)	80 (41M)	Fictional trauma film	Recognition	Intrusive images over 1 week	Correlation not significant (*p*<.05)
Ferree & Cahill (2009)	48 (16M)	Emotional and neutral film clips	Free recall	Rating of intrusive memories after 48 hours	*r* = .57
Krans et al. (2010b)	54 (20M)	Trauma film	Cued recall Recognition	Intrusive images over 1 week	Correlation with cued recall not significant (*p*<.05)
Ferree et al. (2011)	40 (0M)	Emotional film clips	Free recall	Rating of intrusive memories after 48 hours	*r* = .28
Sündermann et al. (2013)	51 (27M)	Traumatic and neutral picture stories	Recognition	Intrusive images over 2 weeks Intrusive images over 3 months	*r* = -.05 *r* = -.28

Footnote. [1] Gender breakdown for sample not available.
M = males.

Table 4
Relation between voluntary episodic recall and involuntary intrusion of same stimuli: Additional experimental studies

Study	N	Stimulus	Voluntary memory measure	Involuntary memory measure	Manipulation	Effect on voluntary (VM) & involuntary (IVM) measures
Krans et al. (2009a)	57[1]	Trauma film	Cued recall	Intrusive images over 1 week	Within-subjects: immediate recognition of scenes vs. no recognition	Recognition increased VM (p < .01) and decreased IVM (*p* < .05)
Bisby et al. (2009)	48 (24M)	Trauma film	Cued recall Recognition	Intrusive images over 1 week	Between-subjects: high alcohol vs. low alcohol vs. placebo	Alcohol had linear effect on VM and quadratic effect on IVM
Bisby et al. (2010)	48 (24M)	Trauma film	Cued recall Recognition	Intrusive images over 1 week	Between-subjects: high alcohol vs. low alcohol vs. placebo	Alcohol had linear effect on VM and quadratic effect on IVM
Hagenaars & Arntz (2012)	51[1]	Trauma film	Cued recall	Intrusive images over 1 week	Between-subjects: imagery rescripting vs. positive imagery	Rescripting increased VM (p < .05) and decreased IVM (*p* < .05)

Pearson et al. (2012) exp. 1	40 (14M)	Positive and negative pictures	Recognition	Intrusive images over 1 week	Within-subjects: Extra context at encoding vs. no context	Extra context had no effect on VM but increased IVM ($p < .05$)
Pearson et al. (2012) exp. 2	40 (19M)	Positive and negative pictures	Free recall Recognition	Intrusive images over 1 week	Within-subjects: Extra context at encoding vs. no context	Extra context had no effect on VM but increased IVM ($p < .001$)
Pearson (2012)	38 (8M)	Trauma film	Cued recall Recognition	Intrusive images over 1 week	Between-subjects: Audio commentary vs. no commentary	Extra context had no effect on VM but increased IVM ($p < .05$)
Ehlers et al. (2012)	122 (58)	Traumatic and neutral picture stories	Recognition	Intrusive images over 1 week	Between-subjects: Verbal elaboration vs. exposure vs. control	Elaboration and exposure had no effect on VM but decreased IVM ($p < .05$)

Footnote. [1] Gender breakdown for sample not available.
M = males.