

Binding Temporal Context in Memory

Impact of Emotional Arousal as a Function of State Anxiety and State Dissociation

Rafaële J.C. Huntjens, PhD,* Ineke Wessel, PhD,* Albert Postma, PhD,†‡
Rineke van Wees-Cieraad, MSc,* and Peter J. de Jong, PhD*

Abstract: Encoding of stressful experiences plays an important role in the development of posttraumatic stress disorder. A crucial aspect of memory encoding is binding: the “gluing” of the temporal and spatial elements of an episode into a cohesive unit. This study investigated the effect of emotional arousal on temporal binding and examined whether temporal binding varied as a function of state anxiety and/or state dissociation. Participants saw picture sequences that varied in arousal and valence. After each sequence, participants were presented with all the pictures simultaneously and had to sort the pictures in the original order. Temporal context binding was indexed by sorting accuracy. Binding was generally lower for high than low arousing pictures. Reduced binding of arousing material was specifically pronounced in participants with high state anxiety, whereas it seemed independent of state dissociation. These findings point to the relevance of impaired temporal binding as a component of aberrant memory encoding in stressful situations.

Key Words: Context memory, binding, emotional arousal, dissociation

(*J Nerv Ment Dis* 2015;203: 545–550)

A number of cognitive models of PTSD claim that the encoding of stressful experiences plays an important role in the development of psychopathology, specifically in trauma-related disorders like post-traumatic stress disorder (PTSD) (for an overview see Brewin, 2014). According to these cognitive models of PTSD (e.g., Brewin et al., 1996; Ehlers and Clark, 2000; for a review see Brewin and Holmes, 2003; but see Rubin et al., 2008), aberrant encoding of the trauma memory (i.e., as compared to other autobiographical memories) results in later PTSD symptomatology. These symptoms include both excessive involuntary retrieval of (aspects of) the trauma memory (i.e., intrusive recollections) as well as impaired voluntary retrieval of trauma-related aspects (i.e., amnesia). To test the validity of these models, it is important to understand how stressful events are encoded in memory and what type of processes might impede or facilitate the encoding of such events (Huntjens et al., 2013). A process possibly involved in aberrant encoding of trauma memories in the context of PTSD is (impaired) context memory binding (Brewin, 2001).

During the encoding of an experience, the target information (“what has happened?”) is combined or bound in memory with the temporal (“when did it happen?”) and the spatial (“where did it happen?”) context in which the experience happened (Farrell, 2012). Memory binding thus refers to the “gluing” of the various elements of an episode into a cohesive unit and maintaining these bound representations in working memory (Mammarella and Fairfield, 2008). Mather (2007)

put forward an Object-Based Framework to explain the relation between emotional arousal and memory binding. In this framework, emotional arousal is hypothesized to impair the binding of an item to its context when multiple bound representations have to be kept in working memory simultaneously or when multiple items are encountered sequentially in a short time interval. In such situations, people could make conjunction errors (i.e., mix up the elements of different items) because the limited memory capacity is “overloaded” by the arousing information (Huijbers et al., 2011).

To test this hypothesis, Mather and colleagues (2006) showed participants a series of emotionally arousing pictures in different spatial locations and subsequently asked them to identify the location of each picture. The results indicated that participants’ ability to correctly identify the original location of the picture was lower for pictures that elicited relatively high emotional arousal. This was true for both negatively as well as positively valenced pictures. This study thus provided evidence for reduced binding of the spatial context to central elements as one possible component of the hypothesized aberrant encoding of emotional or stressful events in the context of PTSD. Converging evidence was obtained by brain imaging studies that investigated the neural correlates of arousal-induced binding errors. For example, it has been found that medium and high-arousing pictures elicited relatively low activity in brain areas associated with memory binding such as the superior area of the precentral gyrus and the intersect of the inferior precentral gyrus and superior temporal gyrus (Mitchell et al., 2000).

The present study focuses on another important element of context binding, that is, *temporal* binding in the context of stressful events. We manipulated stimulus arousal (low or high) and valence (positive and negative) and determined the effect on the binding of the temporal context to the stimulus. Similar to Mather and colleagues (2006), we used pictures from the International Affective Picture System (IAPS; Lang et al., 2008). Participants had to memorize series of sequentially presented pictures (varying in valence and arousal). We then instructed them to place the pictures back in the previously presented order.

Individual Differences

We also examined to what extent differences in temporal context binding were associated with individual differences in state anxiety and state dissociation. We included state anxiety as a likely candidate interfering with the process of memory binding given the anxiety inducing nature of a traumatic event. Most cognitive models of PTSD assume that heightened levels of anxiety experienced during a traumatic event play a role in the development of PTSD. Consistent with this idea, there are findings indicating that those who develop PTSD show elevated heart rate and respiration rate immediately after trauma exposure compared to those who do not develop PTSD (Bryant et al., 2011a). One of the mechanisms that underlie the influence of anxiety on the development of PTSD may be a detrimental impact of peritraumatic anxiety on the encoding of the trauma memory.

State dissociation was included as a second likely candidate interfering with the process of memory binding. State dissociation acts as an experimental analogue of peritraumatic dissociation, referring to a sense of alteration in the perception of time, place, and person, which

*Department of Clinical Psychology and Experimental Psychopathology, University of Groningen, Groningen; †Psychological Laboratory, Helmholtz Institute, Utrecht University; and ‡Department of Neurology, University Medical Centre Utrecht, Utrecht, the Netherlands.

Send reprint requests to Rafaële J.C. Huntjens, PhD, Department of Clinical Psychology and Experimental Psychopathology, University of Groningen, Grote Kruisstraat 2/1, 9712 TS Groningen, the Netherlands.
E-mail: r.j.c.huntjens@rug.nl.

Copyright © 2015 Wolters Kluwer Health, Inc. All rights reserved.

ISSN: 0022-3018/15/20307-0545

DOI: 10.1097/NMD.0000000000000325

makes a (stressful) experience feel unreal (Marmar et al., 1997). Peritraumatic dissociation has been found to be a strong predictor for the development of PTSD (for a meta-analysis see Ozer et al., 2003). Although it has been suggested that peritraumatic dissociative experiences interfere with the encoding of stressful memories and affect the nature of the memory (Brewin and Holmes, 2003), the exact mechanism linking peritraumatic dissociation and subsequent PTSD remains unclear. One candidate mechanism is impaired binding of context in memory.

Although originally not described in these terms, the results of a few previous studies are relevant while considering the association between peritraumatic dissociation and temporal context binding. In one of these studies, nonclinical participants watched an aversive film and were subsequently presented with clips taken from the film. They were asked to indicate the original order in which the clips were shown in the film. The results indicated that dissociation at the time of watching the aversive film was not associated with temporal order performance as indexed by the clip sorting task (Kindt and van den Hout, 2003; Kindt et al., 2005; also see Halligan et al., 2002). Using a comparable task in patients with depersonalization disorder, however, Giesbrecht et al. (2010) did find poorer performance on ordering clips in the clinical group compared to a symptom-free control group. Thus, memory impairment has been reported for a clinical sample but not for a random student sample and may thus indicate selective compromised memory functioning in patients. Yet, it should be noted that the task used by Giesbrecht and colleagues consisted of ordering more clips which were shown for a shorter period and, hence, may have been a more sensitive task compared to the task used in the nonclinical studies of Kindt and van den Hout (2003) and Kindt et al. (2005). Thus, the variability in results may also have been the result of the use of a more sensitive task in the patient sample.

The present study examined memory binding in nonclinical (*i.e.*, low symptomatic) participants. Three issues were addressed. First, we investigated the effect of emotional arousal on the binding of the temporal context of an event in memory. We hypothesized that the participants would show reduced binding of temporal context specifically for emotional (negative, high arousal) stimuli. In an attempt to include a more sensitive temporal binding task compared to the tasks used in previous studies (Giesbrecht et al., 2010; Kindt and van den Hout, 2003; Kindt et al., 2005), we included a task in which more stimuli had to be ordered per trial and we presented a larger total number of trials. Second, to examine the specificity of arousal-induced binding errors, we also investigated memory binding for positive material. Third, we examined to what extent temporal context binding varied as a function of individual differences in emotional state. Especially in participants with relatively high state anxiety and/or high state dissociation, the binding of temporal context for emotionally arousing (*i.e.*, negative, high arousing) pictures was expected to be reduced.

MATERIALS AND METHODS

Participants

A total of 60 first-year psychology students (79.6% female) participated in the study. Mean age of the participants was 19.57 years ($SD = 1.97$, range 18–26 years). The participant mean score on the DES-C (Wright and Loftus, 1999), a scale measuring trait self-reported dissociative experiences fit for nonclinical populations, was 37.05 ($SD = 10.01$). Participants received course credits for their participation. The University of Groningen Psychology Ethical Committee granted ethics approval for this study.

Materials

Stimulus Materials

For the memory task, a total of 320 stimuli were selected from the International Affective Picture System (IAPS; Lang et al., 2008). [Arousal and valence ratings of IAPS items vary between 1 (low

arousal; negative valence) and 9 (high arousal; positive valence).] Four categories of 80 stimuli were created: (1) high arousal negative pictures (*e.g.*, natural disasters, snakes, and weapons; $M_{arousal} = 6.16$ ($SD = 0.72$); $M_{valence} = 3.28$ ($SD = 0.99$)), (2) high arousal positive pictures (*e.g.*, sports and sexually arousing; $M_{arousal} = 6.08$ ($SD = 0.69$); $M_{valence} = 6.57$ ($SD = 0.78$)), (3) low arousal negative pictures (*e.g.*, a cemetery or a baby crying; $M_{arousal} = 4.07$ ($SD = 0.95$); $M_{valence} = 3.50$ ($SD = 0.82$)), and (4) low arousal positive pictures (*e.g.*, cute animals, landscapes; $M_{arousal} = 3.88$ ($SD = 0.61$); $M_{valence} = 6.62$ ($SD = 0.30$)).

Questionnaires

Trait dissociation was assessed with the 28-item Dissociative Experiences Scale with comparisons (DES-C; Wright and Loftus, 1999), a variation of the original Dissociative Experience Scale (DES; Bernstein and Putnam, 1986). Participants indicate, on an 11-point Likert scale, how often they have dissociative experiences in comparison to others. In the current sample, the internal consistency (Cronbach's alpha) was 0.88.

Current anxiety level before and after the task was assessed with the 20 state anxiety items of the State-Trait Anxiety Inventory (STAI; Spielberger et al., 1983). Responses to each item range from 1 (not at all) to 4 (very much so). For a total score, the 20 items are summed. This measure was selected due to its good psychometric properties (Spielberger et al., 1983). In the current sample, the internal consistency (Cronbach's alpha) was 0.92 on pre-test and 0.94 on post-test.

The degree of state dissociation was assessed with the 19 self-report items from the Clinician-Administered Dissociative States Scale (CADSS; Bremner et al., 1998). Participants indicate on a 5-point scale from 0 (not at all) to 4 (extremely) how each item is applicable to them at that very moment (*e.g.*, "Do things seem to be moving in slow motion?"). Overall mean scores range from 0 to 4, higher scores indicating higher levels of state dissociation. The self-report items have satisfactory reliability and validity (Bremner et al., 1998). In the current sample, the internal consistency (Cronbach's alpha) was 0.84 on pre-test and 0.83 on post-test.

Procedure

We tested participants individually. After giving informed consent, participants filled in the CADSS and the STAI. The order in which the participants filled in the questionnaires was counterbalanced. Participants then performed the memory task. This task was an adapted version of a spatial feature binding task used by Mather et al. (2006). We instructed participants that, after a slide with the word "Picture" (100 ms), eight sequentially presented pictures would be shown (1500 ms each and followed by a mask of 100 ms). We instructed participants to memorize the pictures and the order in which the pictures were presented (study phase). One second after the study phase, 16 pictures (eight presented during the study phase and eight distractors) were shown simultaneously. First, we instructed participants to select the (eight) pictures that they had seen before during the study phase (recognition phase). During the subsequent sorting phase, participants were presented with all eight pictures of the study phase displayed in an array on one screen and were instructed to put the pictures back in the original order that was used during the study phase. All eight pictures had to be ordered. During the study phase, the pictures were shown at the size of 1024×768 pixels, during sorting phase at the size of 256×170 pixels. Participants used the mouse to select the stimuli that were shown and to place the stimuli back in order.

Before the actual task, which consisted of 80 trials, there were two practice trials to acquaint the participants with the task. The task consisted of 20 trials per arousal-valence category (*i.e.*, high arousal negative, high arousal positive, low arousal negative, and low arousal positive). Each trial consisted of stimuli from one arousal-valence category (*e.g.*, high arousal negative). The order in which the 80 stimulus trials were presented was fixed random, with a maximum of two trials from

the same category presented successively. Each participant received the same list with a pre-fixed order to reduce method variance. After each trial of sorting eight pictures, participants pressed a “ready” button to indicate they were done selecting or sorting the stimuli. Before pressing “ready”, they were allowed to correct their response. There was no time constraint. At the end of the computer task, participants filled in the CADSS and the STAI again, and afterwards the DES-C.

Data Reduction and Analysis

For the sorting index, Spearman’s rank correlation coefficients were computed between the ranks of the originally presented and the recalled order for every trial (see also Wegner et al., 1996). We then took the mean score of these correlation coefficients for every participant. Coefficients were only calculated for the correctly recognized pictures to have a measure for sorting performance independent of differences in recognition performance. The scores range between -1 and 1 , with 1 indicating the correct recalled original order and -1 indicating the reversed order. For testing the individual differences hypothesis, we computed difference scores for state anxiety and state dissociation from pre- to post-experiment. For testing our directional a priori correlational hypotheses, we used one-tailed analyses. All other analyses were two-tailed.

RESULTS

Preliminary analyses indicated three univariate outliers. Two participants had an extremely low score (<3 SD from the mean) on one or more of the recognition variables and one participant had an extreme high score (>3 SD from the mean) on the CADSS difference score. Furthermore, there was one multivariate outlier in the correlational analyses. Therefore, the data of these four participants were omitted, leaving a number of 56 participants in the analyses.

Recognition

The mean number of recognized pictures was 7.59 (SD = 0.31) for the high arousal negative category, 7.57 (SD = 0.31) for high arousal positive, 7.78 (SD = 0.20) for low arousal negative, 7.75 (SD = 0.25) for low arousal positive, and 7.67 (SD = 0.25) overall. The mean number of false alarms was 0.41 (SD = 0.31) for the high arousal negative category, 0.43 (SD = 0.31) for high arousal positive, 0.23 (SD = 0.20) for low arousal negative, 0.25 (SD = 0.25) for low arousal positive, and 0.33 (SD = 0.25) overall. A 2 (arousal: high, low) \times 2 (valence: negative, positive) repeated measures analysis of variance (ANOVA) was performed to test the differences between the number of correctly recognized pictures for every arousal-valence category. A main effect of arousal [$F(1,55) = 80.72$, MSE = 0.023, $p < 0.001$, $\eta^2_{\text{partial}} = 0.60$] was found, with

participants scoring lower on recognition for high arousal pictures compared to low arousal pictures. There was no main effect of valence [$F(1,55) = 1.44$, MSE = 0.019, $\eta^2_{\text{partial}} = 0.03$] nor an interaction effect of arousal \times valence [$F(1,55) = 0.01$, MSE = 0.013, $\eta^2_{\text{partial}} < 0.001$].

Temporal Memory Binding

A 2 (arousal: high, low) \times 2 (valence: negative, positive) repeated measures ANOVA was performed to test the differences in binding performance between the different picture categories. The mean sorted rank correlations are shown in Figure 1. A main effect of arousal [$F(1,55) = 70.22$, MSE = 0.002, $p < 0.001$, $\eta^2_{\text{partial}} = 0.56$] was found. Participants made more errors sorting high arousal pictures than low arousal pictures. There was no main effect of valence [$F(1,55) = 2.07$, MSE = 0.002, $\eta^2_{\text{partial}} = 0.04$], although there was a nonsignificant tendency of arousal \times valence [$F(1,55) = 3.82$, MSE = 0.001, $p = 0.065$, $\eta^2_{\text{partial}} = 0.07$, see also Fig. 1] suggesting that the negative influence of arousal on participants’ accuracy for sorting pictures was more pronounced for negative than for positive pictures. The differences between negative high and low arousal pictures, $t(55) = 7.69$, $p < 0.001$, as well as between positive high and low arousal pictures, $t(55) = 5.10$, $p < 0.001$, were significant. [On the basis of the current findings, it could not be ruled out that differences in binding performance might not have been due to differences in arousal (or valence) but to differences in perceptual similarity between stimuli across the four stimulus categories. To address this concern, we performed a follow-up experiment. We asked 45 participants (psychology students, 64% female, mean age 21.67, SD = 3.79) to rate the stimuli as presented in the original study on perceptual similarity (*i.e.*, the form, complexity, color, brightness, pattern, and shape of the (items on the) pictures). This was done both for the stimuli that were presented in the recognition trials (*i.e.*, the participants rated, for every trial, the similarity of the picture set as presented in the study phase versus the picture distractor set), as well as the stimuli as presented in the order trials (*i.e.*, the participants rated, for every trial, the similarity of the eight pictures that were presented). The results of the rating task did not support the hypothesis that participants’ performance during the recognition and order task might be driven by differences in similarity across the four categories of trials. Whereas in the original study we found a main effect of arousal, with participants scoring lower on recognition for high arousing pictures, no effect of arousal or valence was found in the relevant similarity rating task. For the order task, the original results indicated that participants experienced more difficulty in ordering both high arousal negative and high arousal positive compared to the low arousal categories. In the relevant similarity rating task, the perceptual similarity of the high arousal, negative valence pictures was rated as

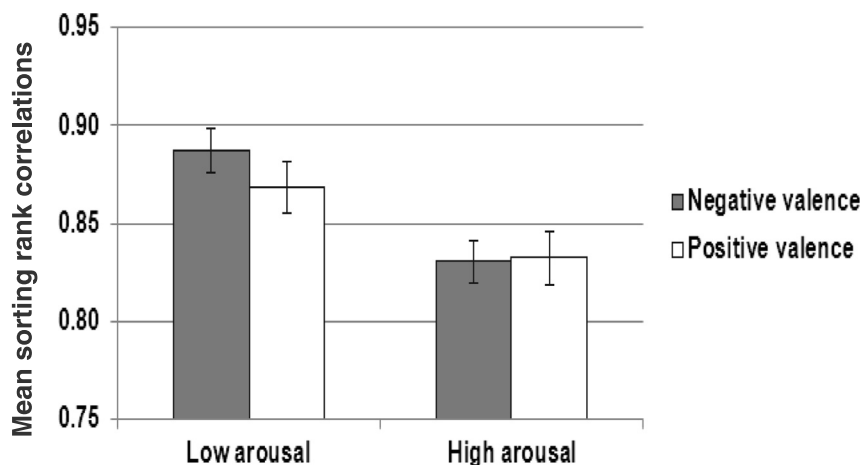


FIGURE 1. Temporal memory binding performance for the arousal and valence categories. The error bars represent the standard error (SE).

TABLE 1. Zero-Order Pearson Correlation Coefficients Between the Sorting Task and the Change in State Dissociation and State Anxiety

	CADSS Difference		STAI Difference	
	<i>r</i>	<i>p</i>	<i>r</i>	<i>p</i>
High arousal–negative valence	−0.09	0.25	−0.25	0.03
High arousal–positive valence	−0.06	0.33	−0.12	0.18
Low arousal–negative valence	−0.00	0.49	−0.18	0.10
Low arousal–positive valence	−0.03	0.43	−0.11	0.20

CADSS = Clinician-Administered Dissociative States Scale; STAI = State-Trait Anxiety Inventory. One-tailed tests were used. The correlational analyses for CADSS difference were repeated with the inclusion of an outlier using a score of mean + 2SD. This yielded equivalent results.

higher compared to the low arousal pictures, but this pattern was not evident in the positive valence categories. An explanation based on differences between categories in terms of valence and arousal thus seems to provide a more parsimonious account of the order data than a differential similarity account.]

Associations With State Dissociation and State Anxiety

Before the binding task, the mean anxiety score was 33.05 (SD = 7.95) and the mean dissociation score was 3.54 (SD = 4.64). At the end of the task, these scores were 36.13 (SD = 9.90) and 4.04 (SD = 4.58) for anxiety and dissociation, respectively. For anxiety, the increase in means was statistically significant, $t(55) = 3.00, p = 0.004$, whereas the increase in means for dissociation was not, $t(55) = 1.35, p = 0.18$. The difference scores showed a considerable range (for anxiety $M = 3.07, SD = 7.66$, range = −10 to 25; for dissociation $M = 0.50, SD = 2.78$, range = −8 to 9). The correlation between the difference scores of the STAI and CADSS was significant ($r = 0.31, p = 0.02$). No significant correlations were found between the recognition performance and either increase in state dissociation or increase in state anxiety (p -values between 0.15 and 0.88). For the sorting task, the increase of state dissociation during the task did not correlate with memory binding performance (see Table 1). The increase of state anxiety during the task, however, correlated negatively with the memory binding performance for negative pictures; this was especially pronounced for high

arousal negative pictures (see Fig. 2). Thus, the higher the increase in state anxiety during the task, the higher the number of errors on sorting the (high arousal) negative pictures.

DISCUSSION

The main results of this study can be summarized as follows: (1) participants recognized fewer high than low arousal pictures, (2) participants made more errors sorting high than low arousal pictures, (3) participants characterized by a stronger increase in state anxiety during the task made more errors sorting (high arousing) negative material independent of their recognition performance, and (4) no significant associations were found between sorting accuracy (temporal context binding) and an increase in state dissociation during the task.

To control for differences in overall recognition on the context binding scores, the latter were only based on the correctly recognized pictures. The results showed that participants made fewer errors sorting low arousal (specifically negative) pictures compared to high arousal pictures. We thus found reduced context binding for the high arousal pictures, which is in line with earlier research (Mather et al., 2006). These findings corroborate the idea that arousal hampers the formation of coherent emotional memories. More specifically, arousal seems to impair remembering of the exact temporal order of a sequence of events.

We also considered individual differences in state dissociation and state anxiety. We hypothesized that participants characterized by higher state dissociation and/or state anxiety experienced during the experiment would show reduced binding of pictures to their temporal location. The present results only partially supported this hypothesis. We did not find reduced context binding in people experiencing a higher increase in state dissociation. We did, however, find a significant association between the increase in state anxiety from pre- to post-task and reduced context binding specifically for high arousing, negative material. Similarly, the anxiety induced while experiencing an actual stressful event might hamper people’s recollection of the temporal order of the situational elements of the event. A possible explanation for the association between state anxiety and reduced context binding might be that anxiety draws attention to the threatening stimuli and away from the context (Cisler and Koster, 2010), which in turn may lead to impeding the binding of the different components of the experience. Due to the correlational design of the study, conclusions about the causality of the effect of anxiety on context binding cannot be made. A next step would be to experimentally induce state anxiety during encoding to see how this affects temporal binding performance.

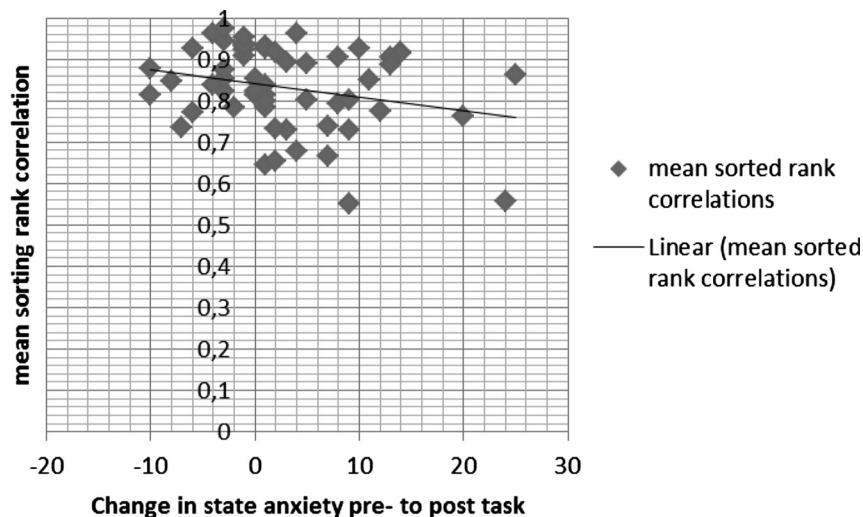


FIGURE 2. Scatterplot for the relation between temporal memory binding performance (high arousal, negative valence category) and change in state anxiety.

The lack of an association between state dissociation and binding performance was unexpected. However, we should acknowledge that the overall increase in dissociation was small and did not reach statistical significance; therefore, we cannot rule out that the current stimuli were not sufficiently intense to reliably elicit dissociation during the binding task. To arrive at more final conclusions regarding the possible role of dissociation in impaired feature binding, it would be important for future studies to use a more powerful procedure.

Consistent with the current data, however, some (Bryant et al., 2011b) have argued that, although peritraumatic anxiety or panic may have a detrimental effect on trauma encoding, the influence of peritraumatic dissociation on encoding may be less important. In contrast, *persistent* dissociation may prove detrimental in the processing of stressful events. It is argued that dissociative reactions during the event may be a normal and transient reaction to stress, and may even serve a protective function, as reduced awareness of the experience may limit encoding of the distressing event. Persistent dissociation, however, may impede the long-term retrieval of stressful memories and associated affect, thereby hampering emotional processing and elaboration of traumatic memories. It would be interesting for future studies to also focus on these more persistent forms of dissociation and their effects on memory processing.

The recognition data showed that participants recognized fewer high arousal pictures compared to low arousal pictures. This finding is inconsistent with earlier findings by Mather and colleagues (2006), who found better memory for arousing items. A possible explanation for these inconsistent findings is the difference in memory tasks employed (*i.e.*, recognition vs. recall). In addition, Mather et al. determined memory performance after a longer interval (*i.e.*, at the end of the task), whereas we measured memory performance immediately after each trial. Although a good memory for threatening stimuli may be beneficial in the long run (*i.e.*, while in safety), a good memory for these stimuli immediately after their occurrence may be detrimental if one becomes overwhelmed by negative emotion during a stressful incident. A diminished memory for threatening pictures right after presentation can thus be considered an evolutionary advantage (Fleming et al., 2003).

Some comments are in place with regard to methodological aspects of this study. The encoding of stressful events can either be studied in real life or in analogue situations. Employing real-life stressful events has the advantage of more directly addressing the phenomenon to be explained. Yet, the disadvantages are that measurement relies on self-report and is, due to ethical reasons, retrospective in nature, with sometimes many months or even years between the event and subsequent study. Also, other variables than the stressful nature of the event may influence the study results (*e.g.*, previous stressful experiences, previous cognitive functioning). These problems are circumvented in analogue studies, which provide a laboratory model of real-life situations. On the other hand, a disadvantage of an analogue study is that the levels of peritraumatic emotional responses are not as high as might be expected in naturally occurring events. This may also explain why the effect size of the association between state anxiety and the order performance was only medium in this study.

Relatedly, we used sequences of IAPS pictures whereas in previous studies, film fragments were used. The pictures were intrinsically unrelated and therefore artificial in comparison to real-life stressors and even in comparison with a film fragment containing a central plot (Giesbrecht et al., 2010). This artificiality limits the external generalizability. Importantly, however, advantages of using picture sequences are the more rigorous experimental control consisting of the ability to choose control stimuli matched in valence and arousal level (which is much more difficult when using a film), and the possibility to use a larger number of stimuli and trials, adding to the sensitivity and reliability of the task. Studying the temporal binding of high arousing negative stimuli with a sensitive measure can therefore be seen as an important first step to model the encoding of stressful events in a laboratory

environment. It would be important for further studies to include more ecologically valid stimuli and measures. For example, as the coding of the temporal aspects of an experience is an important aspect of creating a narrative, it would be worth investigating if reduced binding results in incoherent event narratives for those who experience heightened anxiety during a traumatic event.

Furthermore, we measured state anxiety and state dissociation at the beginning and the end of the entire task. Because the stimuli from the different categories were randomly presented during the binding task, it was not possible to assess the increase in anxiety/dissociation separately for each of the stimulus categories. We used such intermixed stimulus presentation in an attempt to counter undesirable habituation effects. A disadvantage of this strategy is that we could not disentangle the changes in state anxiety and dissociation (and level of variance) during the presentation of positive versus negative stimuli and/or low arousal versus high arousal stimuli. To more specifically assess changes in anxiety/dissociation as a function of stimulus type, future studies might consider using a blocked presentation, as such strategy would allow to measure the changes in state anxiety or state dissociation separately for each arousal and valence condition.

A final point is that we inserted a recognition task before the main sorting task, which may have influenced the performance on the sorting task. Because all participants engaged in the recognition task, it cannot be determined in the current study whether or not recognition performance might indeed have had an effect on sorting performance. Despite this possible drawback, we nevertheless decided to include a recognition task in the current design because it seems critical to control for the confounding influence of individual differences in recognition on participants' ordering performance. That is, without knowledge of participants' recognition performance, errors on the order task could just have been the result of not recognizing one or more stimuli instead of not remembering the correct order of the stimuli. It was obviously no option to insert a recognition task after the order task because during the order task participants were presented for a second time with the original stimuli. We therefore eventually decided to insert the recognition phase before the sorting task.

In conclusion, by using a temporal binding task, this study showed that arousal influences temporal context binding and that for individuals high in state anxiety during the task, binding was more reduced compared to individuals low in state anxiety. These findings provide supportive evidence for reduced temporal context binding as being one of the components of aberrant memory encoding in stressful situations relevant for the context of PTSD. Whether this mechanism is a causal explanation of the symptoms reported by patients suffering from trauma-related disorders like PTSD remains to be investigated.

ACKNOWLEDGMENTS

The authors thank Wouter van der Veen, Inge van Calkar, and Martina Krenz for their assistance in the data acquisition, and Bert Hoekzema for his technical assistance.

DISCLOSURES

This research was supported by Innovative Research Veni grant 451-05-018 from the Netherlands Organization for Scientific Research (NWO) awarded to Rafaële J. C. Huntjens.

The authors declare no conflict of interest.

REFERENCES

- Bernstein E, Putnam FW (1986) Development reliability and validity of a dissociation scale. *J Nerv Ment Dis*. 174:727–735.
- Bremner JD, Krystal JH, Putnam FW, Southwick SM, Marmar C, Charney DS, Mazure CM (1998) Measurement of dissociative states with the clinician-administered dissociative states scale (CADSS). *J Trauma Stress*. 11(1):125–136.

- Brewin CR (2001) A cognitive neuroscience account of posttraumatic stress disorder and its treatment. *Behav Res Ther*. 39:373–393.
- Brewin CR (2014) Episodic memory, perceptual memory, and their interaction: foundations for a theory of posttraumatic stress disorder. *Psychol Bull*. 140:69–97.
- Brewin CR, Dalgleish T, Joseph S (1996) A dual representation theory of posttraumatic stress disorder. *Psychol Rev*. 103(4):670–686.
- Brewin CR, Holmes EA (2003) Psychological theories of posttraumatic stress disorder. *Clin Psychol Rev*. 23(3):339–376.
- Bryant RA, Brooks R, Silove D, Creamer M, O'Donnell M, McFarlane AC (2011a) Peritraumatic dissociation mediates the relationship between acute panic and chronic posttraumatic stress disorder. *Behav Res Ther*. 49(5):346–351.
- Bryant RA, Friedman M, Spiegel D, Ursano R, Strain J (2011b) A review of acute stress disorder in DSM-5. *Depress Anxiety*. 28(9):802–817.
- Cisler JM, Koster EHW (2010) Mechanisms of attentional biases towards threat in anxiety disorders: an integrative review. *Clin Psychol Rev*. 30(2):203–216.
- Ehlers A, Clark DM (2000) A cognitive model of posttraumatic stress disorder. *Behav Res Ther*. 38(4):319–345.
- Farrell S (2012) Temporal clustering and sequencing in short-term memory and episodic memory. *Psychol Rev*. 119(2):223–271.
- Fleming K, Kim SH, Doo M, Maguire G, Potkin SG (2003) Memory for emotional stimuli in patients with Alzheimer's disease. *Am J Alzheimers Dis Other Dement*. 18:340–342.
- Giesbrecht T, Merckelbach H, van Oorsouw K, Simeon D (2010) Skin conductance and memory fragmentation after exposure to an emotional film clip in depersonalization disorder. *Psychiatry Res*. 177(3):342–349.
- Halligan SL, Clark DM, Ehlers A (2002) Cognitive processing, memory, and the development of PTSD symptoms: two experimental analogue studies. *J Behav Ther Exp Psychiatry*. 33(2):73–89.
- Huijbers MJ, Bergmann HC, OldeRikkert MGM, Kessels RPC (2011) Memory for emotional pictures in patients with Alzheimer's dementia: comparing picture-location binding and subsequent recognition. *J Aging Res*. 2011:409364. doi: 10.4061/2011/409364.
- Huntjens RJC, Dorahy M, van Wees-Cieraad R (2013) Dissociation and memory fragmentation. In Kennedy F, Kennerley H, Pearson D (Eds), *Cognitive behavioural approaches to the understanding and treatment of dissociation* (pp 92–103). New York, NY: Routledge/Taylor & Francis Group.
- Kindt M, van den Hout M (2003) Dissociation and memory fragmentation: experimental effects on meta-memory but not on actual memory performance. *Behav Res Ther*. 41:167–178.
- Kindt M, van den Hout M, Buck N (2005) Dissociation related to subjective memory fragmentation and intrusions but not to objective memory disturbances. *J Behav Ther Exp Psychiatry*. 36:43–59.
- Lang PJ, Bradley MM, Cuthbert BN (2008) *International affective picture system (IAPS): affective ratings of pictures and instruction manual. Technical report A-8*. Gainesville, FL: University of Florida.
- Mammarella N, Fairfield B (2008) Source monitoring: the importance of feature binding at encoding. *Eur J Cogn Psychol*. 20:91–122.
- Marmar CR, Weiss DS, Metzler TJ (1997) The peritraumatic dissociative experiences questionnaire. In Wilson JP, Keane TM (Eds), *Assessing psychological trauma and PTSD* (pp 412–428). New York, NY: Guilford.
- Mather M (2007) Emotional arousal and memory binding. *Perspect Psychol Sci*. 2(1):33–52.
- Mather M, Mitchell KJ, Raye CL, Novak DL, Greene EJ, Johnson MK (2006) Emotional arousal can impair feature binding in working memory. *J Cogn Neurosci*. 18(4):614–625.
- Mitchell KJ, Johnson MK, Raye CL, D'Esposito M (2000) fMRI evidence of age-related hippocampal dysfunction in feature binding in working memory. *Cogn Brain Res*. 10(1–2):197–206.
- Ozer EJ, Best SR, Lipsey TL, Weiss DS (2003) Predictors of posttraumatic stress disorder and symptoms in adults: a meta-analysis. *Psychol Bull*. 129(1):52–73.
- Rubin D, Berntsen D, Bohni M (2008) A memory-based model of posttraumatic stress disorder: evaluating basic assumptions underlying the PTSD diagnosis. *Psychol Rev*. 115:985–1011.
- Spielberger CD, Gorsuch RL, Lushene PR, Vagg PR, Jacobs GA (1983) *Manual for the state-trait anxiety inventory*. Palo Alto, CA: Consulting Psychologists Press.
- Wegner DM, Quillian F, Houston CE (1996) Memories out of order: thought suppression and the disturbance of sequence memory. *J Pers Soc Psychol*. 71(4):680–691.
- Wright DB, Loftus EF (1999) Measuring dissociation: comparison of alternative forms of the dissociative experiences scale. *Am J Psychol*. 112(4):497–519.