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A chink in the armor: The influence of training on generalization learning impairments after viewing traumatic stimuli

Shilat Haim-Nachum [a], Einat Levy-Gigi [a, b, *]

[a] *School of Education, Bar-Ilan University, Ramat-Gan 52900, Israel*
[b] *The Multidisciplinary Brain Research Center, Bar-Ilan University, Ramat-Gan 52900, Israel*

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ABSTRACT

Studies have demonstrated that similarly to individuals with PTSD, non-PTSD individuals with repeated traumatic-exposure display selective impairments in hippocampal-related functions. A central example is their impaired generalization learning. Interestingly, previous findings revealed that the nature of this impairment varied as a function of occupation; while firefighters display impaired generalization of negative context, police crime scene investigators (CSI) display impaired generalization of negative cue. One possible explanation for these discrepancies may relate to the different job requirements and unique training. Specifically, firefighters are primed to regard the context during traumatic events whereas CSI police are primed to regard specific objects (cues) in the environment. The aim of the present study was to examine the interactive effect of exposure and training on generalization learning. Eighty-two healthy volunteers were exposed to either neutral or traumatic images while receiving instructions to refer either to the images' general contexts or to their specific cues. It was found that while both groups equally acquired and retained stimulus-outcome associations, only participants who were exposed to traumatic images showed impaired generalization learning. This impairment demonstrated a particular difficulty to generalize negative but not positive outcomes. Most importantly, as expected, there was a significant interaction between type of training and the observed impairments. Specifically, individuals who were previously trained to refer to general contexts showed a selective overgeneralization of negative contexts, while individuals who were trained to refer to specific cues displayed a selective overgeneralization of negative cues. The results suggest that trauma exposed individuals show the most vulnerability in precisely the areas in which they were most trained. We discuss the ways in which improving generalization learning may impact individuals' process of trauma recovery and might set the ground for developing treatment and prevention methods.

1. Introduction

While most individuals who are repeatedly exposed to traumatic events do not meet the diagnostic criteria of PTSD, their repeated exposure has psychological, biological, neurological and behavioral consequences (e.g., Brondolo, Eftekharzadeh, Clifton, Schwartz, & Delahanty, 2017; Carleton, Duranceau, McMillan, & Asmundson, 2017; Geronazzo-Alman, 2017; Goswami, Samuel, Sierra, Cascardi, & Paré, 2012; Jahnke, Poston, Haddock, & Murphy, 2016; Yip et al., 2015). Importantly for the present focus, several studies involving this population have shown significant decreases in brain-related structure and function, independent of PTSD diagnosis (e.g., Aupperle, Connolly, Stillman, May, & Paulus, 2013; Chen et al., 2012; Kuo, Kaloupek, & Woodward, 2012; Sekiguchi et al., 2013; for review see Fa et al., 2014; Lupien, McEwen, Gunnar, & Heim, 2009). One region of interest that is highly associated with repeated traumatic exposure is the hippocampus. Studies have demonstrated that not only individuals with PTSD, but also those who have undergone trauma but have not received a PTSD diagnosis, have a reduced hippocampal volume compared to trauma-unexposed controls (e.g., Winter & Irle, 2004; for meta-analysis see Karl et al., 2006; Woon, Sood, & Hedges, 2010). However, the role the hippocampus plays in PTSD symptomology is still unclear.

Animal and human models imply that the hippocampus is associated with contextual processing. According to the item-in-context model, an object (cue) and its context are processed by the perirhinal

* Corresponding author at: School of Education, Bar-Ilan University, Ramat-Gan 52900, Israel.
Email address: einat.levy-gigi@biu.ac.il (E. Levy-Gigi)

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cortex and parahippocampal respectively. This information is then integrated by the hippocampus. Hence, the hippocampus places perceived cues in their proper contexts (Davachi, 2006; Diana, Yonelinas, & Ranganath, 2012; Dickerson & Eichenbaum, 2010), while distinguishing old and novel cue-context variations (Howard, Shankar, & Jagadisan, 2011). Reduced hippocampal volume impairs such processes. Therefore, it may result in failure to discriminate novel conditions and lead to impaired generalization (Levy-Gigi, Szabo, Richter-Levin, & Kéri, 2015; Moustafa et al., 2013 for review see Acheson, Gresack, & Risbrough, 2012; Maren, Phan, & Liberzon, 2013).

One possible consequence of impaired generalization in trauma exposed individuals is attribution of negative outcomes to harmless or irrelevant conditions (Hermans, Baeyens, & Vervliet, 2013; Levy-Gigi et al., 2012). Such impairment may explain, for example, why a person who was exposed to an explosion in an anemone field may associate all anemone fields (the cue) and every loud sound (the context) with a negative outcome. While impaired generalization is associated with the deleterious effect of traumatic exposure, adequate generalization allows individuals to adjustably discriminate between dangerous and safe environments, despite the possible similarities between them, and modify their thoughts and reactions accordingly (e.g., Levy-Gigi et al., 2015). The ultimate goal of the present study was to shed light on the link between traumatic exposure, training and impairments in generalization learning.

In order to assess generalization learning, we used a hippocampal dependent cue-context reversal paradigm (Levy-Gigi et al., 2015). In a traditional reversal paradigm, participants learn a stimulus-outcome association (S → Positive), which is later reversed without any changes in the stimulus dimension (S → Negative) (e.g., Chudasama & Robbins, 2006; Izquierdo et al., 2006; Jones & Mishkin, 1972; Rudebeck & Murray, 2008). Such a paradigm ignores the fact that stimulus dimensions generally occur in a specific context (Mayes, MacDonald, Donlan, Pears, & Meudell, 1992; Murnane, Phelps, & Malmberg, 1999), and therefore, both the stimulus and its surrounding context may be significant (Wickens, 1987). Our paradigm evaluates generalization learning by using a unique partial reversal design. In this paradigm, participants assimilate positive and negative stimulus-outcome associations (e.g., a hat on an orange background → Positive; a car on a yellow background → Negative) and later view new associations that require reversing the outcome associated either the *context* (a phone on an orange background → Negative; a ball on a yellow background → Positive) or the *cue* (a hat on a gray background → Negative; a car on a purple background → Positive) of the acquired stimuli from negative to positive or from positive to negative. This paradigm accentuates selective impairments in reversing positive and negative outcomes of cue- and context-related information.

In a set of studies, we found that firefighters who experience repeated traumatic exposure as part of their daily routines displayed impaired generalization of negative contexts (Levy-Gigi & Richter-Levin, 2014; Levy-Gigi et al., 2012, 2015). Specifically, after learning that a specific context was negative, they could not learn that the same context became positive when presented later with a new cue. Interestingly, when we compared generalization learning among firefighters and police crime scene investigators (CSI), we were able to replicate our previous results in the firefighters alone. CSI police, on the other hand, had a different selective impairment in negative cue (but not context) generalization. Thus, after learning that a specific cue was associated with a negative outcome, they struggled to learn that it was related with a positive outcome when presented later in a different context (Levy-Gigi, Richter-Levin, & Kéri, 2014). While these results provide further support for the associations between traumatic exposure and impaired generalization learning in non-PTSD individuals (Levy-Gigi & Kéri, 2012; Levy-Gigi et al., 2012, 2014; Brown et al., 2013; Levy-Gigi & Richter-Levin, 2014), the reasons for the observed discrepancies remain unclear.

A possible explanation relates to the matter of different job requirements and unique training. Specifically, while firefighters are primed to regard the context during traumatic events (e.g., locate trapped people or scan for possible hazards such as gas tanks in the general environment), CSI police are primed to regard specific objects (cues) in the environment (e.g., traces of people who set up the fire, or subtle evidence left behind by the murderer, such as hair). Accordingly, it is possible that each group becomes more sensitive in precisely the areas in which it was most highly trained. Further support for this view can be found in automatic behaviors, cognitions and attitudes. Automatic behaviors do not require constant conscious guidance or monitoring. While they allow quick responses and enable task switching and multi-tasking (Dijksterhui, 2010; Sherman et al., 2008; Xu, Li, Ding, & Lu, 2014), they may also have significant costs (Skaugset et al., 2016). The impaired selective performance of firefighters and CSI police may reflect one such pitfall. Specifically, it is possible that training in aversive conditions results in a close proximity between the stimulus (context or cue respectively) and the negative outcome. Hence after repeatedly defining cue/context as negative, such negative associations are quickly acquired and automatically preserved without taking the time to reevaluate the outcome of the stimulus when seeing it again.

The present study sought to test this explanation by using controlled exposure to traumatic or neutral images together with training to regard either specific objects (cue) or the general environment (context). Specifically, we asked how the nature of the exposure (neutral vs. traumatic) and type of training (detail vs. context) would affect different impairments in generalization learning. The usage of such scenes to manipulate exposure is in line with behavioral and neuroimaging studies which have shown that it is likely to induce similar responses as traumatic events (e.g., Coan & Allen, 2007; Glauser & Scherer, 2008; Grandjean, Sander, & Scherer, 2008; Hartikainen, Ogawa, & Knight, 2000; Okon-Singer et al., 2014; Vuilleumier, 2005). Furthermore, the nature of the training aimed to reflect a core characteristic that differentiates firefighters and CSI police in their job requirements, based on the different type of skills that are associated with each of these professions: focusing on context vs details in the scene (see Murnane & Phelps, 1993, 1994, 1995; Rutherford, 2004 for similar manipulations). We postulated that in line with previous studies, individuals would demonstrate an equal capacity to learn and retain positive and negative stimulus-outcome associations, independent of exposure. However, in line with our previous results we anticipated that individuals who were exposed to traumatic (but not neutral) images would show impairments in generalization of negative outcomes as a function of training. Specifically, those who received context-related training would overgeneralize the outcome of previously negative contexts while those who received detail-related training would overgeneralize the outcome of negative cues.

Depression (Kolkow, Spira, Morse, & Grieger, 2007; Orr et al., 2012), anxiety (Shalev, Peri, Canetti, & Schreiber, 1996) and previous life stressful events (Brewin, Andrews, & Valentine, 2000) have been associated with PTSD symptoms, and may be closely related to the ways in which individuals respond and function in the face of trauma. Therefore, we wished to control for the possible effects of these symptoms. Since the current study included participants with no history of psychopathology, who were randomly divided into the experimental groups, we expected to find no significant differences between them.

2. Method

2.1. Participants

Sample sizes were calculated using G*Power software (Faul, Erdfelder, Lang, & Buchner, 2007). Based on the effect size that was found in a previous related study (Levy-Gigi et al., 2014), we conducted a-priori power analysis for repeated measures ANOVA. This revealed a need for 80 participants based on the ability to detect a medium size effect (Cohen's f = 0.25) in the study, with a 5% significance level (α) and 80% power level ($1 - \beta$) (Cohen, 1992). Based on these results we used in-campus advertisements to recruit 82 college students who volunteered to participate in the study (see Table 1 for a detailed description of the sample). Participants had normal or corrected-to-normal vision with no colorblindness. We used the SCID-5-CT (First, Williams, Karg, & Spitzer, 2015) to exclude participants with any current DSM-V psychopathology, including PTSD, and any history of psychiatric or neurological disorders, alcohol abuse or dependence. The investigation was carried out in accordance with the Declaration of Helsinki. All participants provided their written informed consent at the beginning of the experiment after the nature of the procedure was fully explained. At the end of the study participants were debriefed.

2.2. Study design

Participants were informed that the study includes self- report questionnaires and a clinical interview (see more details on the clinical assessment below), as well as two computer-based tasks (by the first task we refer to the training manipulation and by the second to the cue-context reversal learning paradigm). No information was provided regarding the relationship between the different tasks. Before the training manipulation, participants were randomly divided into one of four experimental groups to determine the type of exposure: neutral vs. traumatic images; and the type of training: **context-related training** (i.e., "Indicate what is the dominant color in the picture") or **detail-related training** (i.e., "Indicate how many people are in the picture"). This manipulation resulted in the following experimental groups: (1) Neutral images- context training; (2) Neutral images- detail-related training; (3) Traumatic images – context training; (4) Traumatic images – detail-related training. Participants completed the training manipulation according to their experimental group, immediately followed by the cue-context reversal learning paradigm.

Table 1
Demographic characteristics and clinical measures of the participants* (standard deviations in parentheses).

	Neutral images- context training	Neutral images- detail-related training	Traumatic images- context training	Traumatic images- detail-related training
	(N = 23)	(N = 18)	(N = 21)	(N = 20)
Age (years)	25.09 (2.86)	24.89 (2.08)	23.43 (3.17)	23.42 (3.42)
Women/Men	13/10	14/4	12/9	15/5
Education (years)	14.83 (2.29)	14.22 (2.08)	13.95 (1.59)	13.70 (1.69)
Single/Married	20/3	17/1	18/3	18/2
Depression	7.83 (8.31)	6.39 (6.79)	9.76 (7.27)	6.45 (7.22)
State Anxiety	34.47 (14.71)	29.19 (12.23)	36.76 (12.9)	33.29 (8.09)
Trait Anxiety	37.06 (13.65)	33.88 (9.75)	39.24 (11.13)	32.24 (8.79)
PCL Scores	31 (14.68)	31.61 (18.05)	36.26 (11.74)	26.10 (7.93)
Trauma Exposure	39 (18.38)	38.25 (18.14)	44.94 (20.63)	42.08 (18.94)

* There were no significant differences in depression, state anxiety, trait anxiety, PCL scores and trauma exposure between the four groups (all $F \leq 1.9$, $ps > 0.15$).

2.2.1. Training manipulation

In a preliminary study, 36 participants, who were not part of the present study's sample, viewed a pool of 100 real-life color images. Half of the images presented traumatic incidents depicting, for example, dead bodies, emergency situations or war scenes and half neutral daily scenes. Each image was rated on a 9-point Likert scale ranging from "1: Not at all" to "9: Very much so" to measure feelings of fear, sadness, disgust and distress. The average of these four scores was calculated for each image. We selected the 30 pictures with the lowest scores and the 30 pictures with the highest scores for the neutral and traumatic procedure, respectively (see Fig. 1 for an example of traumatic and neutral images).

Pictures in the two sets were matched in terms of visual complexity to ensure similar training across groups. To that end, 29 participants who were not part of the study's sample rated the complexity of the pictures on a two 7-point Likert scale; one for rating the level of colors (1 = not colorful, 7 = extremely colorful) and one for rating the number of details on each image (1 = not many details, 7 = extremely detailed). Data analysis revealed no significant differences in rating the colors complexity, $t(56) = 0.15$, $p = .88$, and details complexity, $t(56) = -1.39$, $p = .17$.

Participants view the 30 matched pictures (neutral or traumatic) on a 15″ computer screen. Each picture is presented for 4000 ms, followed by 4000 ms dedicated for rating. Rating was done according to the training conditions: participants in the context-related training condition had to indicate what is the dominant color in the picture, whereas participants in the detail-related training condition had to indicate how many people are in the picture.

2.3. Measurements

2.3.1. The cue-context reversal learning paradigm.

In this paradigm (Levy-Gigi et al., 2014, 2015), participants observe a set of boxes on a computer screen. On each box the image of a target cue (one of several objects, e.g., a hat) is placed against a background context (different colors, e.g., blue; see Hockley, 2008; Isarida & Isarin, 2007; Lang et al., 2009; Macken, 2002; Rutherford, 2004 for studies that manipulated context in a similar way). Participants are asked to either open the box or leave it closed.

When opened, each box is associated with a specific outcome (positive, i.e. gold coins, or negative, i.e. a bomb) that leads to either a gain or loss of 25 points, accordingly (see Fig. 2). Such an outcome was found to be an equivalent of money, having strong reinforcing properties (see Breiter & Rosen, 1999; Delgado et al., 2000, 2003, 2005; Delgado, Jou, & Phelps, 2011; Elliott et al., 2000; Knutson, Adams, Fong, & Hommer, 2001, 2003; Vohs, Mead, & Goode, 2006; for review see Sescousse, Caldú, Segura, & Dreher, 2013). The task has two phases: an *acquisition phase* followed by a *retention and reversal phase*

Fig. 1. Example of neutral and trauma-related images. The pictures were taken from an online open access database found on google.com and therefore no copyright permissions are required.

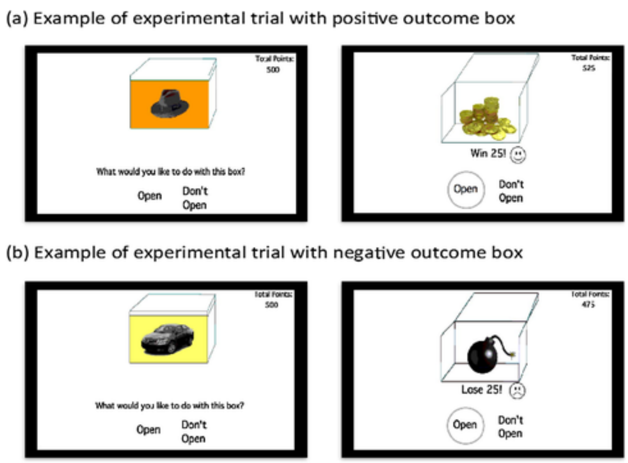

Fig. 2. Examples of experimental trials in which participants chose to (a) open a positive outcome box and (b) open a negative-outcome box. This Figure is being reproduced with the permission of the copyright holder Neuropsychology. *Reference of the original source:* Levy-Gigi, Szabo, Richter-Levin, and Kéri (2015). *Reduced hippocampal volume is associated with overgeneralization of negative context in individuals with PTSD. Neuropsychology 29(1), 151–161.*

(see Fig. 3). In the first phase, participants learn by trial and error to predict the outcome of four different boxes (i.e., open the two positive boxes and skip the two negative boxes). In this phase each box has a unique cue and context (e.g., a box with a hat on a blue background has gold coins inside it whereas a box with a car on a yellow background might have a bomb inside it). The outcome of each box is counterbalanced across participants. The acquisition phase contains a minimum of 40 trials. To complete the acquisition phase and move on to the retention and reversal phase, participants need to achieve 6 consecutive correct responses to the box-outcome associations task. Correct responses refer to conditions in which participants open positive boxes or leave negative boxes closed; incorrect responses refer to conditions in which participants open negative boxes or leave positive boxes closed. Once this has been accomplished, the retention and reversal

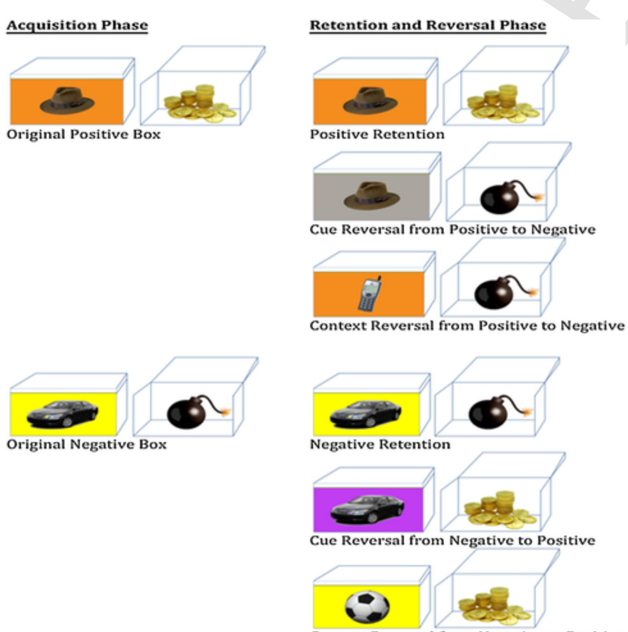

Fig. 3. Illustration of the different experimental conditions. This Figure is being reproduced with the permission of the copyright holder Neuropsychology. *Reference of the original source:* Levy-Gigi, Szabo, Richter-Levin, and Kéri (2015). *Reduced hippocampal volume is associated with overgeneralization of negative context in individuals with PTSD. Neuropsychology 29(1), 151–161.*

phase starts immediately without any signaled switch or delay. In this phase, retention trials are administered to the participants using both the original boxes and the same learned outcomes (e.g., a *hat* on an *orange* background has *gold* inside) in addition to two new types of boxes that share either **cue** (e.g., a *hat* on a gray background) or **context** (e.g., a phone on an *orange* background) with an original box (see Fig. 3). The new boxes are associated with the opposite outcome relative to the original boxes (i.e., if the box with the *hat* on the *orange* background has *gold* inside, then the boxes with the *hat* on a *gray* background and a *phone* on the *orange* background will have *bomb* inside and vice versa). Therefore, in order to successfully learn these new associations, participants need to reverse the association rule of either the original cue or the original context. Boxes in this phase are presented in 10 blocks of 12 boxes each (two boxes from each of the following conditions: positive/negative retention, positive/negative cue reversal, positive/ negative context reversal). Boxes in each block are intermixed and presented in a random order to ensure that there will be no more than two identical consecutive boxes. This is, in sum, a total of 120 trials; 20 trials per condition.

2.3.2. Clinical assessments

We used the Structured Clinical Interview for DSM-V (SCID-5-CT; First et al., 2015), a semi structured interview guide to exclude participants with any current DSM-V psychopathology including PTSD, and any history of psychiatric or neurological disorders, alcohol abuse or dependence. The participants completed the following self-report questionnaires in order to control for possible confounds: the revised version of the Beck Depression Inventory (BDI–II; Beck, Steer, Ball, & Ranieri, 1996), a 21-item instrument (Internal consistency $\alpha = 0.93$, in the current study $\alpha = 0.91$) that assesses symptoms of depression rates items occurrence over the past two weeks. Each item is measured on a scale from 0 to 3, with total scores ranging from 0 to 63; higher scores indicate greater levels of depression; the State-Trait Anxiety Inventory (STAI; Spielberger, Gorsuch, Lushene, Vagg, & Jacobs, 1983), a 40-item instrument (Internal consistency $\alpha = 0.90$, in the current study $\alpha = 0.91$) to assess respondents' state and trait levels of anxiety at the moment, in the recent past, or how they anticipate their feelings in a specific situation that is likely to be encountered in the future, or in hypothetical situations. Each item is rated on a 4-point scale, with scores range from 20 to 80; higher scores represent greater levels of trait anxiety; the Posttraumatic Stress Disorder Checklist-Civilian Version (PCL-5; Weathers, Litz, Huska, & Keane, 1994), a 20-item self-report questionnaire (Internal consistency $\alpha = 0.90$, in the current study $\alpha = 0.88$) that assesses the 20 DSM-5 symptoms of PTSD over the past month, using a 5-point scale ranging from 1 = "not at all" to 5 = "extremely" and the Traumatic Events questionnaire (Vrana & Lauterbach, 1994), an 11-item questionnaire (Internal consistency $\alpha = 0.91$, in the current study $\alpha = 0.86$) that includes nine specific types of potentially traumatic events to assess lifetime exposure, using a 7-point scale (1 = "not at all" to 7 = "extremely"). For each event, respondents are asked to provide the frequency, age at the time(s) of the event, degree of life-threat and how traumatizing it was at the time and is currently. Note that these questionnaires are commonly used to test levels of symptoms not only in clinical populations but also in sub-clinical populations and healthy individuals (e.g., Cipra & Müller-Hilke, 2019; Fang & Chung, 2019; Kim et al., 2019; Sa-Junior et al., 2019).

2.4. Analytic procedures

We used SPSS (version 25) software (SPSS Inc., Chicago, IL) to analyze the data. All data were checked for normality of distribution using Kolmogorov Smirnov tests. We applied a mixed-model ANOVA on the percentage of the correct responses to test group differences in the acquisition and retention trials as well as in the reversal trials. In addition, we utilized Pearson's correlations to test associations between generalization learning and clinical symptoms.

3. Results

3.1. Acquisition and retention of stimulus-outcome association

We conducted an Exposure (trauma vs. neutral stimuli) by Training (detail vs. context) by Phase (acquisition vs. retention) by Valence (positive vs. negative outcome) mixed model ANOVA on the percentage of correct responses. In this model, Exposure and Training were the between subjects factors, while Phase and Valence were the within-subject factors. The results are depicted in Fig. 4. As predicted, the ANOVA revealed no significant main effects of Exposure, $F(1, 78) = 0.69$, $p = .41$, or Training, $F(1, 78) = 0.06$, $p = .81$, and no significant interactions of Phase by Exposure or Training, nor Valence by Exposure or Training (All $ps > 0.1$). Finally, there was no significant interaction of Exposure by Phase by Valence, $F(1, 78) = 2.05$, $p = .16$. These results indicate that there were no significant differences in performance between acquisition and retention. In addition, they show that participants in all four groups were equally able to learn and retain positive and negative stimulus-outcome associations.

3.2. Cue and context reversal learning

We conducted an Exposure (trauma vs. neutral stimuli) by Training (detail vs. context) by Reversal Type (cue vs. context) by Reversal Valence (reversal from positive to negative vs. reversal from negative to positive) mixed model ANOVA on the percentage of correct responses. In this model, Exposure and Training were the between-subjects factor while Reversal Type and Reversal Valence were the within-subject factor. There were no significant main effects of Reversal Type and Training ($ps > 0.1$). However, we found significant main effects of Exposure, $F(1, 78) = 5.12$, $p = .03$, $\eta^2_p = .06$, and Reversal Valence, $F(1, 78) = 7.77$, $p = .01$, $\eta^2_p = .09$, as well as significant triple interaction of Exposure by Training by Reversal type, $F(1, 78) = 9.29$, $p = .003$, $\eta^2_p = .11$. Most importantly we found a quadrangular interaction of Exposure by Training, by Reversal Type by Reversal Valence, $F(1, 78) = 12.79$, $p = .001$, $\eta^2_p = .14$. In order to reveal the nature of this interaction we conducted a mixed model ANOVA in the two exposure conditions separately. In these models, Training was the between-subjects factor while Reversal Type and Reversal Valence were the within-subject factors. We found that participants who were exposed to neutral pictures performed equally well in all the experimental conditions (Fig. 5). Specifically, there were no significant main effects of Reversal Type, $F(1, 39) = 0.14$, $p = .71$, Reversal Valence, $F(1, 39) = 2.18$, $p = .15$, or Training, $F(1, 39) = 0.17$, $p = .68$, nor interaction between Reversal Type, Reversal Valence and Training, $F(1, 39) = 2.92$, $p = .10$. The results suggest that in conditions of no traumatic exposure, the participants are equally able to reverse cue and context stimulus-outcome associations from positive to negative and vice versa independent of the type of training.

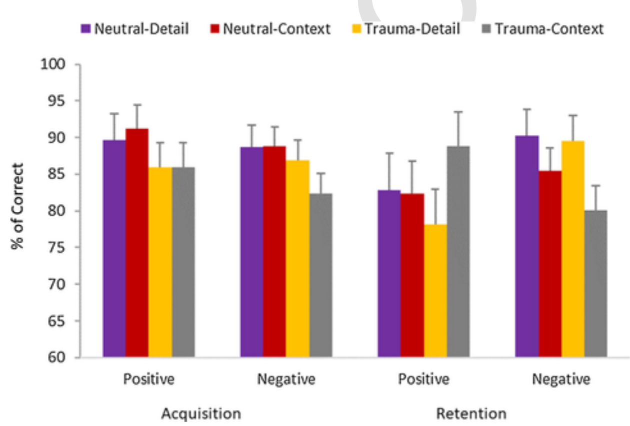

Fig. 4. Percentage of correct responses as a function of Exposure (trauma vs. neutral stimuli), Instructions (detail vs. context), Phase (acquisition vs. retention) and Valence (positive vs. negative outcome). *Error bars represent standard errors.*

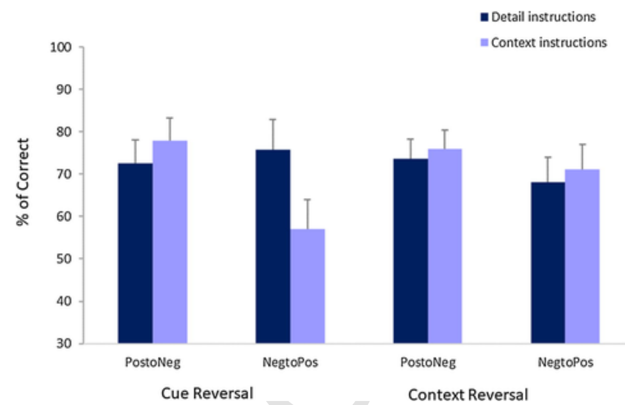

Fig. 5. Percentage of correct responses in the neutral exposure condition as a function of Instructions (detail vs. context), Reversal Type (cue vs. context), and Reversal Valence (positive to negative vs. negative to positive). *Error bars represent standard errors.*

On the other hand, participants who were exposed to traumatic pictures showed impaired performance as a function of the Training (Fig. 6). Specifically, while there were no significant main effects of Reversal Type, $F(1, 39) = 0.04$, $p = .85$ or Training, $F(1, 39) = 0.09$, $p = .77$, there was a significant main effect of Reversal Valence, $F(1, 39) = 6.52$, $p = .02$, $\eta^2_p = .14$. Most importantly, there was a significant interaction between Reversal Type, Reversal Valence and Training, $F(1,39) = 12.9$, $p = .001$, $\eta^2_p = .25$. To reveal the nature of this interaction, we conducted pairwise *t*-test comparisons of participants who received detail vs. context related training. The results revealed that participants who received detail-related training were significantly more impaired in negative to positive cue reversal trials, $t(39) = -2.38$, $p = .023$, $d = 0.7$, while participants who received context-related training were significantly more impaired in the negative to positive context reversal trials, $t(39) = 2.64$, $p = .012$, $d = 0.8$.

3.3. Clinical measures

Table 1 depicts the comparison of participants as a function of exposure on the Beck Depression Inventory-II (Beck et al., 1996), the State-Trait Anxiety Inventory (Spielberger et al., 1983), the Posttrau-

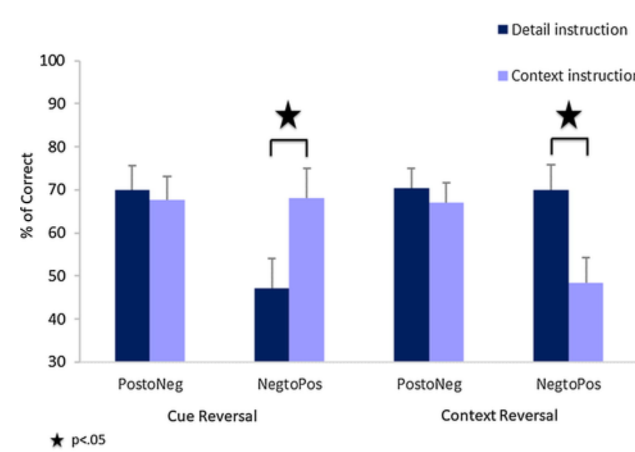

Fig. 6. Percentage of correct responses in the trauma exposure condition as a function of Instructions (detail vs. context), Reversal Type (cue vs. context), and Reversal Valence (positive to negative vs. negative to positive). Error bars represent standard errors.

matic Stress Disorder Checklist- Civilian Version (PCL-C; Weathers et al., 1994) and the Life Stressful Events questionnaire (Vrana & Lauterbach, 1994). As expected, there were no significant differences in levels of depression, anxiety and PTSD symptoms between the groups (all $ps > 0.15$). In accordance with past findings (e.g., Al-Bitar & Al-Ahmad, 2016; Hensley & Varela, 2008; Weems et al., 2007), there were significant correlations between PTSD symptoms and levels of trait symptoms of anxiety, $r(65) = 0.50$, $p = .000$. However, there were no significant correlations between PTSD symptoms and levels of state symptoms of anxiety, $r(65) = 0.05$, $p = .68$. Moreover, there were no significant correlations between generalization learning and levels of clinical symptoms. Finally, since there were both men and women in all experimental groups, we tested and found no significant differences as a function of gender in acquisition, retention and reversal learning, as well as no differences between men and women in the observed levels of clinical symptoms (all $ps > 0.1$). These correlations were not corrected for multiple-comparisons.

4. Discussion

4.1. Summary and theoretical implications

The aim of the current study was to test the interactive effect of exposure to traumatic images and type of training on generalization learning. As predicted, all participants were equally able to acquire and retain positive and negative stimulus- outcome associations independent of the nature of the exposure or type of training. These findings are in line with previous studies which showed intact associative learning in trauma-exposed individuals when using neutral images with positive or negative outcomes (e.g., Levy-Gigi & Richter-Levin, 2014; Levy-Gigi et al., 2014, 2015; Myers et al., 2003).

While there were no preliminary differences between the participants when entering the reversal stage, individuals who were exposed to traumatic images showed impaired generalization compared to those exposed to neutral images, suggesting that traumatic exposure has a price (Levy-Gigi & Richter-Levin, 2014; Levy-Gigi et al., 2014, 2015). Moreover, we found that impairments in generalization learning were selective to reversal conditions from negative to positive. Hence, while participants who viewed traumatic images were able to learn that previously positive associations had become negative, they struggled to obtain that negative associations had become positive. Such impairment may explain why, for example, a person who was exposed to an explosion in an anemone field may associate all anemone fields and every loud sound with a negative outcome and may therefore react with fear even in situations considered neutral and safe.

One possible explanation for these results may relate to the way individuals process aversive information (Acheson et al., 2012; Brewin, Gregory, Lipton, & Burgess, 2010; Lee, Rony, & Galia, 2018; Levy-Gigi et al., 2015). One central view in this field suggests that aversive events can be represented in one of two forms: conjunctive or elemental (for review see Rudy, Huff, & Matus-Amat, 2004; Rudy, 2009(. In the first form, a conjunctive representation of all the individual features present in the environment is encoded as a whole. Thus, a conditioned response would occur only in an environment with stimuli that fits the full representation (e.g., a loud noise in an anemone field in times of war). In the second form, elements present at the same time as the aversive event are encoded separately and become independently associated with it (e.g., a loud noise and an anemone field would both become independently associated with a negative outcome). Studies revealed that exposure to traumatic events may impair hippocampal- dependent processes and result in the domination of elemental representation strategy (Barrientos, O'Reilly, & Rudy, 2002; Iordanova, Burnett, Aggleton, Good, & Honey, 2009; Rudy & Matus-Amat, 2005). Accordingly, in the current study, individuals who were exposed to traumatic images may exhibit such domination. Hence, instead of perceiving each new box at the reversal phase as a distinct stimulus, the similar or shared features result in overgeneralization of the negative outcome and attributing it to the novel boxes (see also Levy-Gigi & Richter-Levin, 2014; Levy-Gigi et al., 2014, 2015).

Alternatively, the results may be explained due to memory encoding alterations caused by the exposure to traumatic images (e.g., Bisby & Burgess, 2014; Sauerhöfer et al., 2012; for review see Bisby & Burgess, 2017). Specifically, it was found that viewing traumatic images strengthens the encoding of negative items due to hyper activation of the amygdala, while disrupting the ability of the hippocampus to bind its associations with the surrounding context (Berkers, Klumpers, & Fernández, 2016; Bisby, Horner, Horlyck, & Burgess, 2016; Ritchey, LaBar, & Cabeza, 2011). In the current study, it is possible that individuals who were exposed to traumatic images created stronger stimulus-outcome associations when acquiring the negative boxes. These strong associations did not interfere with acquiring other distinct positive associations (possibly since the acquisition phase was relatively simple, containing only four stimulus-outcome associations). However, it might have interfered with reversal learning from negative to positive, making it difficult to learn that new boxes that only share some features with negative boxes, have actually a positive outcome.

Most importantly, as predicted, different types of training resulted in different selective generalization impairments. Specifically, individuals who were trained to refer to the general context showed a selective overgeneralization of negative contexts. Hence, they struggled to learn that a previously negative context was later associated with a positive outcome. On the other hand, individuals who were trained to refer to specific cues displayed a selective overgeneralization of negative cues. Hence, they could not learn that a previously negative cue was later associated with a positive outcome. These results may have important practical implications, suggesting that training for specific tasks can become a liability in and of itself. Accordingly, selective overgeneralization of negative contexts among firefighters could be attributed to their focused training to regard the general environment. This improved contextual awareness, crucial while facing potential traumatic events, may result in an impaired ability to reverse negative contextual associations. Similarly, the selective impairment in generalization of negative cues in CSI police may stem from their training to regard to specific details when arriving to a crime scene. These results may suggest that while specialized training is highly important for adequate performance and survival in emergency situations (e.g., scanning the scene for gas balloons that may explode), it can make individuals sensitive in precisely the areas in which they were most highly trained.

The study highlights the need for improving training and developing a focused intervention method to prevent and treat the deleterious effects of traumatic exposure. Such intervention should aim to teach individuals not only how to react in certain conditions, but also how to flexibly modify their reactions in accordance with changing situational demands (Buitenweg, Van De Ven, Prinssen, Murre, & Ridderinkhof; Olfers & Band, 2018; Van De Ven et al., 2017). One way to do it is by including a feedback-based trials during the reversal phase of a partial reversal learning paradigm. Such trials would train individuals to recognize that a given stimulus can be associated with either positive or negative outcomes. This would help refine the awareness of the distinction between old and novel conditions and the possibility that, despite some similarities, such conditions may have different outcomes. Ultimately, this intervention would improve individuals' generalization learning and may help them becoming more skilled at adapting to and coping with traumatic situations.

4.2. Limitations and future directions

Although highly important, the current study suffers from several limitations. First, while neuroimaging studies support the associations between reduced hippocampal volume and impaired generalization learning (Bonne et al., 2008; Cisler et al., 2014; Flor & Nees, 2014; for meta-analysis see Kühn & Gallinat, 2013; see Levy-Gigi et al., 2015 for a neuroimaging study using the same paradigm), future neuroimaging studies may aim to explore whether there are differences in brain function and structure between trauma-exposed individuals who receive different training. Second, it is possible that other variables that are linked with both training and performance may explain the current results. One possible example is cognitive style. Cognitive style refers to the way in which individuals tend to process and organize information, which often ranges between two extremes: wholistic and analytic (Nitzan-Tamar, Kramarski, & Vakil, 2016). Thus, individuals with wholistic cognitive styles, who are more capable of responding to stimuli in the general environment, may have greater context awareness but may also suffer an impaired ability to reverse the outcome of negative contextual associations. In a similar way, individuals with analytic cognitive styles are more likely to pay attention to details and detect possible cues, but may also suffer an impairment in reversing the outcomes of negative cues. Hence, it is possible that cognitive style both affects job selection and is developed through specific training and experience. Future studies may aim to test the relationship between cognitive style and specific impairments after exposure to neutral or traumatic incidents.

Another point of consideration relates to the laboratory nature of the study. The current study exposed individuals to aversive images in the lab. Such manipulation does not entirely represent real-life trauma exposure. However, studies have shown that not only real-life traumatic exposure, but also controlled exposure in a lab setting may influence the way individuals perceive and process information (for review see James et al., 2016; Lau-Zhu et al., 2018). For instance, it was found that healthy participants who viewed traumatic film footage of death and injury or trauma-related pictures showed flashbacks and traumatic memories (Elsesser, Sartory, & Tackenberg, 2004; Holmes, James, Kilford, & Deeprose, 2010; Okon-Singer, Tzelgov, & Henik, 2007; Okon-Singer et al., 2014; for review see Weber, 2008). Importantly, to our knowledge, this is the first study to demonstrate the effects of in-vitro trauma exposure and training on generalization learning. Future studies may aim to test the effects of training on different first responders, while extending them beyond the limits of a specific task, and testing how long they may last. Moreover, while the training was designed to capture the core characteristics of different professions (i.e., firefighters vs. CSI police), it is not likely to encompass the varied components that differentiate real-life training. Future studies may aim to extend the training to include more real-life characteristics. Finally, while the current study serves as a first step towards understanding the relationship between training and impairments, future studies, especially if conducted in a lab setting, may aim to increase the number of participants to better account for possible individual differences.

4.3. Conclusions

To summarize, the present study highlights the interactive effect of exposure and different types of training on generalization learning. Awareness to this relationship is significant in the context of trauma recovery and mental-health. Specifically, impaired generalization learning may severely affect the way trauma-exposed individuals interpret and react to various aspects of their environments and, hence, disrupt or impede their daily life functioning. The study suggests that improving professional training and developing a focused intervention to improve generalization learning may promote and optimize the ways in which individuals cope with traumatic situations.

Author contributions

ELG developed the study concept and study design. SHN supervised the testing and data collection. Both authors conducted the data analysis and interpretation and drafted the manuscript.

Uncited references

Levy-Gigi et al. (2011), Rudy et al. (2002) and Wechsler (1997).

Declaration of Competing Interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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