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Enhanced perceptual priming for neutral stimuli in a traumatic context: A pathway to intrusive memories?

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Clinical observations suggest that re-experiencing symptoms are triggered by stimuli that are perceptually similar to those present shortly before the trauma or its worst moments. Two experiments investigated the possible role of perceptual priming in this phenomenon. Volunteers ($N = 28$, $N = 62$) watched a series of ''traumatic'' and neutral picture stories, and completed blurred object identification (priming) and recognition memory tasks. Neutral objects that immediately preceded the ''traumatic'' stories were more strongly primed, but not better recognised, than objects from neutral stories. Enhanced priming predicted subsequent re-experiencing symptoms. The results support the role of perceptual priming in re-experiencing.

After traumatic events, many people experience unwanted intrusive memories. These usually consist of brief, sensory segments of the event. Visual intrusive memories are particularly common (e.g., Ehlers, Hackmann, Steil, Clohessy, Wenninger, & Winter, 2002; Mellman & Davis, 1985). One important characteristic of intrusive memories is that they are triggered by a remarkably wide range of external and internal triggers (Brewin, Dalgleish, & Joseph, 1996; Foa, Steketee, & Rothbaum, 1989; Michael, Ehlers, Halligan, & Clark, 2005b). The present experiments were designed to explore a possible mechanism of the easy triggering of intrusive memories.

Clinical observations suggest that triggers often appear to be stimuli that are *perceptually* similar to the stimuli that are re-experienced, or to stimuli that immediately preceded them (Ehlers & Clark, 2000; Ehlers, Hackmann, & Michael, 2004; Southwick, Krystal, Morgan, Johnson, Nagy, & Nicolaou, 1993). For example, a patient with post-traumatic stress disorder (PTSD) kept seeing headlights coming towards him, just as he had seen them shortly before his head-on car crash. Observations in therapy suggested that these intrusions were often triggered by round patches of light on a dark surface, (e.g., a patch of sunlight on a lawn, white spots on a dark cloth). It is important to note that these triggers bear no semantic connection to the trauma—the relationship is one of similarity in perceptual pattern to the intrusion. This makes it difficult for patients

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with PTSD to identify these triggers, and the intrusive memories often appear to come ''out of the blue''. In other examples, the triggering stimuli appear to be perceptually similar to those that immediately preceded the stimulus that is re-experienced. For example, Reemtsma (1997), who was kidnapped and held hostage in a cellar, re-experienced a knocking sound. His kidnappers had knocked at the door of the cellar before bringing him food, and he had feared for his life when they came into the room. Reemtsma (1997) describes that he became gradually aware that the intrusions of the knocking sound were triggered by the sound of footsteps, a sound that he perceived shortly before the knocking sound.

Ehlers and Clark (2000) suggested that the easy triggering of re-experiencing in PTSD by perceptually similar cues is in part a function of *strong perceptual priming* for stimuli that occurred shortly before and during the traumatic event. The authors suggested that in PTSD perceptual priming works in conjunction with two other memory mechanisms in producing distressing and intrusive trauma memories. First, *strong associative learning* is thought to facilitate the retrieval of the corresponding affect by strong associations between trauma-related stimuli and strong affective responses (S–R associations, see also Foa et al., 1989; Keane, Zimering, & Caddell, 1985), thus making the intrusions distressing.[1] Associative learning, like priming, is also thought to contribute to the easy cue-driven retrieval of corresponding aspects of the trauma memory by strong associative links between the stimuli experienced shortly before and during trauma (S–S associations). Second, cue-driven retrieval is thought to be *poorly inhibited* in PTSD because the traumatic moments during the event are poorly elaborated and poorly integrated into a context of previous and subsequent events (see also Conway & Pleydell-Pearce, 2000, for related ideas). The three memory processes (priming, associative learning, and poor elaboration) are thus thought to work in conjunction in producing re-experiencing symptoms in PTSD. The hypothesised role of priming in the Ehlers and Clark (2000) model resembles the emphasis on implicit memory for trauma by other theorists (e.g., Bower & Sivers, 1998; Brewin, 2001; Siegel, 1995). For example, Brewin et al. (1996) hypothesised that intrusive memories reflect a representation of the trauma in memory that is situationally, but not verbally, accessible.

The present experiment was designed to investigate the *enhanced priming* hypothesis. Perceptual priming is a form of implicit memory that refers to the facilitated identification of perceptual objects as a consequence of prior exposure. In laboratory experiments, perceptual priming can be demonstrated by enhanced identification rates for degraded presentations (e.g., blurred pictures, fragmented words) of stimuli with previous exposure versus those without previous exposure. Importantly, perceptual priming can occur independently of any conscious recollection of a previous encounter with the stimuli (Schacter, 1992). Perceptual priming is assumed to be responsible for certain mind-popping phenomena. For example, the painter Cheryl Warrick noticed that in the aftermath of the birth of her baby, shapes of knobby, fistlike structures attached to thin tubes kept intruding into her mind. One day, while playing with the baby, she spotted the intruding shapes: baby rattles. Such memories are not explicit recollections of certain objects or events. Instead they represent implicit memories of perceptual fragments of experience that materialise in awareness unattached to further information (Schacter, 1996).

In applying the enhanced priming hypothesis to re-experiencing in PTSD, it is of interest to note that the association between the stimuli that are later re-experienced and the traumatic event does not necessarily require a meaningful relationship at the time of the event; a temporal association appears sufficient (Ehlers et al., 2002). Intrusive memories may be about markers of the location where the trauma happened, or about salient stimuli that the trauma survivor perceived shortly before the onset of the trauma or its worst moments. For example, a man who witnessed the suicide of a person who jumped in front of a train re-experienced the sight of railway tracks as he had seen them before the person jumped. He did not re-experience the sight of the train approaching or the sight of the person jumping, both of which would have a more meaningful relationship to the person's death. Thus, the stimuli that are re-experienced in PTSD may have been neutral before the event, and only by association with the subsequent trauma acquired a threatening meaning.

[1] As distressing intrusions are more persistent than non-distressing intrusions (Michael et al., 2005b), people with persistent PTSD, who have persistent distressing intrusive memories, are expected to show both strong priming and strong associative learning.

It is these neutral stimuli that immediately precede trauma that are of core interest to this paper. According to Ehlers and Clark (2000), there may be enhanced perceptual priming for such stimuli (compared to neutral stimuli in a neutral context), leading to a reduced threshold for their identification, and correspondingly, to a greater chance that intrusive memories are triggered. Conditioned emotional responses may work in conjunction with the enhanced priming by facilitating cue-driven retrieval and corresponding affect, thus making the intrusive memories distressing. The present study was designed to test these hypotheses.

Very few studies to date have investigated the role of priming in re-experiencing or PTSD. Amir, McNally, and Wiegatz (1996) and Michael, Ehlers, and Halligan (2005a) found evidence of greater priming for trauma-related sentences or words compared to control sentences or words (but see McNally & Amir, 1996, for negative results). Priming for assault-related words predicted PTSD severity 6 months later (Michael et al., 2005a). The above experiments studied priming for words or sentences, which are related to, but dissimilar to, the sensory impressions that are re-experienced after trauma. As visual intrusive memories are the most common form of re-experiencing (e.g., Ehlers, et al., 2002), it would be desirable to study priming for visual trauma-related material. This is difficult to achieve in clinical populations as the stimuli differ from one trauma survivor to the other and are often unknown. The present paper presents an experimental paradigm that was designed to study visual priming for neutral objects that occur in a ''traumatic'' context by presenting picture stories. An analogue design has the advantage that the stimuli presented during the ''trauma'' are under experimental control, and are the same for all participants.

The present experiment also explored the effects of cognitive processing on re-experiencing, and its relationship with priming. Ehlers and Clark (2000) suggested that data-driven processing contributes to the development of re-experiencing symptoms. Data-driven processing refers to encoding that focuses on the surface level (i.e., sensory details) of information rather than its meaning. Prospective studies of assault and motor vehicle accident survivors (Halligan, Michael, Clark, & Ehlers, 2003; Murray, Ehlers, & Mayou, 2002; Rosario, Ehlers, Williams, & Glucksman, 2005) have indeed supported a relationship between reported data-driven processing during trauma and subsequent intrusive memories. Data-driven processing may facilitate perceptual priming during trauma. Memory research has established that performance on a memory test benefits as a direct function of similarity in cognitive operations between the encoding and testing phase (Roediger, 1990). One may therefore expect that perceptual priming, which relies heavily on perceptual, unconscious operations, should profit from encoding that favours such information.

In summary, the present experiments examined the following hypotheses:

- *Hypothesis 1: Enhanced perceptual priming*. We predicted that neutral stimuli that immediately precede a ''traumatic'' event are more strongly primed than neutral stimuli that precede a neutral event.
- *Hypothesis 2: Intrusive memories*. We expected that intrusive memories at follow-up would be predicted by enhanced priming for potential trigger stimuli (i.e., neutral stimuli that preceded the traumatic scene), conditioned anxiety responses, and their interaction.
- *Hypothesis 3: Data-driven processing*. We predicted that data-driven processing would be related to enhanced priming and subsequent intrusive memories.

For purposes of comparison, the experiments also tested perceptual priming for ''traumatic'' (e.g., knife used in a stabbing, rope used in a hanging) versus neutral objects, and recognition memory for the material from the picture stories. On the basis of eye-witness research (Christianson, 1992), we expected that object importance would be a critical factor in recognition memory in that central information would be better recognised than peripheral information.

METHOD

Participants

Participants were students of Oxford University and Oxford Brookes University, UK, who responded to an invitation to participate in the study. Participants received £5 travel expenses. Volunteers were excluded if they had a history of trauma, suffered from current blood/injury phobia or severe depression.

Experiment 1. Participants were 28 students (14 men, 14 women) aged between 18 and 26

years, $M = 20.2$, $SD = 1.4$. Their mean score for trait anxiety on the State-Trait Anxiety Inventory (STAI, Spielberger, Gorsuch, Lushene, Vagg, & Jacobs, 1983) was 39.9, $SD = 9.7$, and for state anxiety $M = 34.2$, $SD = 8.9$.

Experiment 2. Participants were 62 students (27 men, 35 women) aged between 18 and 24 years, $M = 19.5$, $SD = 1.2$. Their mean score for STAI trait anxiety was 42.4, $SD = 10.6$, and for state anxiety $M = 33.6$, $SD = 6.2$.

Materials

The experimental software for all parts of the experiment was programmed with SuperLab. Picture stories and memory tests were presented on a 15″ screen of an APPLE Macintosh computer.

Picture Stories

Participants saw eight analogue ''traumatic'' (e.g., woman being strangled) and eight neutral picture stories (e.g., woman making a phone call), each consisting of three pictures. One additional neutral story was used to familiarise the participants with the task. The picture stories all follow a particular pattern: The first picture (presented for 20 seconds) is always neutral and shows the main character in a neutral setting, regardless of whether the story later unfolds in a ''traumatic'' or neutral fashion. The first picture contains two neutral objects (*preceding* objects). These objects parallel the stimuli that are thought to become later triggers for intrusive memories (Ehlers et al., 2002). The second picture (presented for 20 seconds) depicts the plot of the story and shows something traumatic or neutral happening. It contains one *central* object that determines whether the content is traumatic or neutral. The third and last picture (presented for 15 seconds) shows the final outcome for the main character of the story. It focuses on and underlines the traumatic vs neutral content of the story.

In order to make the material as realistic as possible, the stories were made up from documentaries or feature films starring actors and actresses who were not well known. The cultural background of the stories was embedded in a ''Western'' context so that the participants (who all lived in a similar context) could easily identify with the main characters.

The unpleasant and neutral picture stories were matched for the number of males, females, and objects occurring in them, and whether the event happened indoors or outdoors. For example, one unpleasant story contains a dog killing a man and the matching story depicts a cat stealing a sandwich from its owner. Table 1 illustrates the structure of one unpleasant (a man being stabbed and decapitated) and one neutral picture story (a man coming home and seeing his wife repairing a boot on the dining table), and lists what objects occur in these stories.

Participants were told that it was the purpose of the experiment to test how pictures affect people's emotions. They were asked to watch the pictures closely and to imagine that they were present at the scene. After each picture story, they were

TABLE 1
Story structure

	''Traumatic'' story	*Neutral story*
PICTURE 1: Main character in neutral setting *Preceding stimuli*	A man is watching TV *bottle, cushion*	A man is entering the kitchen *spatula, frying pan*
PICTURE 2: Main character experiences ''traumatic'' or neutral event *Central stimuli*	The man is attacked with a knife by an intruder *knife*	The man notices that his wife is repairing an old boot on the kitchen table *boot*
PICTURE 3: ''Traumatic'' versus neutral outcome	Decapitated man	Puzzled man

Story structure, example of a ''traumatic'' and the parallel neutral story. The objects for which priming and recognition memory were later tested are in italics.

asked to rate the pictures for valence and arousal (see description of scales below). There was no indication that memory for the pictures would be tested later.

Picture stories were presented in two blocks of unpleasant and neutral stories, in counterbalanced order. Blockwise presentation was chosen to prevent crossover of negative emotions produced by unpleasant picture stories to neutral ones. Order of presentation did not influence the results. Between blocks participants had a 5-minute break. The order of the stories within each block was randomised and different for every participant.

Memory measures

Memory for objects shown in the picture stories was tested with a blurred object identification task (assessing perceptual priming) and a recognition task (assessing explicit memory). In designing the memory tests, objects from the picture stories were isolated and edited using Adobe PhotoShop. All objects were left in their original size. As each participant completed both memory tests, two equivalent sets of objects were created for each task. The sets contained one of the two preceding objects from each story and half of the central objects from unpleasant and neutral scenes, respectively. Half of the participants saw objects from set 1 in the perceptual priming task and objects from set 2 in the recognition task. For the other half of the participants, sets were reversed.

Perceptual priming task. Visual priming leads to an enhanced identification rate for previously seen objects. Perceptual priming was assessed with a blurred object identification task. The task included primed preceding and central objects from the ''traumatic'' and the neutral stories, and unprimed objects that had not featured in the picture stories (e.g., a hole punch, scissors), which served as distractors. These unprimed objects were matched for size to the primed objects from the picture stories.

Participants were told that they were now doing a different task that was unrelated to the picture stories. They were informed that the task was about how easy it is for people to identify blurred pictures. They were instructed to look at the pictures and guess what the object might be, working as quickly and as accurately as possible. The experimenter wrote down the answers, which were later coded for accuracy. If participants could not guess what the object might be, they indicated that they did not know. After their answer, participants moved on to the next object by pressing the space bar. The objects were presented on the computer screen in successive, random order that varied with each participant.

Recognition task. Object recognition performance was assessed as one way to estimate possible influences of explicit memory on the results of the priming task. For each ''old'' object from the picture stories, a parallel new object was chosen that looked somewhat different in appearance. These parallel new objects matched the objects from the picture stories in size and object type (e.g., if the object from the picture story was a watch, another watch of approximately the same size was used as the parallel object). Objects were presented on a computer screen in successive, random order that was different for each participant. Participants were asked to indicate whether or not they had seen the object previously in the stories by pressing the corresponding keys on the computer keyboard.

Pilot studies on suitability of stimulus material for perceptual priming task

Objects were blurred with a Gaussian filter to a degree that allowed approximately 40–50% correct identification in pilot participants with no prior exposure to the picture stories. A series of pilot studies was run to adjust filter levels. The baseline identification rates of the blurred objects from ''traumatic'' and neutral stories were as follows (in percent). For Experiment 1 (20 pilot participants), preceding objects: $M = 50.6$, $SD = 20.2$ versus $M = 50.0$, $SD = 16.7$, respectively, $t(15) = 0.12$, $p = .90$; central objects: $M = 50.0$, $SD = 20.7$ versus $M = 57.5$, $SD = 17.5$, respectively, $t(7) = 0.73$, $p = .49$; distractor items $M = 63.7$, $SD = 18.0$. For Experiment 2 (27 pilot participants), preceding objects: $M = 54.1$, $SD = 14.3$ versus $M = 55.9$, $SD = 21.1$, respectively, $t(15) = 0.29$, $p = .77$; central objects: $M = 51.3$, $SD = 25.6$ versus $M = 55.1$, $SD = 18.7$, respectively, $t(7) = 0.36$, $p = .73$; distractor items $M = 51.7$, $SD = 19.4$.

Comparability of the material used in the memory tasks. As priming for the preceding objects from the first (neutral) picture of the stories was of major interest to the paper, we

conducted a further test to ensure that objects from ''traumatic'' and neutral stories were not only similar in baseline identification rates, but also in salience. In a further pilot study for Experiment 1, 18 participants saw only the first picture of the picture stories, and completed perceptual priming and recognition tests for the preceding items from these pictures. Preceding objects from the ''traumatic'' stories did not differ in identification rates, $M = 0.65$, $SD = 0.15$, from those that occurred in neutral stories, $M = 0.65$, $SD = 0.16$, $t(17) = 0.04$, $p = .97$. There were no differences in recognition sensitivity, $t(17) = 0.28$, $p = .79$, ''traumatic'' stories: $M = 1.71$, $SD = 1.36$, neutral stories: $M = 1.62$, $SD = 1.15$, or response bias, $t(17) = 0.33$, $p = .74$, ''traumatic'' stories: $M = 0.41$, $SD = 0.60$, neutral stories: $M = 0.37$, $SD = 0.87$. For Experiment 2, a similar pilot study was conducted. A further 18 participants saw only the first picture of the stories and completed a perceptual priming task. Preceding objects from the ''traumatic'' stories did not differ in identification rates, $M = 0.63$, $SD = 0.14$, from those that occurred in neutral stories, $M = 0.63$, $SD = 0.16$, $t(17) = 0.10$, $p = .93$.

As none of the pilot studies indicated any differences in memory when the objects were presented without their emotional context, one can attribute possible memory differences for the preceding objects from the first picture stories in the three experiments reported in this paper to the emotional character of the stories.

Pilot study on enhanced priming effect. Prior to the experiments described in this paper, we ran a further pilot study to explore the hypothesised enhanced priming effect, using 12 central and 12 preceding objects from 10 traumatic and 10 neutral picture stories ($N = 30$, 20 men, 10 women, aged between 19 and 47 years). Participants identified 48% of the primed objects, and 38% of the unprimed distractor objects. Preceding objects from traumatic stories were more likely to be identified than preceding objects from neutral stories: $F(1, 29) = 4.58$, $p = .041$. Compared to baseline identification rates, participants who had seen the picture stories identified neutral objects that preceded ''traumatic'' stories with 16% greater probability than baseline identification rates, whereas neutral objects from neutral stories were only identified at baseline probability levels (note that identification rates were overall somewhat lower than in the pilot study that determined baseline probability levels). For recognition sensitivity, as expected, there was a main effect of object importance; central objects were better discriminated than preceding objects, Experiment 1: $F(1, 29) = 52.23$, $p < .001$, but no main effect, $F(1, 29) = 1.47$, $p = .24$, or interaction with ''traumatic'' versus neutral story context, $F(1, 29) = 0.02$, $p = .90$. Thus, the results of this pilot study were consistent with enhanced priming for neutral objects that occur in a traumatic context.

Further measures

The *Past Experience Questionnaire* screens participants for trauma history, blood/injury phobia, and severe depression. Participants who met any of these criteria were excluded from the study for ethical reasons.

Participants rated each picture story in terms of pleasantness and activation on two rating scales, each on a scale from –10 to 10. The *Pleasantness Rating* was labelled ''extremely unpleasant'' to ''very pleasant'' and the *Arousal Rating* ''very relaxing'' to ''very activating (e.g., pounding heart, tense muscles)''.

In Experiment 2, data-driven processing during the ''traumatic'' stories was measured with a 5-item version of the *Data-driven Processing Scale* (Halligan, Clark, & Ehlers, 2002). The Data-driven Processing Scale assesses the extent to which participants processed surface-level/perceptual features of the picture stories rather than their meaning (e.g., ''My mind was fully occupied with different impressions and sensations'', ''I was confused and could not fully make sense of what was happening''). The scale has been shown to have satisfactory to good internal consistency and to predict the development of PTSD symptoms in motor accident survivors (Rosario et al., 2005) and assault victims (Halligan et al., 2003), as well as the development of analogue PTSD symptoms following exposure to a distressing videotape (Halligan et al., 2002).

Conditioned emotional responses. As an indirect indicator of conditioned emotional responses, participants in Experiment 2 were asked at 1 week after the experiment whether they had felt more nervous or tense than usual since the experiment, on a scale from 0 (not at all) to 3 (very much).

Intrusive memories questionnaire. Participants in Experiment 2 received this questionnaire by mail at 3 months after the experiment. The questionnaire asks the participants whether they had

any intrusive memories about the picture stories from the experiment in the preceding week.

Procedure

The studies were approved by the Oxfordshire Psychiatric Research Ethics Committee. Participants received an information sheet about the study and were given further information on the telephone when arranging the appointment. They were informed in writing and verbally that the study involved watching some unpleasant pictures and that they could drop out of the study at any point without having to give a reason. On arrival at the laboratory, participants gave written consent. They then completed the Past Experience Questionnaire. Participants were then given oral and written instructions for watching the picture stories, and watched the two blocks of picture stories. After a 10-minute break, during which the experimenter served a drink and conversed with the participant about unrelated matters, the perceptual priming task was given, followed by the object recognition task.

The experimenter made sure that participants felt well before leaving and gave participants her contact details, encouraging them to get in touch if they felt in any way distressed about the experiment. However, none of the participants took up this offer and none reported that they found the experiment too distressing.

Participants of Experiment 2 received the Intrusive Memories Questionnaire 3 months after the experiment. This time point was chosen as the Ehlers and Clark (2000) model focuses on persistent PTSD rather than transient PTSD symptoms, and DSM-IV (American Psychiatric Association, 1994) defines 3 months as the point where PTSD becomes chronic.

RESULTS

All significance levels are two-tailed unless mentioned otherwise.

Validity of picture stories

Before examining the hypothesised effect of story context on perceptual priming, we checked whether participants perceived the ''traumatic'' stories as unpleasant and the neutral stories as neutral. Pleasantness and Arousal Ratings were compared with paired *t*-tests.

Participants rated the ''traumatic'' stories as more unpleasant than the neutral stories, Experiment 1: $M = -6.35$, $SD = 1.70$ versus $M = 0.99$, $SD = 1.88$, $t(27) = 13.43$, $p < .001$; Experiment 2: $M = -6.13$, $SD = 2.32$ versus $M = 0.89$, $SD = 1.43$, $t(60) = 20.13$, $p < .001$. They also rated the ''traumatic'' stories as more arousing, Experiment 1: $M = 4.02$, $SD = 2.43$ versus $M = -0.41$, $SD = 2.33$, $t(27) = 6.76$, $p < .001$; Experiment 2: $M = 4.69$, $SD = 1.93$ versus

TABLE 2
Results of Experiments 1 and 2

	Priming task	*Recognition task*	*Recognition task*
	Identification Rate *M* (*SD*)	*Sensitivity (d')* *M* (*SD*)	*Response Bias (c)* *M* (*SD*)
Experiment 1 ($N = 28$)			
Preceding			
''Traumatic''	0.60 (0.16)	1.79 (1.17)	0.52 (0.74)
Neutral	0.51 (0.21)	1.31 (1.16)	0.40 (0.76)
Central			
''Traumatic''	0.66 (0.21)	2.91 (1.58)	0.42 (1.04)
Neutral	0.55 (0.23)	3.12 (1.82)	0.87 (0.95)
Experiment 2 ($N = 62$)			
Preceding			
''Traumatic''	0.62 (0.18)	1.75 (1.26)	0.28 (0.66)
Neutral	0.55 (0.20)	1.36 (1.24)	0.46 (0.67)
Central			
''Traumatic''	0.75 (0.21)	2.97 (1.82)	0.27 (0.84)
Neutral	0.55 (0.20)	3.08 (1.67)	0.38 (0.91)

$M = 0.25$, $SD = 1.38$, $t(60) = 16.41$, $p < .001$. Hence, the stories were experienced as either moderately distressing or neutral.

Perceptual priming task

In no case did participants falsely identify an object from the picture stories when another object was presented.

Did priming occur? To test whether watching the picture stories led to perceptual priming, identification rates for the objects from picture stories (primed objects) were compared with those of distractor items that participants had not seen before (unprimed objects). As the baseline identification rates for the unprimed objects had been set higher than that of the primed objects in Experiment 1, the mean baseline identification rates were subtracted from mean identification rates to obtain an index of incremental identification. Note that the expected incremental identification rate for unprimed objects is 0, although scores can be below 0 if participants are overall worse at identifying the objects than the pilot participants. The incremental identification index for primed and unprimed objects was then compared with paired *t*-tests for preceding and central objects, respectively.

Primed objects from picture stories were identified with greater probability than unprimed objects without prior exposure. This was the case for both preceding objects, Experiment 1: $M = 0.05$, $SD = 0.15$ versus $M = –0.09$, $SD = 0.13$, $t(27) = 4.90$, $p < .001$; Experiment 2: $M = 0.02$, $SD = 0.08$ versus $M = –0.11$, $SD = 0.20$, $t(61) = 5.63$, $p < .001$; and central objects, Experiment 1: $M = 0.07$, $SD = 0.16$ versus $M = –0.09$, $SD = 0.13$, $t(27) = 4.86$, $p < .001$; Experiment 2: $M = 0.06$, $SD = 0.08$ versus $M = –0.11$, $SD = 0.20$, $t(60) = 6.75$, $p < .001$.

Influence of story context on priming? The results of the perceptual priming task are presented in Table 2. Identification rates for objects from picture stories were compared by 2 × 2 repeated measures ANOVA, with story context (''traumatic'' versus neutral) and object importance (central versus preceding) as the within-subject factors. The ANOVAs showed a significant main effect of story context, Experiment 1: $F(1,27) = 6.17$, $p = .019$, Experiment 2: $F(1,61) = 44.29$, $p < .001$. Blurred objects from ''traumatic'' stories were more likely to be identified than blurred objects from neutral stories. Experiment 2 also showed an interaction of story context and object importance, $F(1,61) = 8.88$, $p = .004$. A post-hoc contrast supported the hypothesis that blurred preceding objects from ''traumatic'' stories were more likely to be identified than preceding objects from neutral stories, $F(61) = 6.07$, $p = .017$. There were trends or main effects of object importance, Experiment 1: $F(1,27) = 4.11$, $p = .053$; Experiment 2: $F(1,61) = 7.18$, $p = .009$. Central objects tended to be identified more frequently than preceding objects.

Further analyses

Recognition memory. The results of the object recognition task are presented in Table 2. Data analysis of the object recognition task followed signal detection theory (SDT) (MacMillan & Creelman, 1991). From the hits (correct recognition of original objects) and false alarms (erroneous recognition of parallel objects), sensitivity (d′) and response bias (c) scores were calculated, for both preceding and central objects. Sensitivity is a standard measure of recognition memory performance that measures how well participants discriminated between objects from the stories and parallel objects that they had not seen before, calculated as d′ = probit (hits) – probit (false alarms). Response bias is a measure of leniency in endorsing an object as ''old'', calculated as c = –0.5 * (probit (hits) + probit (false alarms)). On the basis of eye-witness research (Christianson, 1992), we expected greater sensitivity for central than for preceding objects. Sensitivity and response bias were analysed using 2 × 2 repeated measures ANOVAs, with story context (''traumatic'' versus neutral) and object importance (central versus preceding) as within-subject factors.

As expected, there was a main effect of object importance; central objects were better discriminated than preceding objects, Experiment 1: $F(1,27) = 32.16$, $p < .001$; Experiment 2: $F(1,61) = 62.90$, $p < .001$. In contrast to the perceptual priming task, story context (''traumatic'' versus neutral) did not influence the sensitivity with which the objects were identified in the recognition task. There was neither a main effect of story context, Experiment 1: $F(1,27) = 0.37$, $p = .55$, Experiment 2: $F(1,61) = 0.51$, $p = .48$; nor an interaction with object importance, Experiment 1:

$F(1, 27) = 1.90$, $p = .18$; Experiment 2: $F(1, 61) = 1.63$, $p = .21$.

Table 2 also presents the results of response bias analyses. In Experiment 1 there were no main effects of object importance or story context, but a significant interaction, $F(1, 27) = 7.29$, $p = .01$. The only significant post-hoc effect was that participants used a more liberal response criterion for central objects from neutral stories than for preceding objects from neutral stories. In Experiment 2, there were no significant main effects or interactions.

Sensitivity or response bias for objects from ''traumatic'' stories in the recognition task did not correlate with identification rates in the perceptual priming test, Experiment 1, all rs < .27, all ps > .18; Experiment 2, all rs < .18 all ps > .17.

Associations between enhanced priming for objects from traumatic stories and self-reports. Pearson correlations tested the hypothesised association between data-driven processing and enhanced perceptual priming in Experiment 2. Enhanced perceptual priming was defined as the difference in identification rates between neutral objects preceding ''traumatic'' stories and those preceding neutral stories. Correlations were also calculated for other variables that may affect priming such as perceived valence and arousal during the picture stories, and trait and state anxiety. Enhanced perceptual priming correlated with reported data-driven processing during the ''traumatic'' stories, $r = .37$, $p = .004$, but not with Pleasantness ($r = -.02$, $p = .90$) and Arousal Ratings ($r = .13$, $p = .32$) for these stories. The association of enhanced priming and data-driven processing remained significant when Pleasantness or Arousal ratings were partialled out, $r = .36$, $p = .005$ for both. There were no associations of enhanced priming with STAI state ($r = .06$, $p = .63$) or trait anxiety ($r = .04$, $p = .77$).

Priming, conditioned emotional responses and subsequent intrusive memories. In Experiment 2, 52 participants returned the Intrusive Memories Questionnaire. Of these, 14 reported intrusive memories at 3 months after the experiment. The association between enhanced perceptual priming and conditioned emotional responses and subsequent intrusive memories was tested by comparing participants who reported intrusive memories at 3 months with those who did not report intrusive memories, by t-tests. Participants with intrusive memories at 3 months had shown greater enhancement of priming during the experiment for objects from ''traumatic'' stories than those without intrusions, $M = 0.17$, $SD = 0.16$ versus $M = 0.03$, $SD = 0.21$ during the experiment, $t(50) = 2.21$, $p = .031$. There were no differences between participants with and without intrusive memories in their performance in the recognition task, d′: $t(50) = 0.075$, $p = .94$; c: $t(50) = 0.003$, $p = .997$. Participants with subsequent intrusive memories had also reported greater conditioned emotional responses in the week after the experiment $M = 0.86$, $SD = 0.95$ versus $M = 0.21$, $SD = 0.58$, $t(50) = 2.98$, $p = .004$.

A logistic regression analysis further tested Ehlers and Clark's (2000) prediction that these processes work in conjunction in facilitating cue-driven retrieval of intrusive memories. In the first step, enhanced perceptual priming and conditioned emotional reactions were entered simultaneously. In the second step, the interaction between these variables (i.e., the product of z-transformed variables) was entered.

In the first step, both enhanced priming, $B = 5.75$, $SE = 2.34$, $Wald = 6.05$, $p = .014$, and conditioned emotional reactions, $B = 1.57$, $SE = 0.60$, $Wald = 6.89$, $p = .009$, significantly contributed to the prediction of subsequent intrusions, χ^2 $(2, 52) = 15.35$, $p < .001$, and 76.9% of the participants were correctly classified. When the interaction between priming and conditioned responses was entered in the second step, the accuracy of the prediction rose to 84.6% correct classifications, χ^2 $(1, 52) = 6.40$, $p = .011$; enhanced priming, $B = 5.02$, $SE = 2.46$, $Wald = 4.18$, $p = .041$, conditioned emotional reactions, $B = 1.72$, $SE = 0.74$, $Wald = 5.41$, $p = .020$, and their interaction $B = 17.88$, $SE = 9.00$, $Wald = 3.95$, $p = .047$, each contributed significantly to the prediction.

Trait and state anxiety, and pleasantness and arousal ratings for the ''traumatic'' stories were not associated with subsequent intrusive memories; STAI-trait: $t(50) = 0.48$, $p = .634$; STAI-state: $t(50) = 1.04$, $p = .303$; pleasantness: $t(50) = 0.25$, $p = .807$; arousal: $t(50) = 0.98$, $p = .331$.

DISCUSSION

In line with hypothesis 1, the results offer preliminary evidence for the hypothesis that neutral objects that occur in a ''traumatic'' context are more strongly primed than comparable stimuli

that occur in a neutral context. The experiments were motivated by clinical observations suggesting that intrusive memories of traumatic events often appear to be triggered by perceptual cues that bear physical similarity to stimuli that are perceptually similar to the intrusion, or to stimuli that immediately preceded them (e.g., Ehlers & Clark, 2000; Ehlers et al., 2004).

The experimental data are consistent with these clinical observations. In three experiments (pilot study, Experiments 1 and 2), neutral objects that preceded ''traumatic'' pictures were more strongly primed than corresponding objects from neutral stories. In line with hypothesis 2, the degree of enhanced priming for these objects predicted re-experiencing symptoms 3 months later (Experiment 2).

The results of the present experiments complement those demonstrating that people with PTSD show stronger priming for trauma-related sentences or words than trauma survivors without PTSD (Amir et al., 1996; Michael et al., 2005a), and that enhanced priming for trauma-related words measured shortly after the traumatic event predicted subsequent flashbacks (Michael et al., 2005a). The current study adds to the emerging literature on priming in PTSD, as an enhanced priming effect was experimentally induced by embedding the neutral pictures that included the preceding objects in a context of either ''traumatic'' or neutral picture stories. When presented without this context, the degree of priming for the objects from these scenes did not differ. Thus, the differences in priming can be attributed to the different emotional context in which the objects occurred. The predictive role of the experimentally induced enhanced priming for subsequent re-experiencing symptoms is in line with, but not a proof of, a causal role of priming in re-experiencing. It is conceivable that this relationship was caused by an unidentified common factor that correlated with both priming and subsequent re-experiencing. However, none of the potential factors measured in the studies, such as reported arousal when seeing the picture stories, or state anxiety, predicted re-experiencing.

There has been a debate in the literature on the influence of explicit memory on the performance in implicit memory tasks such as priming tests (e.g., Jacoby, Toth, & Yonelinas, 1993; Tulving, Schacter, & Stark, 1982). The present study was not designed to address this issue, so that we cannot conclude with certainty that a pure implicit memory effect was observed. However, the pattern of findings makes it very unlikely that the enhanced priming effect for objects from the traumatic stories stemmed from the intentional search for these objects and the use of explicit knowledge. The experiments consistently showed a dissociation between recognition memory and priming for the neutral preceding objects occurring in a traumatic context. Recognition memory sensitivity was related to object importance, but not to story context. In contrast, the perceptual priming task consistently showed effects of story context. On the basis of eye-witness research (e.g., Christianson, 1992), one might have expected enhanced sensitivity in the recognition test for central objects from traumatic stories compared to central objects from neutral stories. This was not the case in the present experiments, possibly due to ceiling effects as all participants showed very good sensitivity in recognising central objects. Importantly, there was no indication of an enhanced sensitivity in recognising preceding objects from traumatic stories. Furthermore, previous research would suggest that if negative emotional context has an effect on preceding stimuli, it would be in the direction of poorer rather than better recall (Christianson, 1992). Thus, it is extremely unlikely that the enhanced priming effect for these stimuli can be explained by enhanced explicit memory. Nevertheless, the inclusion of central objects in the perceptual priming task may have increased the chance that participants realised that their memory was being tested. In a subsequent experiment, therefore, our group has only used preceding objects and a greater number of distractor objects in the perceptual priming test and found identical results (Michael & Ehlers, 2005).

The theoretical explanation for the observed enhanced priming for stimuli from a traumatic context remains uncertain at this stage. The experiments were modelled on clinical observations rather than on theories of implicit memory. However, the results are in line with recent findings showing that task-relevance influences perceptual priming (Holbrook, Bost, & Cave, 2003). Holbrook et al. (2003) suggested that priming might be selective in that it facilitates processing of items that are important now and likely to be important in the future. The trend and main effects of object importance in the priming task are in line with this hypothesis.

The present experiment extended the previous literature results in that enhanced priming was also found for neutral objects that preceded the

''traumatic'' stories. Together, these results suggest that perceptual priming may be more influenced by stimulus context and possibly interacts more closely with conditioning processes than previously thought (e.g., Squire, 2004). Overall, the results appear to be consistent with theories that emphasise the role of associative learning in perceptual learning (e.g., McLaren & Mackintosh, 2000).

The enhanced priming for neutral stimuli that occur in a traumatic context described in this paper may have evolved as an adaptive response to traumatic situations. Much of learning can be conceptualised as increasing the organism's ability to respond adequately to future events. The enhanced priming of stimuli that led up to danger may facilitate identification of danger cues on a presemantic and relatively effortless level and thus help organisms to avoid potentially perilous situations in the future. After traumatic experiences, it may be adaptive, at least in the short term, to preferentially process stimuli that resemble those present shortly before and during the traumatic event. However, strong priming may also come at a cost, in that it increases the chance that harmless cues in the environment trigger re-experiencing symptoms. It is indeed very common for trauma survivors to have intrusive memories in the initial days after the traumatic event (e.g., Shalev, 1992).

One possible mechanism for the enhanced priming effect is that during trauma people are more likely to engage in data-driven processing than during other experiences. This, in turn, may enhance priming. Experiment 2 included a measure of data-driven processing, and showed, in line with hypothesis 3, that reported data-driven processing during the ''traumatic'' stories correlated with enhanced priming for objects from these stories. Prospective longitudinal studies of trauma survivors have shown that data-driven processing predicts subsequent PTSD symptoms (Halligan et al., 2002, 2003; Murray et al., 2002; Rosario et al., 2005). The correlations between reported data-driven processing and enhanced priming for objects from ''traumatic'' stories remained significant even when ratings of the unpleasantness and arousal of the stories were partialled out. These results suggest that the degree of priming during traumatic experiences depends not only on the aversiveness of the event and accompanying arousal, but also on the quality of cognitive processing. This parallels findings from prospective studies of trauma survivors showing that cognitive processing during trauma predicts over and above the objective and subjective stressor severity (e.g., Halligan et al., 2003; Rosario et al., 2005). Processing perceptual rather than the meaning aspects of the event appears to put people at risk for enhanced priming and subsequent intrusive memories.

The results were in line with Ehlers and Clark's hypothesis (2000) that enhanced priming and associative learning both contribute to re-experiencing symptoms. These processes are thought to work in conjunction so that persistent distressing intrusive memories are most likely if both enhanced priming and conditioned emotional responses are present. In line with hypothesis 2, intrusive memories at 3 months were predicted by priming, conditioned anxiety responses, and their interaction. Just like priming, conditioned anxiety responses to stimuli encountered during a traumatic experience can be considered adaptive in the short term. However, if people develop very strong responses to objectively harmless stimuli that do not extinguish, this may result in psychopathology such as phobias or persistent PTSD (e.g., Foa et al., 1989; Keane et al., 1985). Previous studies have shown that PTSD patients demonstrate enhanced acquisition in an aversive learning procedure (Orr, Metzger, Lasko, Macklin, Peri, & Pitman, 2000) as well as reduced extinction (Peri, Ben-Shakhar, Orr, & Shalev, 2000). However, the present results on conditioning and intrusive memories have only pilot character and need to be interpreted very cautiously, as the conditioned emotional response was measured only with a simple question.

The study had several limitations. First, the experiments used an analogue design and it remains unclear to what extent the results would generalise to traumatic events that would meet DSM-IV (American Psychiatric Association, 1994) criteria. Ethical considerations limit the induction of trauma in the laboratory. Participants rated the picture stories as moderately to strongly unpleasant, but nevertheless the stories remain relatively mild stressors compared to traumatic events. Similarly, it remains uncertain to what extent the re-experiencing symptoms that participants reported are comparable to re-experiencing in PTSD, although it is known that witnessing horrific events can be sufficiently traumatic to induce PTSD (American Psychiatric Association, 1994). Furthermore, the measure of intrusive memories was very simple, and it would be desirable in further studies to obtain more

detailed data on these memories and their triggers (e.g., Holmes, Brewin & Hennessy, 2004). The present experiments should therefore be interpreted in the context of emerging findings on perceptual priming in trauma survivors (e.g., Michael et al., 2005a).

Second, the stimulus material had some limitations. The results are based on a relatively small number of objects, so that it would be desirable to replicate the enhanced priming effect with larger stimulus sets. In order to make the material as realistic as possible, we used film clips that showed the main character from the story throughout the picture series. This made it impossible to counterbalance the objects across the neutral and ''traumatic'' picture stories. Although we took great care in matching the objects for ease of identification, salience, and memorability, and all pilot studies consistently showed that the objects were comparable in these respects, we cannot completely rule out that subtle material effects influenced the results. Future studies should therefore aim to replicate the findings while counterbalancing objects across story contexts. Furthermore, the measure of conditioning used in this study was very simple, so that the findings are preliminary. Future studies using objective measures would be desirable, for example, using psychophysiological measures of conditioned responses (e.g., Elsesser, Sartory, & Tackenberg, 2004).

Third, participants had a short break before doing the priming task, and it is conceivable that some of them thought about the picture stories during this break. If they thought more about the traumatic stories than about the neutral stories, this may have influenced the results of the memory tasks. We think that such a possible confound is unlikely as the experimenter engaged participants in a neutral conversation during the break. Furthermore, thinking about the traumatic pictures would not necessarily lead to enhanced priming, as subsequent elaboration modelled on Cognitive Therapy for PTSD (Ehlers & Clark, 2000: Ehlers et al., 2003), which is thought to inhibit cue-driven retrieval from memory (Conway & Pleydell-Pearce, 2000; Ehlers & Clark, 2000) has been shown to *decrease* the enhanced priming effect in a subsequent experiment (Michael & Ehlers, 2005).

Fourth, in the present experiments data-driven processing was only assessed at the end of the block of ''traumatic'' stories, so that we cannot ascertain with certainty that participants engaged in data-driven processing during the first pictures. However, it is possible that the shocking and surprising character of the second picture brought on data-driven processing that effected the processing of the first picture that had just faded, while it was still available in consciousness.

Fifth, it remains unclear whether the enhanced priming effect is specific to an aversive context. It is conceivable that an equally arousing positive emotional context would have the same effect, and that such enhanced priming is also involved in cue-driven retrieval of extremely positive emotional, absorbing memories.

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