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Boundary restriction for negative emotional images is an example of memory amplification.

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Abstract

We investigated whether boundary restriction—misremembering proximity to traumatic stimuli—is a form of memory amplification, and whether re-experiencing trauma plays a role in boundary restriction errors. In four experiments, subjects viewed a series of traumatic photographs. Later, subjects identified the photographs they originally saw amongst distracters that could be identical, close-up or wide-angled versions of the same photographs. Subjects also completed measures of mood, analogue PTSD symptoms, phenomenological experience of intrusions and processing style. Across experiments, subjects were more likely to incorrectly remember the photographs as having extended boundaries: *boundary extension*. Despite this tendency, the extent to which subjects re-experienced traumatic aspects of the photographs predicted how often they incorrectly remembered the photographs as having narrower boundaries: *boundary restriction*. Our data suggest that although boundary extension is more common, boundary restriction is related to individual differences in coping mechanisms post-trauma. These results have theoretical implications for understanding how people remember trauma.

Boundary restriction for negative emotional images is an example of memory amplification.

People often have vivid, graphic memories of traumatic events (Levine & Edelstein, 2009). Sometimes, those memories are focused closely on one aspect of the event: when a weapon is present at a crime, witnesses often have difficulty remembering any other details (e.g., Fawcett, Russell, Peace, & Christie, 2013). Indeed, people are more likely to remember emotionally salient or central, compared to peripheral, details about negatively arousing events (e.g., Christianson & Loftus 1987; Safer, Christianson, Autry, & Osterland, 1998; Waring, Payne, Schacter, and Kensinger, 2010). Importantly, this pattern of amplified memory for salient details extends to memory distortion. Both field and lab data show that people often claim to remember salient parts of a traumatic experience that were not previously reported, or known to be not experienced, and further, that such distortions are often associated with poor adjustment (e.g., Giosan, Malta, Jayasinghe, Spielman, & Difede, 2009; Roemer, Litz, Orsillo, Ehlich, & Friedman, 1998; Strange & Takarangi, 2012, 2014). We wondered whether memory amplification might also manifest as misremembering “proximity” to traumatic stimuli: some data suggest people remember negative images as having *narrower* boundaries than they actually had, a phenomenon called *boundary restriction*. Our aim in these experiments was twofold: to provide further evidence of boundary restriction as a form of memory amplification, and to investigate whether re-experiencing aspects of the trauma—via involuntary intrusions—is related to memory distortion—via boundary restriction—for a traumatic experience.

We know people are susceptible to memory distortion for traumatic events. In one line of research, victims of trauma often claim to have experienced a greater number of traumatic events over time (Bolton, Gray, & Litz, 2006; Engelhard, van den Hout, &

McNally, 2008; Giosan et al., 2009; King et al., 2000; Koenen, Stellman, Dohrenwend, Sommer, & Stellman, 2007; Krinsley, Gallagher, Weathers, Kutter, & Kaloupek, 2003; Roemer et al., 1998; Southwick, Morgan, Nicolaou, & Charney, 1997; Wessely et al., 2003; Wyshak, 1994). For example, Southwick et al. (1997) asked Gulf War veterans about exposure to war related stressors during their service (e.g., experiencing sniper fire) at one month and two years post-deployment. Veterans' reports were inconsistent: 88% changed their response to at least one event and the majority of changes were from non-endorsements to endorsements. This pattern of memory distortion is termed memory "amplification." Importantly, the more severe the victim's PTSD symptoms, the more likely they exhibit amplification (Engelhard et al., 2008; Giosan et al., 2009; King et al., 2000; Koenen et al., 2007; Roemer et al., 1998; Southwick et al., 1997). This amplification effect appears to be exclusively associated with the re-experiencing symptoms of PTSD (Giosan et al., 2009; Koenen et al., 2007; Roemer et al., 1998).

In a second line of research, Strange and Takarangi (2012) demonstrated memory distortion for analogue trauma under controlled experimental conditions. Subjects watched a film showing a multiple-fatality car accident. The film appeared as short clips separated by blank screens, with some traumatic and non-traumatic scenes missing. Twenty-four hours later, subjects completed a surprise recognition test comprised of old and missing clips as well as new (control) clips. Subjects judged whether each clip was old (from the film) or new (not from the film). Although subjects most often correctly identified old and control clips, they also claimed to have seen 26% of the missing clips. Most often, those missing scenes were traumatic (e.g., a child screaming for her parents). Interestingly, the more subjects reported re-experiencing parts of the film in the 24-hour delay period, the greater their propensity to falsely recognize the traumatic missing clips, or, to amplify their memory.

Collectively, these data fit with Rubin, Berntsen and Bohni's (2008) memory-based model of PTSD, which argues that a person's current memory of a traumatic event—not the traumatic event per se—determines symptomatology. To date, however, amplification has been operationalized exclusively as endorsing additional aspects of trauma, or parts of a traumatic experience known to be not experienced. We wondered whether there are other ways in which this memory distortion might manifest itself.

One possibility is that misremembering *proximity*—falsely remembering being closer—to a traumatic event is a form of memory amplification. For example, a subset of witnesses to a school shooting misremembered their location during the shooting when asked about it months later (Schwarz, Kowlaski & McNally, 1993). In another study, subjects were most likely to recall being closer to enemy lines—changing their responses from "no" to "yes"—and here this change was related to PTSD symptomology (Southwick et al., 1997). Although the relationship between proximity to trauma and symptoms has not been examined systematically, the literature on memory for visual scenes provides a potential method.

We know people often falsely remember seeing details beyond the boundaries of a visual scene: *boundary extension*. In one study, subjects saw a picture of a teddy bear on a single step and later drew the bear sitting on a *flight* of stairs; extending their memory of the scene (Intraub, Gottesman, Willey & Zuk, 1996). This effect has replicated across materials (drawings, photographs, recognition tests, and judgments of camera distance; e.g., Intraub, & Bodamer, 1993; Intraub, Daniels, Horowitz, & Wolfe, 2008; Intraub et al., 1996) and fMRI data suggest the effect occurs because people tend to imagine beyond the boundaries of a scene. In two studies, patients with profound hippocampal damage—who tend to have trouble imagining themselves in the future, or visualising an imaginary scene—did not display boundary extension (Hassabis, Kumaran, Vann, & Maguire, 2007; Mullally, Hassabis, and Maguire, 2012).

Interestingly, however, after viewing *emotional* pictures, people often recall that the pictures had *narrower* boundaries: *boundary restriction*. In one example, subjects saw a series of slides depicting either a traumatic or neutral version of the same event (e.g., an injured woman lying on the grass vs. the same woman crouching on the grass, picking a flower; Safer et al., 1998). Later, subjects viewed original slides amongst distracters that depicted wider angled and close-up versions of the slides. They rated whether the perspective was closer, the same distance or further away than the original. When subjects saw the neutral event, they were more likely to make boundary extension errors. Yet, when they saw the traumatic event, subjects were more likely to make boundary *restriction* errors. These results echo those of *autobiographical memory narrowing* where positive affect enhances recall of peripheral details, while negative affect impairs it (e.g., Bernsten, 2002; Talarico et al., 2009). Although subsequent attempts to demonstrate boundary restriction have produced mixed results—likely due to distinct methodological differences across studies (Candel, Merckelbach, & Zandbergen, 2003; Mathews & Mackintosh, 2004)–these studies do provide some evidence that misremembering *proximity* to a traumatic image may be another example of memory amplification. Might boundary restriction, then, also be related to psychological symptoms?

One explanation for the relationship between amplified memory and greater re-experiencing symptoms is a failure in source monitoring (Johnson, Hashtroudi, & Lindsay, 1993: Lindsay, 2008). For example, intrusive re-experiencing may stimulate the production of other imagined thoughts or images relating to the event that may, over time, be mistaken for genuine memory traces. This imagination of new traumatic material might result in a person misremembering a traumatic event as being more personally threatening than it actually was. Indeed, Mathews and Mackintosh (2004) found that boundary restriction was stronger among subjects with high compared to low trait anxiety, which fits with data showing that high-anxiety people tend to focus on and engage with the threatening component of materials (Bar-Haim, Lamy, Pergamin, Bakermans-Kranenburg, and van IJzendoorn, 2007). These ideas also fit with Fredrickson's (1998; 2001; Fredrickson & Branigan, 2005) *broaden-and-build* theory of positive emotions, which argues that positive emotions broaden an individual's attention to peripheral features and their thought-action repertoire. The theory also posits that aspects of an emotional event that help identify and perpetuate the emotion provoked by the experience will be enhanced relative to the other aspects of the event. Hence, negative emotions would narrow attention to the threatening components.

We suspect that misremembering the threat associated with negative images may lead a person to infer they were closer to the event than they actually were and, thus, later overestimate their proximity to the traumatic event. To test this idea, we used an analogue trauma design. Subjects viewed traumatic still photos taken from the International Affective Picture System (IAPS; Lang, Bradley, & Cuthbert, 2008). A series of questionnaires allowed us to measure changes in mood and analogue trauma symptoms in relation to the photographs. We tested subjects' memory for the photographs after a brief delay, manipulating whether subjects saw the same photographs or photographs that were wider-angled or close-up versions of the originals. In the context of this series of studies, overestimating proximity would be reflected in a bias to select close-up photographs or remembering the boundaries of a photo as being more restricted than what they actually were. In particular, we predicted that people with re-experiencing symptoms would be especially prone to boundary restriction errors.

Experiment 1

Method

Subjects.

We recruited 157 subjects from Amazon Mechanical Turk. We excluded data from 13 people who failed to accurately complete the instructional manipulation checks embedded within the study (see Oppenheimer, Meyvis & Davidenko, 2009), 29 who did not conform to our procedure[1], and seven who reported they had technical issues resulting in them not seeing one or more photographs at encoding or during the test. Thus, our analyses focus on the remaining 113 subjects; all were US residents. We did not collect any demographic or socioeconomic information.

Materials

Traumatic stimuli. We selected fifty photographs from the IAPS and divided them into two sets (A and B) of 25 photographs, matched for valence ($M_{\text{Set A}}$= 1.87 [95% CI: 1.77, 1.96], $M_{\text{Set B}}$= 1.86 [1.76, 1.96], $t<1$), and arousal ($M_{\text{Set A}}$= 6.28 [6.06, 6.50], $M_{\text{Set B}}$= 6.32 [6.11, 6.54], $t<1$). We selected photographs with standardized ratings of negative valence (<2.5 on a scale where 1=low pleasure and 9=high pleasure) where it was also possible to crop the photograph so that the central objects were magnified but entire objects or people were not removed.

Positive Affect Negative Affect Schedule (PANAS; Watson, Clark & Tellegen, 1988*)*. We assessed subjects' mood before and after viewing the photographs using the 20-item

1 People spent either too little or too much time overall viewing the photographs at encoding (based on page timing data), suggesting that they could have paused, skipped or replayed the

version of the PANAS. Subjects rated their current feelings according to 10 positive (e.g., “enthusiastic”) and 10 negative (e.g., “nervous”) adjectives. The scales have been shown to have excellent convergent correlations with other more extensive measures of mood (.76 to .92) (Watson et al., 1988). In addition, both the negative affect (NA) and positive affect (PA) subscales correlate with other measures of distress and psychopathology, including the Hopkins Symptom Checklist (HSCL; negative affect: $r = .56$; positive affect: $r=-.29$) and Beck Depression Inventory (BDI; negative affect: $r = .74$; positive affect: $r = -.36$).

PTSD Checklist Revised (PCL-R). We created a modified[2] version of the PCL (Weathers, Litz, Herman, Huska & Keane, 1993) to assess subjects’ analogue trauma symptoms in relation to their exposure to the traumatic photographs. Subjects rated the extent to which they had been bothered by 14 symptoms (e.g., “Repeated, disturbing memories, thoughts, or images…”) in relation to the photographs (1=not at all, 2=a little bit, 3=moderately, 4=quite a bit, 5=extremely). Thus, possible scores ranged from 14-70 with higher scores indicating more distress relating to the photographs. The PCL has been shown to have excellent convergent validity, correlating highly with the Clinician Administered PTSD Scale (CAPS) ($r = .93$) (Blanchard, Jones-Alexander, Buckley, & Forneris, 1996).

Procedure

This research was approved by the Social and Behavioural Research Ethics Committee at Flinders University and conducted in accordance with the provisions of the World Medical Association Declaration of Helsinki. We administered the study as an

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[2] We omitted 3 items that could not be sensibly rated in relation to the photographs given the timeframe between the encoding and test phases: “repeated, disturbing dreams…” “loss of

online survey using Qualtrics software. We told subjects the study was about juror decision-making and would allow us to evaluate the impact of different types of graphic visual evidence on mock juror decision-making; particularly whether graphic material exacerbates the difficulty for jurors in remaining objective and attending to their task. After indicating their consent to take part, subjects completed the PANAS.

Encoding Phase. We next presented subjects with 25 close-up and 25 wide-angled photographs (counterbalanced across Sets A and Set B)[3]. Close-up photographs were edited to 50% of their original size and appeared for 5s each, separated by a 1s black screen, in a video format created using iMovie. We counterbalanced the order of the photographs, using two versions to control for order effects. After viewing the photographs, we asked subjects to complete the PANAS again, then rate—on an 7-point Likert-type scale (1=not at all, 7=extremely) (a) how unpleasant they found the photographs, (b) how distressed they felt after viewing the photographs, and (c) how closely they paid attention to the photographs. We next asked subjects to work on unrelated puzzles for 20 minutes, after which time the survey allowed them to proceed to the next study phase.

Test Phase. We first administered the PCL, followed by the recognition test. The test was a 2 alternative forced choice (2AFC) procedure; subjects saw both the close-up and wide-angled versions of all 50 photographs, and indicated which photograph they had seen during the encoding phase, and how confident they were in their decision (1=not at all, 5=extremely).

At the conclusion of the online survey, subjects were thanked and debriefed.

[3] Due to a technical error in the photograph editing, some subjects saw one or two moving images at encoding. Because movement could be confused with proximity, we removed the

Results

Emotional impact of photos

We first examined subjects' mood change and ratings of the photographs after exposure. Subjects experienced a decrease in positive mood (Time 1: M=29.49, 95% CI [27.85, 31.13]; Time 2: M=23.07 [21.49, 24.66]; $t(112)=11.02$, $p<.01$, $d=.74$ [.58, .90]) and an increase in negative mood (Time 1: M=12.40, 95% CI [11.63, 13.17]; Time 2: M=20.81 [19.20, 22.41]; $t(112)=11.47$, $p<.01$, $d=1.25$ [.98, 1.51]) after viewing the photographs. They rated the photos as being very unpleasant ($M=6.12$, $SD=1.53$), and distressing ($M=5.12$, $SD=1.67$). Subjects' scores on the modified PCL ranged from the scale minimum of 14, to 55 ($M=24.08$, $SD=10.11$). Cronbach's Alpha for the modified PCL was high (.91). In analyses using the PCL, we used a log-transformation to correct for positive skew in the distribution of scores. Subjects reported that they had paid close attention to the photographs: $M=6.50$ ($SD=.70$), Range 3-7.

Memory accuracy

We next examined subjects' accuracy at recognizing the photographs using a signal detection approach. This approach is advantageous because it allows us to separate subjects' ability to discriminate between old and new photos at test (d')—which depends on the strength of a memory trace—from the response criterion (c), a measure that reflects a subject's tendency to boundary extend or boundary restrict at test. We arbitrarily classified wider-angled photos as signal events and close-up photographs as noise events. Thus, for example, correctly choosing a wider-angled photograph was coded as a hit, and incorrectly choosing a wider-angled photograph was classified as a false alarm. We calculated signal detection measures d' and c, where d' denotes the ability to correctly remember the viewing angle, $c < 0$ is a response bias toward selecting wider-angled photographs, and $c > 0$ is a bias toward selecting close-up photographs.

Our d' data indicate low sensitivity (*M*=1.08, 95% CI [.96, 1.21]) among our subjects, suggesting they had difficulty discriminating between the wide-angled and close-up versions of the photographs. Put another way, subjects were fairly inaccurate at identifying the photograph they saw originally. Indeed, this d' corresponds to an accuracy level of approximately 69%, assuming unbiased responding. However, our c data suggest a reasonably strong bias towards selecting wide-angled photographs (*M*=-.45 [-.38, -.52]); in other words, subjects were most likely to make boundary extension errors.

Analogue PTSD symptoms and memory accuracy

Recall that we were particularly interested in the relationship between memory errors and analogue symptoms. However, before examining subjects' reactions to the photographs, we first examined the potential influence of pre-existing individual differences in negative affect and dysphoria. Correlating d' and c with subjects' baseline scores on the PANAS showed that people with heightened negative affect did not have poorer memory (r_{NA}=-.15, *p*=.12). The other effects surrounded zero (*r*s -.03 to -.05). We next correlated d' with subjects' scores on the PCL. This analysis revealed that the more symptoms people experienced in relation to the photographs, the poorer their memory discriminability, *r*= -.19, *p*=.04, 95% CI [-.37, -.01]. That is, the more analogue trauma symptoms subjects reported, the greater their inability to correctly remember their proximity to the photo they were shown during encoding. Of course, we were most interested in whether people who experienced more adverse analogue symptoms in relation to the photographs would show a greater bias towards selecting close-up photographs (making boundary *restriction* errors). To test this hypothesis, we correlated c with total PCL scores. This analysis revealed that people who reported more symptoms were not more likely to select close-up photos (i.e., to make boundary restriction errors): r=.17, p=.07, 95% CI [-.02, .34].

We also hypothesised that re-experiencing symptoms in particular would be most likely to predict memory errors. To investigate this prediction, we broke down the PCL into four subscales: re-experiencing, avoidance, numbness and hyperarousal. Table 1 presents the correlation between subscale scores and d' and c scores. The more overall symptoms—and numbness symptoms—that people experienced, the poorer their memory (d'). Of relevance to our hypothesis, more re-experiencing symptoms—and also more avoidance symptoms—were associated with a tendency to select close-up photos (c), and thus to make BREs.

Confidence

Finally, we were interested in whether subjects had a different phenomenological experience at test for the two different types of errors. To this end, we calculated mean confidence classified by incorrect and correct responses, and whether photographs were wide-angled or close-up at encoding. A 2 x 2 within-subjects ANOVA revealed that subjects were more confident in correct answers (M=3.83 [3.71, 3.96]) compared to incorrect answers (M=3.36 [3.20, 3.52]), $F(1, 106)$=102.64, p<.01, η^2=.49 [.36, .49]); they were also more confident in their responses to photos that were originally presented as wide-angled (M=3.69 [3.55, 3.83]), compared to close-up (M=3.51 [3.37, 3.65]), $F(1, 106)$=18.53, p<.01, η^2=.15 [.05, .27]). When there is potential for subjects to make boundary restriction errors, they are more confident in their responses, compared to when there is opportunity for subjects to make boundary extension errors. This result makes sense given that subjects were far more inclined overall to make boundary extension errors compared to boundary restriction errors.

In summary then, although re-experiencing and avoidance symptoms were associated with boundary restriction errors, the overall rate of BREs was low. In Experiment 2, we changed the format of the memory test, in order to increase the rate of BREs.

Experiment 2

Method

Subjects

We recruited 163 subjects from Amazon Mechanical Turk. We excluded data from 8 people who failed to accurately complete the embedded instructional manipulation checks, 31 who did not conform to our procedure,[4] 11 who reported technical issues resulting in them not seeing one or more photographs during the encoding or test phases, and two who did not pass the practice items. Thus, our analyses focus on the remaining 112 subjects. These subjects were US residents, aged 19-70 (M= 33.64, SD = 10.31). Approximately half (52%) were male and the majority identified their ethnicity as Caucasian (including White; 74.77%). Others identified as African American (including Black; 9.91%), Hispanic (2.70%), Asian American (2.70%), Caribbean American (.9%), Arab (.9%) and mixed ethnic origin (8.12%). Socioeconomic data were not collected.

Materials and Procedure

We used the same materials as in Experiment 1, plus two additional measures.

Experience of Intrusions Scale (EIS; Salters-Pedneault, Vine, Mills, Park & Litz, 2009). We used this brief, five-item scale to assess both the frequency of intrusive thoughts about the photographs (0=almost never, 1=infrequently, 2=occasionally, 3=frequently, 4=very frequently), and the phenomenology of those intrusive experiences,

[4] These subjects spent either too little or too much time viewing the photographs at encoding

such as the extent to which they created interference and distress, and were unpredictable and unwanted (0=not at all, 1=a little, 2=moderately, 3=quite a bit, 4= extremely). Previous psychometric examination revealed good internal consistency values and convergent validity with total re-experiencing (Cluster B) scores on the PCL-C, (r = .22) (Salters-Pedneault et al. 2009). Our own data revealed a strong Cronbach's alpha of .90.

Cognitive Processing Questionnaire, data-driven processing subscale (CPQ-DD; Halligan, Clark, & Ehlers, 2002*)*. We used this 8-item subscale to assess the extent to which subjects processed the perceptual features of the photographs, to indirectly assess how much attention subjects paid to these features. Subjects rated the extent to which items such as "My mind was fully occupied with what I saw, heard, smelled, and felt" applied to them while they were viewing the photographs, using a 5-point scale (1=not at all, 2=a little, 3=moderately, 4=strongly, 5=very strongly). The original CPQ has good psychometric properties (Ehlers, 1998), and predictive validity for PTSD, with the Data Driven Processing Scale correlating significantly with PTSD (PDS) scores following assault, r = .40. (Halligan et al., 2002). Our own data revealed a strong Cronbach's alpha of .82.

The procedure was identical to Experiment 1 with the following exceptions: (1) Subjects completed the CPQ-DD subscale after the second PANAS, and the EIS items prior to the PCL. (2) The recognition test used a "camera distance" rating (Intraub et al., 1992; Safer et al., 1998). We told subjects: "These pictures are similar to the pictures you saw earlier in the session, during the video. However, some of these pictures have been altered so that the camera is either slightly closer to, or slightly further away from, the main object(s) in the picture." We asked subjects to judge whether the "camera distance" of each test picture matched the camera distance of the picture they had seen earlier, using a 5-point scale: -2 (much closer than the original), -1 (slightly closer), 0 (no change), 1 (slightly farther), 2 (much farther). We explained that a closer camera distance meant seeing less background than in the original and a farther distance meant seeing more background. We showed subjects example picture pairs illustrating one picture being closer, farther away, and the same camera distance. We also had subjects complete practice items with unrelated neutral slides and required them to accurately rate two of each type (closer, same, farther) to remain in the study. The test included the same 50 negative photographs that had been presented at encoding, of which half were close-up and half were wide-angled (again, we counterbalanced across Sets A and B). However, it is important to note that subjects saw all the photographs at the *same* camera distance on the test (i.e., the correct camera distance rating was 'no change' for all items). Figure 1 illustrates the photographs presented at encoding and test, and the correct vs. incorrect responses. We also asked subjects to rate how confident they were in their camera distance decision (1=not at all confident, 5=extremely confident). At the conclusion of the online survey, subjects were thanked and debriefed.

Results

Emotional impact of photos

Again, we first examined subjects' overall reactions to the photographs. Similar to Experiment 1, subjects experienced a decrease in positive mood (Time 1: M=28.72, 95% CI [26.97, 30.46]; Time 2: M=22.13 [20.88, 23.38]; $t(109)=9.66$, $p<.01$, $d=.82$ [.62, 1.02]) and an increase in negative mood (Time 1: M=12.03 [11.37, 12.68]; Time 2: M=19.53 [18.12, 20.95]; $t(110)=10.90$, $p<.01$, $d=1.28$ [.99, 1.56]) after viewing the photographs. They rated the photos as being very unpleasant ($M=6.14$ [5.86, 6.41]), and distressing ($M=5.03$ [4.69, 5.37]). Subjects' scores on the modified PCL were similar to those in Experiment 1, ranging from 14-53 ($M=23.63$ [21.85, 25.42]), with Cronbach's

Alpha = .91. Again, we used a log-transformation to correct for positive skew in the distribution of PCL scores. Subjects' scores on the PCL were positively correlated with EIS scores (also log-transformed), $r(111)=.68$ [.56, .77], $p<.01$. Again, subjects reported that they had paid close attention to the photographs: $M=6.39$ ($SD=.73$), Range 5-7.

Memory accuracy

On average, subjects rated photographs as much closer (15.84%), slightly closer (31.30%), no change (48.79%), slightly farther (3.55%) and much farther (0.52%). Thus, in about half of all instances subjects correctly recognised that the photograph was unchanged from encoding. However, the mean reported camera distance on the -2 to +2 scale across all 50 photographs was significantly less than zero (where 0 indicates no change), $M=-.58$ [.52, .64], $t(110)=-19.29$, $p<.01$, $d=1.83$ [1.52, 2.13]. Taken together, these data show that subjects again exhibited a tendency toward boundary extension errors, incorrectly perceiving that they were seeing less background at test. Put another way, they remembered the boundaries of the original picture as having been greater. We were primarily interested in boundary restriction (incorrectly judging the pictures as being farther), an error that subjects made infrequently. Indeed, the distribution of errors was skewed; hence we used a log transformation on this variable.

Analogue PTSD symptoms and memory accuracy

As in Experiment 1, we first examined whether baseline differences in affect influenced memory accuracy. There was no relationship between subjects' baseline scores on the PANAS subscales and the proportion of boundary extension errors they made ($r_{PA}=.03$ [-.16, .22], $p=.73$; $r_{NA}=.06$ [-.13, .24], $p=.50$). Neither positive affect ($r=-.01$ [-.20, .18], $p=.96$) nor negative affect was related to making BREs ($r=.18$ [-.01, .36], We next correlated both types of memory errors with each of the PCL subscales, and—to focus more specifically on the role of intrusive memories—with EIS scores.[5] Table 2 presents the results. These data provide no conclusive evidence for a relationship between memory errors and symptoms. However, people who scored higher on the EIS made more boundary restriction errors (BREs; selecting either 'slightly farther' or 'much farther'). Recall that the EIS captures information about the frequency of intrusions, and also the *unpredictability, unwantedness, interference and distress* associated with the experience of intrusions. The re-experiencing subscale of the PCL captures how much subjects were bothered by repeated intrusions, a sense of reliving, upsetting reminders, and physical reactions relating to the photographs. It is possible that these subtle differences between the scales (note that in this sample the correlation between them was r=.67 [-.55, .76]) could explain why the EIS—but not re-experiencing—is significantly associated with boundary errors in this experiment. Alternatively, the new method for assessing boundary errors in this experiment could explain the different pattern of results. We also cannot rule out the possibility that the relationships are merely spurious. Given the low rate of BREs overall, we next examined the subgroup of subjects (58) who did make one or more BRE. As shown in Table 2, subjects who made more BREs did not score significantly higher on the symptom subscales. However, this analysis is limited by sample size.

Confidence

As in Experiment 1, we calculated mean confidence classified by correct responses ("no change") and the two different types of incorrect responses (farther and closer). Due to the small rate of BREs, we compared subjects' confidence on "no change" and

[5] Subjects' scores on the CPQ-DD were positively correlated with all subscales of the PCL

"closer" (boundary extension error) responses. A paired t-test revealed that subjects were more confident in correct answers (M=3.68 [3.56, 3.81]) compared to incorrect (BRE) answers (M=3.43 [3.29, 3.57]), $t(110)=3.74$, $p<.01$, $d=.37$ [.17, .56]).

Overall, our boundary error results were very similar to Safer et al. (1998), in that subjects were quite accurate in recognizing that the photographs at test had not changed from the encoding phase, and we again had a low rate of BREs. Of course, as Safer et al. suggest, some of the correct answers may actually represent people who were unsure and thus *guessed* 'no change'. In other words, potential guesses were confounded with accurate responses in this experiment. In Experiment 3, we presented subjects with photographs at test that were either more close-up or wider-angled than what they saw at encoding. Hence, subjects could no longer be accurate simply by guessing no change. On the other hand, we did not want guess responses to count as genuine memory errors. Thus, in Experiment 3, we excluded 'no change' responses. If subjects extend the boundaries of a photograph, they should inaccurately judge a wide-angled distracter photograph as closer (boundary extension); if they restrict the boundaries of a photograph, they should inaccurately judge a close-up distracter as farther away (boundary restriction). Again, we were interested in the relationship between these judgements and subjects' analogue symptoms relating to the photographs.

Experiment 3

Method

Subjects

We recruited 157 subjects from Amazon Mechanical Turk. We excluded data from 9 people who failed to accurately complete the instructional manipulation checks embedded technical issues and one who did not pass the practice task. Thus, our analyses focus on the remaining 110 subjects. Subjects were US residents, aged 21-68 (M= 33.72, SD = 10.67). Approximately half (53.51%) were male and the majority identified their ethnicity as Caucasian (including White; 72.81%). Other subjects identified as African American (including Black; 6.14%), Hispanic (7.01%), Asian American (5.26%), Eastern European (2.63%), European (3.51%), or mixed ethnic origin (2.63%). Socioeconomic data were not collected.

Materials and Procedure

The materials and procedure were identical to Experiment 2, except for one critical alteration to the recognition test (see Figure 1). When a photograph was presented as close-up during the encoding phase, it was presented as wider-angled on the test. Similarly, when a photograph was presented as wider-angled during the encoding phase, it was presented as close-up on the test. Subjects received the same camera distance instructions, examples, practice items, camera distance and confidence rating scales as in Experiment 2.

Results

Emotional impact of photos

As in the previous experiments, subjects experienced a decrease in positive mood (Time 1: M=27.46, 95% CI [25.78, 29.14]; Time 2: M=22.62 [21.07, 24.16]; $t(109)=8.22$, $p<.01$, $d=.57$ [.41, .72]) and an increase in negative mood (Time 1: M=12.04 [11.10, 12.97]; Time 2: M=18.47 [16.96, 19.98]; $t(109)=9.88$, $p<.01$, $d=.97$ [.74, 1.20]) after viewing the photographs. They rated the photos as being very unpleasant ($M=6.17$ [5.92, 6.41]), and distressing ($M=4.74$ [4.38, 5.09]). Subjects' scores on the modified PCL were similar to those in Experiments 1 and 2, ranging from 13-70 ($M=23.23$ [21.40, 25.05]) with Cronbach's Alpha = .93. Subjects' scores on the PCL were positive correlated with EIS scores, $r(110)=.63$ [.50, .73], $p<.01$. Again, subjects reported that they had paid close attention to the photographs: $M=6.37$ ($SD=.86$), Range 3-7.

Memory accuracy

Recall that half the photos were presented as close-up at encoding, but wide-angled at test. On average, subjects rated these photographs as much closer (7.89%), slightly closer (24.74%), no change (52.70%), slightly farther (11.96%) and much farther (2.70%). These data show that subjects were most likely to incorrectly remember the photographs as having had extended boundaries. Indeed, the majority of subjects (70%) were incorrect for all of these photographs. This finding fits with the previous results showing a general tendency toward boundary extension errors.

We presented the other half of photographs as wide-angled at encoding and close-up at test. Subjects were likely to correctly recognize at test that these photographs were closer. More specifically, on average, subjects rated these photographs as much closer (40.00%), slightly closer (38.31%), no change (18.95%), slightly farther (2.21%) and much farther (0.49%). The rate of BREs ("farther" judgements) was similar to Experiment 2, though recall that we did not include "no change" judgements, which were technically inaccurate in this procedure.

Analogue PTSD symptoms and memory accuracy

Again, we first examined how affect influenced memory accuracy. There was no significant relationship between subjects' baseline scores on either PANAS subscale with proportion of boundary extension errors ($r_{PA}=.05$ [-.14, .24], $p=.57$; $r_{NA}=.01$ [-.18, .20],

p=.95). or boundary restriction errors (r_{PA}=.13 [-.06, .31], p=.19; r_{NA}=.10 [-.09, .28], p=.29).

To focus on the role of specific symptoms, as in Experiment 2, we calculated the relationship between BEEs, BREs and the PCL subscales and EIS.[6] Table 3 presents these data. Subjects who made boundary restriction errors were also more likely to have had negative reactions to the photographs, across all the PCL subscales and the EIS.

Confidence

We calculated mean confidence classified by accuracy (correct vs. incorrect) and proximity of photographs at test relative to encoding (farther or closer). A 2 x 2 within subjects ANOVA—using subjects who had complete data for all four conditions (n=33)—revealed that subjects were more confident in correct answers (M=3.18, 95% CI [2.91, 3.46]) compared to incorrect answers (M=2.88, 95% CI [2.59, 3.17]), F(1, 32)=11.19, p<.01, η^2= *.26* [.04, .47]). Subjects were also more confident in photographs that were closer, with the potential for boundary restriction (M=3.15, 95% CI [2.87, 3.44]) compared to photographs that were farther away, with the potential for boundary extension (M=2.91 [2.62, 3.21]), F(1, 32)=4.84, p=.04, η^2= *.13* [.00, ..34]. The interaction between accuracy and proximity was not statistically significant, F(1, 32)=1.62, p=.21, η^2= *.04* [.00, .24]).

To examine whether we would replicate our pattern of results, and to provide more stable estimates of the effect sizes involved, we conducted a further experiment using a larger sample. We also addressed the issue of whether some subjects may have looked away from the photographs during the encoding phase.

[6] Again, subjects' scores on the CPQ-DD were positively correlated with all subscales of the PCL and the EIS (rs = .29-.49), but were not related to recognition memory

Experiment 4

Method

Subjects

We recruited 502 subjects from Amazon Mechanical Turk. We excluded data from 37 people who failed to accurately complete the instructional manipulation checks embedded within the study, 90 who did not conform to our procedure, 10 people who reported technical issues and 18 who did not pass the practice task. Thus, our analyses focus on the remaining 347 subjects.[7] Subjects were US residents, aged 18-74 (M= 36.79, SD = 10.33). Approximately half (51.9%) were male and the majority identified their ethnicity as Caucasian (including White; 77.30%). Other subjects identified as African American (including Black; 8.62%), Hispanic (3.74%), Asian American (3.16%), European (2.88%), or mixed ethnic origin (2.88%). Socioeconomic data were not collected.

Materials and Procedure

The materials and procedure were identical to Experiment 3. However, at the end of the study, we told subjects "*It is very important for our research that we use data only from people who followed directions exactly. We ask that you answer the following questions honestly to help us analyze our data. Your answers will not affect payment*." We then asked them: *"Did you ever find yourself closing your eyes or looking away from the photos during the video?"* Subjects who answered yes to this question were also asked: *"For approximately how many photos do you estimate that you closed your eyes or looked away?"* We next asked subjects: *"Did you ever find yourself closing your eyes or looking away from the photos during the memory test?"* Subjects who answered yes to

[7] Note that despite a larger sample size, the percentage of subjects we retained (69%) is

this question were also asked: *"For approximately how many photos do you estimate that you closed your eyes or looked away?"*

Results

Attention to photos

Approximately 26.22% of our final sample reported that they closed their eyes or looked away at least once during the encoding phase. Of these subjects, the majority (63.73%) estimated looking away or closing their eyes for 10% or fewer of the photos we showed them, and around 7.69% indicated doing so for only one or two (less than 5%) of the photos. A small proportion of subjects (7.69%) reported looking away from half or more of the photos. Approximately 15.85% of subjects reported that they looked away or closed their eyes at least once during the test. Of these, 13.46% reported that they looked away/closed their eyes for less than 5% of the photos; half said they did so for 10% or fewer of the photos; and 13.46% looked away from half or more of the photos. We compared subjects who looked away/closed eyes at either encoding or test, with subjects who did not, on measures of distress. These analyses showed that subjects who reported looking away were more distressed by the film (M=5.47, SD=1.66) and reported more analogue PTSD symptoms on the PCL scale (M=26.57, SD=9.51), than participants who did not report looking away [Distress: M=4.57, SD=1.86, $t(344)=4.22$, $p<.01$, $d=.50$ [.26, .73]; PCL: M=21.41, SD=8.16, $t(345)=5.08$, $p<.01$, $d=.60$ [.36, .84]. In the analyses that follow, we consider the data with and without subjects who reported closing their eyes or looking away during either the encoding or test phases (n=100). It is important to note, however, that excluding subjects who looked away is a conservative approach; to look away from the photo implies that they attended to the photo enough to recognize that they did not want to focus on the them initially full on and then sometimes find myself looking at the same photo from my peripheral vision").

Emotional impact of photos

As in the previous experiments, subjects experienced a decrease in positive mood (Time 1: M=29.01, 95% CI [28.08, 29.93]; Time 2: M=22.67 [21.88, 23.47]; $t(346)=17.61$, $p<.01$, $d=.78$[8]) and an increase in negative mood (Time 1: M=11.72 [11.36, 12.08]; Time 2: M=19.11 [18.25, 19.97]; $t(346)=18.91$, $p<.01$, $d=1.18$) after viewing the photographs. They rated the photos as being very unpleasant (M=6.06 [5.90, 6.21]), and distressing (M=4.83 [4.38, 5.09]). Subjects' scores on the modified PCL were similar to those in the previous experiments, ranging from 13-59 (M=22.90 [21.96, 23.84]) with Cronbach's Alpha = .91. Subjects' scores on the PCL were positive correlated with EIS scores, $r(347)=.69$ [.63, .74], $p<.01$. Again, subjects reported that they had paid close attention to the photographs: M=6.36 (SD=.92), Range 2-7.

Memory accuracy

First, we considered photos presented as close-up at encoding, but wide-angled at test. On average, subjects rated these photographs as much closer (11.71%), slightly closer (30.78%), no change (53.78%), slightly farther (3.32%) and much farther (0.42%). These data show subjects were very likely to remember these photographs as having had extended boundaries. Again, the majority of subjects (64%) were incorrect for all of these photographs. Next, we considered photographs presented as wide-angled at encoding and close-up at test. Subjects were likely to correctly recognize at test that these photographs were closer. More specifically, on average, subjects rated these photographs as much closer (20.78%), slightly closer (35.82%), no change (40.31%), slightly farther (2.61%)

[8] We used ESCI software (Cumming, 2012) to calculate confidence intervals. However, CI

and much farther (0.48%). These proportions are generally similar to Experiment 3, though subjects were more likely to judge closer photographs as the same. The proportions are also almost identical when subjects who reported closing their eyes or looking away are excluded (much closer (20.76%), slightly closer (36.03%), no change (40.40%), slightly farther (2.27%) and much farther (0.50%)).

Analogue PTSD symptoms and memory accuracy

We examined whether baseline differences in affect influenced memory accuracy. Here, higher positive affect was associated with a greater number of boundary extension errors (r_{PA}=.16 [.06, .26], p<.01), but not with boundary restriction errors (r_{NA}=-.04 [-.15, .07], p=.46). The opposite was true for negative affect: it was not associated with a greater number of boundary extension errors (r_{PA}=-.03 [-.14, .08], p=.56), but people with heightened negative affect made more BREs (r=.16 [.06, .26], p<.01). These data are consistent when people who closed their eyes are excluded (r=.32 [.20, .43]). These results make sense if fewer boundary extension errors are seen as a type of boundary restriction.

Table 3 presents the data relating to symptoms.[9] As in Experiment 3, subjects who made boundary restriction errors were also more likely to have had negative reactions to the photographs across all subscales of the PCL. The relationship between BREs and intrusive experiences as measured by the EIS, appears less consistent. Importantly, the relationship between memory errors and analogue trauma symptoms remains when we remove subjects who reported looking away or closing their eyes during encoding or test from the analysis.

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[9] Again, subjects' scores on the CPQ-DD were positively correlated with all subscales of the PCL and the EIS (rs = .35-.55). In this experiment subjects who reported more processing of

Confidence

As in Experiment 3, we calculated mean confidence classified by accuracy (correct vs. incorrect) and proximity of photographs at test relative to encoding (farther or closer). A 2 x 2 within subjects ANOVA—using subjects who had complete data for all four conditions (n=81)—revealed that subjects were more confident in correct answers compared to incorrect answers, but only when the errors were for photographs that were closer, with the potential for boundary restriction ($M_{correct}$=3.25, 95% CI [3.09, 3.42]; $M_{incorrect}$=2.94 [2.74, 3.14]). When the errors were for photographs that were farther away, with the potential for boundary extension, subjects were more confident in their incorrect answers ($M_{correct}$=2.91, 95% CI [2.75, 3.07]; $M_{incorrect}$=3.16 [3.00, 3.33]), $F(1, 80)=17.26$, $p<.01$, $\eta^2= .18$ [.05, .32]). These data replicate the pattern from Experiment 3, with a larger sample size, which may have allowed us to detect a statistically significant interaction.

General Discussion

Our findings replicate earlier work on boundary errors for visual scenes (e.g., Intraub et al., 1992; Intraub & Bodaner, 1993; Intraub et al., 1996): across all four experiments, subjects were most likely to remember the photos as having more extended boundaries than they really had. This bias to remember the photos as having extended—as opposed to restricted—boundaries did not occur because the images were not sufficiently traumatic. Indeed, our subjects rated the images, on average, as extremely unpleasant, and reported a more negative mood state after viewing them.

Importantly, although the rate of boundary restriction errors (BREs) was low overall, we found in the latter two experiments that individual differences in analogue symptoms we have argued, boundary restriction errors are analogous to misremembering an event as being “more traumatic,” then our results parallel findings from field studies showing that re-experiencing is associated with memory amplification. Indeed, the size of the effects we find in our data are comparable to effects from the field data, for example; .20, 95% CI [.16, .24] (Giosan et al., 2009); .23 [.06, .38] (Engelhard et al., 2008); .26 [.22, .30] (King et al, 2000);.32 [.17, .60] (Southwick et al., 1997).[10] However, we also saw a relationship with other symptom clusters, particularly in Experiment 4 where we had the largest sample.

Our findings therefore have important theoretical implications. The fact that re-experiencing the images was associated with boundary restriction is consistent with the idea that boundary restriction errors occur due to a failure in source monitoring. There are several possible routes by which this failure could occur. One possibility, which we call the *rehearsal-via-re-experiencing* account, is that subjects tend to rehearse the worst—or most salient—part of the photographs via their re-experiencing symptoms. Therefore, it is these salient or central parts of the traumatic images that are most likely to be amplified, leading subjects to remember a closer version of the photographs. However, BREs were also associated with other symptom clusters, not only re-experiencing symptoms. A second, but not mutually exclusive, possibility is that symptoms increase the arousal associated with the photographs, and thus enhance subjects’ perception of the level of threat associated with the events depicted in the photographs. This possibility aligns with Ehlers and Clark’s (2000) model. According to Ehlers and Clark’s (2000) cognitive model, PTSD becomes a persistent disorder when people process the trauma in a way that leads to a sense of serious, current threat. Once activated, the perception of threat is

[10] We used ESCI software (Cumming, 2013) to estimate 95% confidence intervals for

accompanied by re-experiencing symptoms, such as intrusive thoughts, nightmares and flashbacks, in addition to arousal and anxiety. Our data appear to fit with the idea that people who reported more symptoms, and therefore processed the trauma in a way that is thought to lead to a sense of current threat, also had a tendency to misremember the photos as being closer. In other words, they showed a bias to remember the event as being more threatening than it actually was. Finally, our data are consistent with the *broaden-and-build* theory of positive emotions, which also predicts that negative emotions result in more attention to the threatening components of an event.

There are, of course, other possible explanations for our findings. First, the unpredictable nature of boundary restriction errors could be a result of individual differences. For example, we know that people prone to anxiety are more likely to rapidly and selectively attend to and encode emotionally threatening words or pictures (Derryberry & Reed, 1998; Mathews & MacLeod, 1994; Yiend & Mathews, 2001). This idea could also explain why we found that avoidance predicted susceptibility to boundary restriction in some of our data: people who are more prone to anxiety may also be more motivated to avoid thinking about the trauma. However, we also saw a relationship between avoidance and BE errors in Experiment 3. This correlation may have resulted from subjects avoiding the stimuli altogether—for example, by looking away—and hence making more errors in general, a possibility we addressed in Experiment 4.

A second alternative explanation for our results is that people are motivated to justify their level of distress and apparent symptomatology (Bolton et al., 2006; Engelhard et al., 2008; King et al., 2000; Southwick et al., 1997). Indeed, a number of researchers have speculated that the memory amplification effect may be the result of a reappraisal process, whereby people who are suffering from current problems are motivated to attribute those problems to stressors from the trauma (Bolton et al., 2006; Engelhard et al., 2008; King et al., 2000; Southwick et al., 1997). Perhaps then, the relationship we observed between the different symptom clusters and boundary restriction errors is simply the result of differences in motivation to justify distress. The relationship with re-experiencing symptoms may be the most consistent because re-experiencing the event is arguably one of the more distressing reactions to a traumatic event and may be more readily considered to have a negative idiosyncratic meaning (e.g, ‘I am going crazy’) compared to other symptom clusters, such as avoidance or numbing. Hence, people with more frequent re-experiencing may be more motivated to justify their level of distress and as such infer that they were closer to the traumatic elements of the images during encoding.

Of course, our study has several limitations. Our design is correlational, which means we cannot determine causality or the directionality of the relationship between memory amplification and analogue symptoms. Furthermore, we are unable to compare the pattern of effects relating to negative images, to a comparable group of neutral images. We also assessed intrusive memories—and other analogue PTSD symptoms—20 min after exposure to the photos. One could argue, therefore, that, our measure of intrusive memories may not be an appropriate analogue for intrusive memories in PTSD, especially because memory for the trauma is still being consolidated during this time. However, a number of studies have assessed intrusions using short monitoring periods immediately following analogue trauma exposure (e.g., Davies & Clark, 1998, Horowitz & Becker, 1971; Nixon, Cain, Nehmy & Seymour, 2009a; 2009b). Indeed, Davies and Clark (1998) found that the frequency of immediate intrusions was significantly correlated with the frequency of intrusions experienced over the following week. Thus, the laboratory setting. Finally, however, our paradigm is of course artificial due to the constraints of examining trauma in the laboratory. Thus, the generalizability of our findings to clinical populations may be limited. Nevertheless, our paradigm provides a necessarily practical and ethical methodology to investigate boundary restriction and memory amplification. Indeed, prior research has shown that the IAPS photos elicit consistent fear-related physiological and behavioral responses (Hairi, Tessitore, Mattay, & Weinberger, 2002; Smith, Bradley, & Lang, 2005).

Several important future research directions arise from our data. Although our data are consistent with the idea that boundary restriction errors occur due to a failure in source monitoring, we are not able to draw any firm conclusions about the specific mechanism. We would argue that disentangling the mechanisms involved is therefore a high research priority. We have suggested that BREs may occur because people rehearse the worst parts of their experience and it is this re-experiencing of the trauma via rehearsal that biases memory for proximity. This process is distinct from one in which people justify existing distress and thus experience memory distortion. Although both processes may be at work, teasing out the mechanisms involved in the relationship between symptomatology and boundary restriction errors may be important for psychological treatment. In other words, to determine the best ways to treat maladaptive reactions to trauma, we must know to what extent memory (in)accuracy plays a role. One possibility is that reliving and rehearsing the salient aspects of trauma worsens symptoms via memory distortion.

In order to more closely examine the underlying mechanisms we have discussed, it would be critical to examine what happens between encoding and retrieval. A longer delay would make it possible to measure intrusion frequency, content and characteristics (such as distress), for example by having subjects complete a thought diary (Davies & Clark, 1998). If subjects who had more intrusions about the central, traumatic, aspects of the photographs also had more boundary restriction errors than subjects who did not think about the photos as much, it might suggest that rehearsal—over time—of the salient parts of the photographs, is responsible for the amplification effect.

The second area of future research that would advance understanding in this area and allow us to make firmer links to theory concerns whether subjects' arousal and sense of threat relating to the trauma at the time of encoding leads to memory distortion, and whether changes in threat perceptions over time are associated with symptoms. A study addressing these questions could also assess whether individual differences in trait anxiety affect boundary restriction errors.

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Author Contributions

M.T. developed the study design, supervised data collection and performed data analysis. All authors assisted with data interpretation. M.T., J.O., and D.G. drafted the paper, and D.S. provided critical revisions. All authors approved submission of the final version.

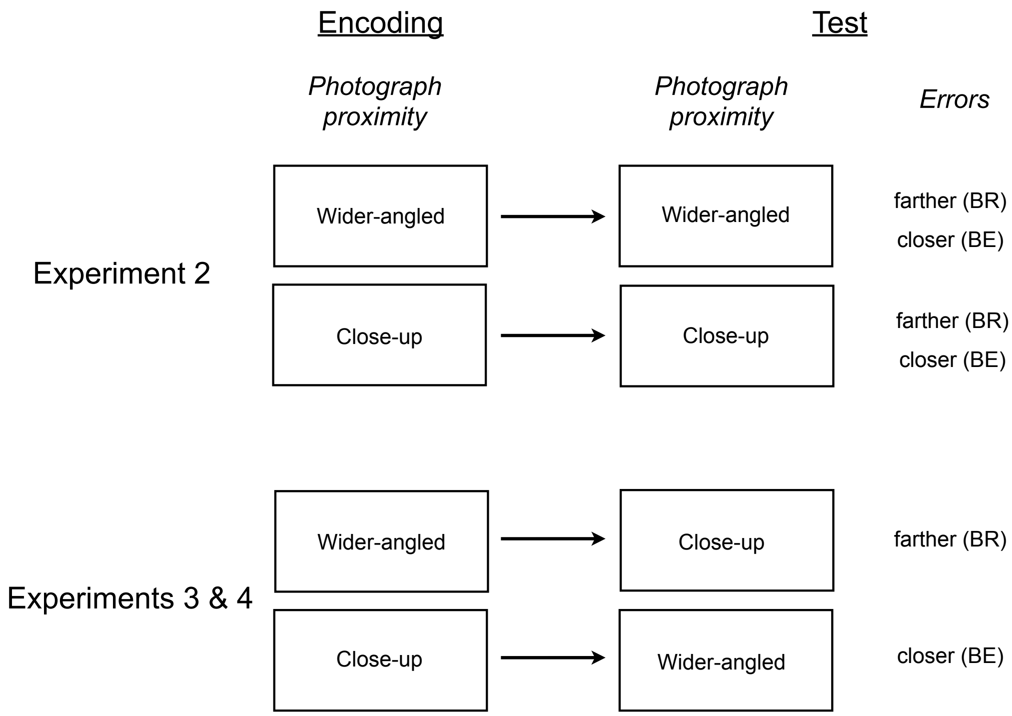

Figure 1. Encoding and Test Procedure (Experiments 2-4)

Table 1.

Correlations (and 95% CIs) between d' and c scores and the PCL subscales (Experiment 1).

	Subscale			
	Re-experiencing	Avoidance	Numbness	Hyperarousal
d'	-.16 [-.34, .03]	-.13 [-.31, .06]	-.21* [-.38, -.03]	-.15 [-.33, .04]
c	.20* [.02, .37]	.20* [.02, .37]	.12 [-.07, .30]	.09 [-.10, .27]

Note: *p<.05