Contents lists available at ScienceDirect

Behaviour Research and Therapy

journal homepage: www.elsevier.com/locate/brat

Leaving the door open: Trauma, updating, and the development of PTSD symptoms

Marie R. Sopp[a,b,1], Shilat Haim-Nachum[b,1], Benedikt E. Wirth[a], George A. Bonanno[c], Einat Levy-Gigi[a,d,*]

[a] Faculty of Education, Bar-Ilan University, Ramat-Gan, Israel
[b] Department of Psychology, Saarland University, Saarbrücken, Germany
[c] Department of Counseling and Clinical Psychology, Teachers College, Columbia University, USA
[d] The Gonda Multidisciplinary Brain Research Center, Bar-Ilan University, Ramat-Gan, Israel

ARTICLE INFO

Keywords:
Trauma exposure
Updating
Predictive processing
PTSD symptoms
High-risk occupations
Firefighters

ABSTRACT

Humans try to make sense of the world using hypotheses that were formed by prior experiences. After trauma, these hypotheses can be exaggerated and resistant to change. This may result in difficulties to update expectations regarding the negative outcomes associated with traumatic stimuli. Critically, it has been proposed that such difficulties may drive the development of posttraumatic stress disorder (PTSD). However, direct evidence on the associations between trauma and impaired expectation updating is still absent. Moreover, it remains unclear whether such an impairment is correlated with PTSD symptoms. To address these gaps, we compared the ability to update traumatic and neutral stimulus-outcome expectations in 81 active-duty firefighters. Participants completed a performance-based updating task and were assessed for PTSD symptoms. We predicted and found a selective impairment in updating trauma-related expectations. This impairment was evident for negative-to-positive but not for positive-to-negative updating. Moreover, impaired negative-to-positive updating was positively associated with PTSD symptoms. These findings support the predictive processing account of PTSD and suggest that strengthening updating processes could be an important goal for promoting resilience after trauma.

Although many individuals experience potential traumatic events during their lifetime (Kessler et al., 2017), some settings – such as the work environment of first responders (e.g., firefighters, medical personnel, police officers) – inevitably result in high trauma exposure (Kim et al., 2019; Patterson, 2001; Teoh, Lima, Vasconcelos, Nascimento, & Cox, 2019). Critically, first responders are not just exposed to potential trauma once but repeatedly (Geronazzo-Alman et al., 2017), which makes them an ideal population for testing the effects of traumatic exposure as well as possible mechanisms that may account for the development of posttraumatic stress disorder (PTSD).

Cognitive models propose that learning processes during trauma may play a key role in PTSD symptom development (for reviews, see Ehlers & Clark, 2000; Liberzon & Abelson, 2016). Taking a broader perspective, recent accounts have focused on the role of predictive processing (Linson & Friston, 2019; Kube, Berg, Kleim, & Herzog, 2020; Radell, Myers, Sheynin, & Moustafa, 2017; Wilkinson et al., 2017). According to predictive processing frameworks, humans process sensory input using hypotheses that are based on prior experiences. These prior hypotheses are – in turn – continuously updated by new sensory input. That is, updating is initiated when a mismatch between prediction and actual sensory input occurs, which is referred to as *prediction error*. However, the likelihood that a prediction error will result in updating depends on the quality of the sensory input. That is, updating is only initiated if the certainty of the sensory information outweighs the confidence (i.e., precision) in the prior hypothesis (also referred to as prior). Thus, if a prior has a very high perceived precision, it can override disconfirmatory information from new sensory input and become highly resistant to change.

Due to the life-threatening nature of traumatic events, trauma-related hypotheses predicting danger are assigned a very high precision (Kube et al., 2020). As a result, subsequent non-threatening sensory input may fail to update these hypotheses. According to the predictive processing framework proposed by Kube et al. (2020), this failure may be especially pronounced for new contextual input that trauma-exposed

* Corresponding author. Faculty of Education, Bar-Ilan University, Ramat-Gan, Israel.
E-mail address: einat.levy-gigi@biu.ac.il (E. Levy-Gigi).
[1] These authors contributed equally to this work.

https://doi.org/10.1016/j.brat.2022.104098
Received 29 August 2021; Received in revised form 9 February 2022; Accepted 8 April 2022

individuals face in their harmless posttrauma environment (Garfinkel et al., 2014). Consequently, trauma-related hypotheses predicting danger become resistant to change and are continuously activated in the everyday life of trauma-exposed individuals. By constantly predicting danger in the everyday environment, these hypotheses are believed to promote a sense of continuous threat, which is assumed to facilitate the development of PTSD symptoms. Specifically, the failure to use disconfirmatory contextual information (indicating a harmless environment) for updating is considered critical for PTSD symptom development, since such failure is assumed to decrease the precision of incoming sensory input, giving rise to vivid re-experiencing of trauma in the form of intrusive trauma memories (Kube et al., 2020). This assumption is also supported by other accounts focusing on the role of predictive processing in PTSD, although Wilkinson et al. (2017) propose that the link between predictive processing biased towards trauma-related hypotheses and intrusive re-experiencing may be stronger after Type I Trauma than after Type II Trauma.[2] In addition, they highlight secondary effects of intrusive re-experiencing on interoceptive affective states, which themselves require an explanation and – as a result – further support the selection of trauma-related hypotheses. The repeated selection of trauma-related hypotheses is assumed to maintain rigid behavioral patterns and reduce the overall tendency to explore new behaviors, resulting in avoidance behaviors (Radell, Myers, et al., 2017). Such behavioral patterns – in turn – may lead to biased sampling of the world, further reducing the likelihood that trauma-related hypotheses will be revised (Linson & Friston, 2019).

Although predictive processing frameworks provide a consistent and timely account of how PTSD symptoms may emerge after trauma exposure, empirical research testing their assumptions is scarce. Initial evidence supports the framework of Kube et al. (2020) by showing that posttraumatic expectations – assessed by means of a self-report questionnaire – are correlated with PTSD symptoms (Herzog, Kaiser, Rief, Brakemeier, & Kube, 2021) and that negative expectations about intrusive memories are associated with a higher frequency of intrusions (Herzog, Barth, Rief, Brakemeier, & Kube, 2021). However, a comprehensive test of the underlying assumptions of the predictive processing framework (Kube et al., 2020) is still outstanding. The current study aimed to provide such a test. Specifically, the study aimed to test whether updating of stimulus-outcome expectations is reduced for traumatic – as compared to neutral – content. Moreover, it sought to test whether reductions are stronger for contextual than for central stimulus features. Finally, the study aimed to investigate whether reduced updating – especially for contextual stimulus features – is linked to PTSD symptoms.

The first aim was based on the assumption of the predictive processing framework that danger-related hypotheses formed during traumatic events are more resistant to change than hypotheses formed during neutral events. In support of this assumption, Haim-Nachum and Levy-Gigi (2019) found that exposure to traumatic as compared to neutral images impaired updating in a subsequent task. In this study, participants were exposed to traumatic or neutral images and then completed an updating task. In the first phase of the task, neutral stimuli were associated with a negative (i.e., loss) or positive (i.e., gain) outcome. Following successful acquisition, the associations were reversed and participants needed to update stimulus-outcome associations from positive to negative (i.e., a stimulus associated with gain was now associated with loss) or from negative to positive (i.e., a stimulus associated with loss was now associated with gain). Results revealed that participants who had been exposed to traumatic images prior to the task showed reduced updating. This impairment was selective to conditions of negative-to-positive updating, whereas positive-to-negative updating remained intact. A similar pattern was also observed in individuals with repeated trauma exposure as compared to unexposed controls (Levy-Gigi & Richter-Levin, 2014; Levy-Gigi, Richter-Levin, & Kéri, 2014; Weiss, Levy-Gigi, Adelson, & Peles, 2019). This may suggest a difficulty in learning that stimuli previously predictive of danger are now associated with safety. However, it remains to be shown that traumatic – as compared to neutral – content directly reduces negative-to-positive updating. To test this hypothesis, we assessed updating simultaneously for neutral and traumatic content by directly embedding this different content into the same updating task. Moreover, we used traumatic content that was linked to real-life traumatic events experienced by our sample, which was comprised of professional firefighters. We predicted that traumatic as compared to neutral content would impair updating and that this impairment would be particularly evident in conditions of negative-to-positive updating.

The second aim of the study was based on the assumption of the predictive processing framework that the extent to which trauma-related hypotheses are resistant to updating should be directly linked to PTSD symptoms. That is, trauma-exposed individuals with greater resistance to updating of trauma-related hypotheses should show more severe PTSD symptoms than those with lower resistance. Relatedly, previous studies demonstrate that individuals with repeated trauma exposure experience more PTSD symptoms if they show rigid rather than flexible regulation; that is, if they stick to a limited set of cognitive, emotional, and behavioral strategies rather than efficiently switching between strategies based on contextual demands (Levy-Gigi et al., 2016; Rodin et al., 2017). However, in the context of updating processes, it remains to be examined whether impaired negative-to-positive updating of traumatic content correlates with PTSD symptoms. Correspondingly, we hypothesized to find a significant association between impaired negative-to-positive updating for traumatic content and PTSD symptom severity.

Finally, tying together both aims, the predictive processing account posits that trauma-exposed individuals particularly struggle to use contextual information to update trauma-related hypotheses and that this specific deficit in context updating is linked to PTSD symptoms. To investigate such effects, we used an updating task that differentiates between updating target (presented at central vision) and contextual (presented peripherally) stimulus features, enabling the independent assessment of both target and context updating. Previous studies using this task with neutral stimulus-outcome associations revealed selective impairments in context updating in trauma-exposed individuals (Haim-Nachum & Levy-Gigi, 2021; Levy-Gigi, Szabo, Richter-Levin, & Kéri, 2015; Levy-Gigi & Richter-Levin, 2014; Zabag, Deri, Gilboa-Schechtman, Richter-Levin, & Levy-Gigi, 2020). However, no specific associations were found between this updating deficit and levels of PTSD symptoms (Levy-Gigi et al., 2015; Levy-Gigi & Richter-Levin, 2014). Here, we tested whether using traumatic content would lead to similar impairments in negative-to-positive context updating and whether this selective impairment would correlate with PTSD symptoms.

In sum, we examined the ability to update hypotheses regarding gains and losses formed in relation to neutral images and images relating to occupational trauma. We expected to find that traumatic images would reduce updating performance and that this would be selectively evident for negative-to-positive context updating. Moreover, we expected to find that this trauma-related deficit in negative-to-positive context updating would be selectively linked to PTSD symptoms. When examining associations between updating and PTSD symptoms we aimed to exclude potential confounding effects by including intelligence, depressive symptoms, and adverse life events as covariates.

[2] The authors propose that the life-threatening significance of singular (Type I) trauma results in the nervous system continuously reselecting trauma-related hypotheses in order not to overlook potentially threatening situations, resulting in the emergence of intrusive memories. The repetitive and prolonged nature of Type II trauma, on the other hand, is assumed to result in a generalized impression that the world is not a safe place, therefore giving rise to a general bias toward threatening hypotheses, rather than the reliving of a highly specific and rich hypothesis related to trauma.

Lower intelligence has been shown to correlate with more PTSD symptoms (Breslau, Chen, & Luo, 2013; Sopp et al., 2021) and is often controlled for in the context of updating tasks such as the current one (Leeson et al., 2009). Depressive symptoms and adversity are similarly found to be related to PTSD symptoms and have been linked to updating performance (Haim-Nachum & Levy-Gigi, 2021; Haim-Nachum, Sopp, Bonanno, & Levy-Gigi, 2021).

1. Methods

1.1. Participants

Eighty-two Israeli male firefighters participated in the study. Sample size was based on the detection of medium-sized associations ($r = 0.30$; two-sided)[3] between updating and PTSD symptoms with a power of 0.80, using G*Power software (Faul, Erdfelder, Lang, & Buchner, 2007). The study was not preregistered. One participant was discarded because he did not reach the required acquisition criterion (i.e., six consecutive correct responses during acquisition; see 2.2.1 for details). Hence, the final analysis sample comprised 81 participants ($M_{age} = 29.02$, $SD_{age} = 4.99$). All participants had completed military service, with 40 participants indicating that they had been involved in combat and experienced military-related events. These include, for example, rocket and grenade attacks, suicide bombings, gun violence, and anti-tank missiles.

Participants were recruited while taking part in a basic training course. Assessment took place after they had completed the 8-month course. During this time, they were involved in active service, which had included exposure to traumatic events (for an overview of events that this population regularly experiences see Levy-Gigi et al., 2016). A team of researchers introduced all participating firefighters to the study objectives and procedures. Those volunteering to participate were asked to provide written informed consent and completed the updating task as well as several self-report questionnaires. Potential participants were excluded if they reported a current or past diagnosis of Axis I disorders other than PTSD, suicidal ideation, substance abuse within the past month, or neurological injuries (e.g., concussion, loss of consciousness for over 10 min) or diseases (e.g., epilepsy, multiple sclerosis, stroke, or encephalitis). Study eligibility was assessed during a phone interview conducted by doctoral and postdoctoral level clinical psychologists. Axis I disorders were assessed using the Structured Clinical Interview for the Diagnostic and Statistical Manual for Mental Disorders–Fourth Edition Axis I Disorders (First, Spitzer, Gibbon, & Williams, 1996). Neurological issues and suicidal ideation were assessed using semi-structured questions that were designed for the purpose of the study. All study procedures were approved by the local ethics committees (Reference #65).

1.2. Measures

1.2.1. Assessment of updating for traumatic and neutral content

Updating for traumatic and neutral content was assessed using a novel task, which was based on a validated reversal learning task using neutral stimuli (Haim-Nachum & Levy-Gigi, 2019, 2021; Levy-Gigi et al., 2014, 2015; Levy-Gigi & Richter-Levin, 2014; Zabag et al., 2020). During the acquisition phase, participants see the front view of a wall with a door (see Fig. 1). The wall serves as the context and displays either a neutral or traumatic image. Traumatic images were selected to resemble traumatic scenes that first responders may witness in their work environment, while neutral images were similar in scene composition (e.g. similar number of people) but displayed a neutral event. The door is white and contains a symbol that is prominently displayed in the center, serving as the target. After the presentation of each door, participants are asked whether they wish to open the door or not. After opening the door, participants either receive a reward or lose a portion of their previous rewards. Thus, participants learn by trial and error to predict the outcome of each door according to its surrounding wall and symbol. Participants see a total of four doors during this phase. Two doors are surrounded by neutral images and two doors are surrounded by traumatic images. One door of each stimulus category is associated with a positive outcome (gain) whereas the other one is associated with a negative outcome (loss). Outcomes of individual doors are counterbalanced across participants. To complete the acquisition phase and move on to the retention and updating phase, participants need to reach a criterion of six consecutive trials with correctly predicted outcomes within a minimum of 40 trials. Correct predictions are reflected in opening doors that are associated with positive outcomes and not opening those that are associated with negative outcomes. Participants who do not reach this criterion have a chance to complete a maximum of 16 cycles of 8 trials each. If they reach the criterion after one cycle, they move on to the retention and updating phase. If they do not reach the criterion in all 16 cycles, the experiment is terminated prematurely.

After successful completion of the acquisition phase, participants enter the retention and updating phase. In this phase, participants see the original doors (associated with either positive or negative outcomes) as well as new doors. New doors share either the context or target of the original doors but are associated with the opposite outcome. During context updating trials, the same background picture is presented with a new symbol. During target updating trials, the same symbol is presented with a new background picture. Thus, successful responding to new doors requires updating the association rule of either the original target or the original context from positive to negative or from negative to positive. The entire retention and updating phase consists of 120 trials (10 trials per condition). Trials are presented blockwise (one block consisting of one trial per condition) with a random order of trials within blocks. Performance is quantified by calculating accuracy rates for each condition. Reaction times were also recorded. However, since a substantial number of participants had an accuracy rate of zero in at least one experimental condition, reaction times were not used in the main analyses.

1.3. Assessment of PTSD symptoms

The PTSD Checklist for DSM-IV (PCL) was used to assess PTSD symptoms during the past month in accordance with DSM symptom criteria (Weathers, Litz, Herman, Huska, & Keane, 1993). Due to the timing of the study, symptoms were assessed using the version based on DSM-IV criteria for PTSD. The proposed clinical cut-off for a likely diagnosis of PTSD on this version is 50 (McDonald & Calhoun, 2010; Weathers, Litz, 1993). The questionnaire comprises 17 items, which are rated on a scale ranging from 1 (= not at all) to 5 (= extremely). Reliability and validity of the original measure are good and internal consistency is high (Blanchard, Jones-Alexander, Buckley, & Forneris, 1996). Internal consistency in the current sample was also high ($\alpha = 0.86$). The total score across symptom domains was used for the current analyses. The PCL score can range between 17 and 85. Scores in the current sample ranged from 17 to 35 ($M = 19.83$, $SD = 3.59$). Since PCL scores were non-normally (right-skewed) distributed, they were log-transformed to approximate normality. Transformed scores were used for all analyses.

1.4. Assessment of covariates

Exposure to adverse life events was assessed using a 10-item checklist developed by ELG. The checklist includes common adverse events such

[3] Effect size estimation was based on a previous study, suggesting that the correlation between negative-to-positive context updating and PTSD symptoms may amount to $r = 0.39$ (Levy-Gigi et al., 2015). Given that the sample in Levy-Gigi et al. (2015) consisted of clinically diagnosed patients, the effect size was corrected to $r = 0.30$ for the current sample.

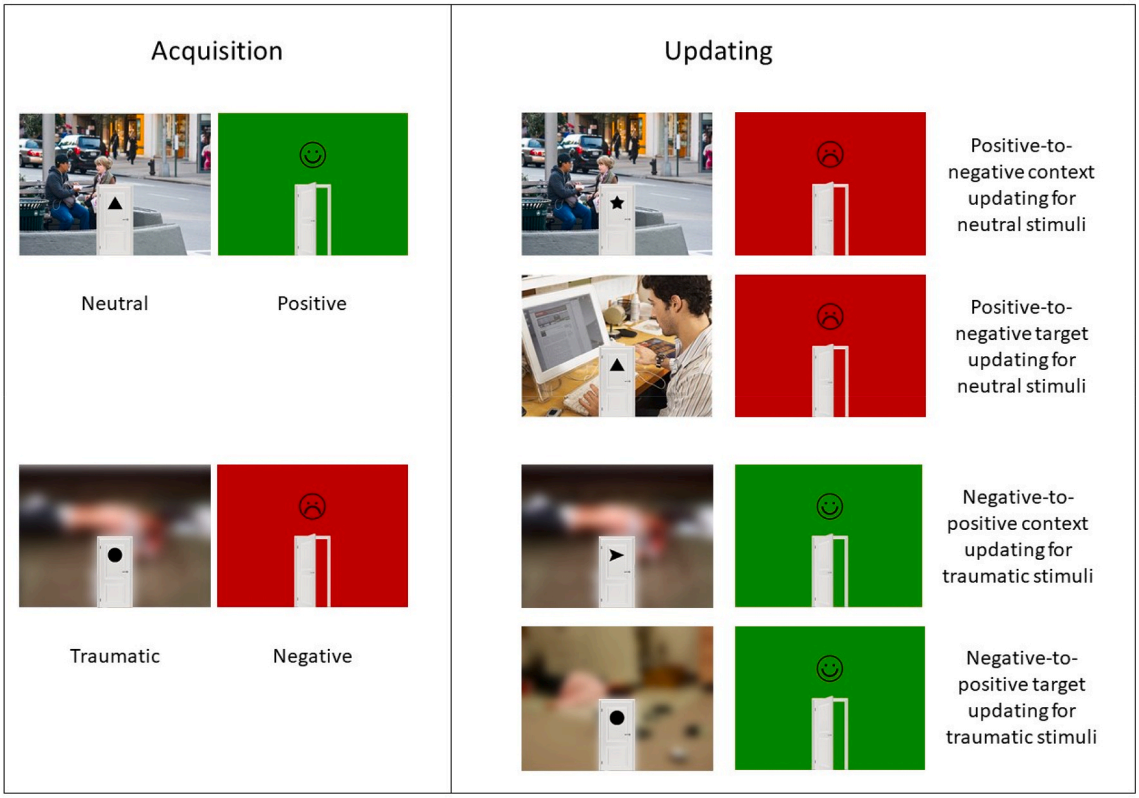

Fig. 1. Illustration of the updating task. Traumatic pictures are blurred due to sensitive content.

as death of a parent/sibling, chronic illness in the family, severe economic difficulties, and domestic violence. Participants were asked to indicate whether the event happened to them (Yes/No/I do not remember) and whether it happened during childhood (age <10), adolescence (18 > age >10), and/or adulthood (age >18). As such, the scale allows the assessment of adverse and potentially traumatic events in relation to different developmental phases. A sum score of experienced events was computed separately for each life period for further analyses. Participants reported a range of 0–3 experiences during childhood ($M = 0.43$, $SD = 0.74$), 0 to 3 experiences during adolescence ($M = 0.56$, $SD = 0.76$), and 0 to 8 experiences during adulthood ($M = 1.65$, $SD = 1.83$).

Depression was assessed using the Beck Depression Inventory (BDI-II) developed by Beck, Steer, and Brown (1996). High reliability and validity of the scale have been established by previous research (Whisman, Perez, & Ramel, 2000; for review, see; Wang & Gorenstein, 2013). Internal consistency in the current sample was high ($\alpha = 0.88$). 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 sum score of all items was used for the current analyses. BDI scores ranged from 0 to 19 in the current sample ($M = 3.10$, $SD = 4.47$).

Verbal intelligence was assessed using the Wechsler Adult Intelligence Scale–III (WAIS-III) Vocabulary subtest (Wechsler, 1997). The verbal intelligence test requires participants to try to define up to 30 words. The reliability and validity of the test have been extensively documented and also extend to clinical populations (Ryan & Rosenberg, 1984). Scores ranged from 6 to 15 in the current sample ($M = 9.90$, $SD = 2.16$).

1.5. Data analysis

Data analysis was performed using IBM SPSS Statistics for Windows, version 25.0 (SPSS Inc., Chicago, IL). The α-level was set to 0.05 for all analyses. Our first set of analyses investigated the impact of traumatic content on updating. We conducted an ANOVA including the factors Stimulus Type (trauma vs. neutral), Valence (negative-to-positive vs. positive-to-negative reversal), and Updating Type (target vs. context). Significant interaction effects were followed up by conducting independent *t*-tests. Partial η^2 and Cohen's *d* were calculated to illustrate effect sizes.

Our second set of analyses aimed to investigate the association between negative-to-positive context updating and PTSD symptoms. To this end, we conducted hierarchical linear regression analyses. In a first step, all control variables (Exposure to adverse life events, depression, and verbal intelligence) and acquisition performance were simultaneously entered into the model to account for any variance explained by these variables. In a second step, negative-to-positive updating was entered as a predictor. Analyses were conducted separately for neutral and traumatic content.

If the model including negative-to-positive updating as predictor yielded a significant improvement of model prediction, we conducted a separate analysis entering both context and target updating as independent predictors to examine incremental validity. Finally, to address potential speed-accuracy trade-offs, we conducted sub-analyses in the subsample of participants with accuracy levels >0, introducing reaction times for context and target updating as independent variables prior to entering accuracy rates for context and target updating.

In order to test the selectivity of found effects, analyses were repeated for positive-to-negative updating (see Supplementary file A for details). Unstandardized regression coefficients with confidence intervals as well as overall model tests are reported. Effect sizes are illustrated in terms of the amount of variance accounted for by each model (R^2 and adjusted R^2), standardized regression weights, and Cohen's f^2 (Selya, Rose, Dierker, Hedeker, & Mermelstein, 2012).

2. Results

2.1. Impact of traumatic vs. neutral content on updating

An ANOVA including the factors Stimulus Type (neutral vs. traumatic), Valence (positive-to-negative vs. negative-to-positive reversal), and Updating Type (target vs. context updating) and accuracy rates as dependent variable revealed a significant main effect of Updating Type, $F(1,80) = 15.80, p < .001, \eta_p^2 = 0.17$, reflecting higher accuracy rates for context as opposed to target updating, $t(80) = 3.97, p < .001, d = 0.66$. The effect size was in the medium-to-large range (Cohen, 1988). In addition, a significant interaction between Stimulus Type and Valence emerged, $F(1,80) = 10.48$, $p = .002$, $\eta_p^2 = 0.12$ (see Fig. 2). For negative-to-positive updating, lower accuracy rates were evident for traumatic as compared to neutral stimuli, $t(80) = 2.89$, $p = .005$, $d = 0.34$. The effect size was in the small-to-medium range (Cohen, 1988). Conversely, no differences were evident for positive-to-negative updating, $t(80) = 1.76, p = .083, d = 0.19$. Finally, a significant interaction between Stimulus Type and Updating Type, $F(1,80) = 4.32$, $p = .041$, $\eta_p^2 = 0.05$ emerged (see Fig. 3). Follow-up analyses revealed that accuracy rates were lower for traumatic than for neutral target updating, $t(80) = 2.13, p = .036, d = 0.25$. The effect size was in the small range (Cohen, 1988). By contrast, no significant difference emerged for context updating, $t(80) = 0.60, p = .553, d = 0.07$. None of the other main or interaction effects reached significance ($p > .280$). In summary, our analyses indicate that traumatic content selectively weakened negative-to-positive rather than positive-to-negative updating and target rather than context updating.

2.2. Associations between updating and PTSD symptoms

Bivariate correlations between updating, PTSD symptoms, and covariates are presented in Table 1. In order to assess associations between updating and PTSD symptoms while controlling for acquisition performance, depression, verbal intelligence, and exposure to adverse life events, we conducted a series of hierarchical regression analyses (see Tables 2 and 3). Including negative-to-positive updating for traumatic content as independent variable resulted in a significant small improvement in prediction as compared to the baseline model, $\Delta R^2 = 0.05, F(1,72) = 5.56, p = .021, f^2 = 0.08$. That is, greater negative-to-positive updating for traumatic stimuli was associated with fewer PTSD symptoms (see Table 2). The strength of this association ($\beta = -0.23$) was in the medium range (Acock, 2014). Introducing negative-to-positive updating for neutral content as independent variable did not significantly improve prediction of PTSD symptoms as compared to the baseline model, $\Delta R^2 = 0.02, F(1,72) = 2.31, p = .133$, $f^2 = 0.03$ (see Table 3). Similarly, positive-to-negative updating for neutral and traumatic content did not significantly improve prediction (all $ps > .491$; see Supplementary file A).

In order to assess whether the association between negative-to-positive updating for traumatic content and PTSD symptoms is stronger for target or context updating, we simultaneously introduced negative-to-positive target and context updating into the baseline model. The analysis yielded a significant small improvement in prediction, $\Delta R^2 = 0.06, F(2,71) = 3.81, p = .027, f^2 = 0.11$. Inspection of individual regression weights revealed that reduced target updating predicted PTSD symptoms whereas reduced context updating did not (see Table 2). The strength of this association ($\beta = -0.26$) was again in the medium range (Acock, 2014). Finally, to address potential speed-accuracy trade-offs, we repeated this analysis in the subsample of participants whose accuracy rate exceeded zero for negative-to-positive target and context updating. In this analysis, reaction times for correct negative-to-positive target and context updating trials were entered as additional predictors prior to the entry of accuracy rates of updating trials. In line with the previous analysis, entering accuracy rates for negative-to-positive target and context updating resulted in a significant medium-sized improvement in prediction, $\Delta R^2 = 0.04, F(2,39) = 4.52$, $p = .017$, $f^2 = 0.23$. Moreover, inspection of individual regression weights confirmed that reduced target – but not context – updating predicted PTSD symptoms (see Supplementary File A). The strength of this association ($\beta = -0.33$) was in the medium range (Acock, 2014).

3. Discussion

The current study investigated whether traumatic – as compared to neutral – content impairs updating and whether this impairment correlates with PTSD symptoms in a sample of active-duty firefighters. In line with the predictive processing framework, we postulated and found that traumatic – as compared to neutral content – impaired updating. This effect was only evident for negative-to-positive updating and not for positive-to-negative updating. Moreover, we found that impaired negative-to-positive updating was associated with PTSD symptoms of

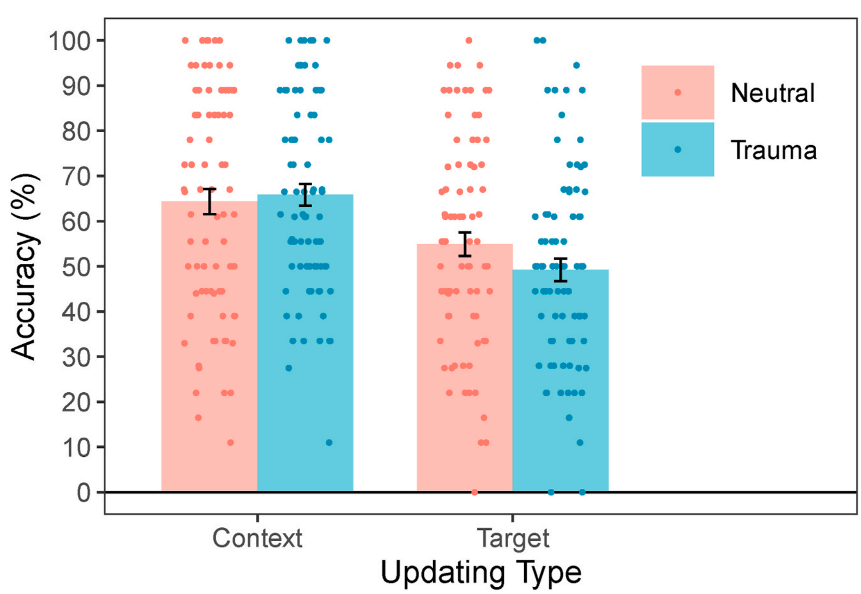

Fig. 2. Illustration of the interaction between Updating Type and Stimulus Type. Error bars depict ±1 SEM (standard error of the mean). Points represent individual participants. The graphs were made using the ggplot2 library (Wickham, 2016) for R (R Core Team, 2019).

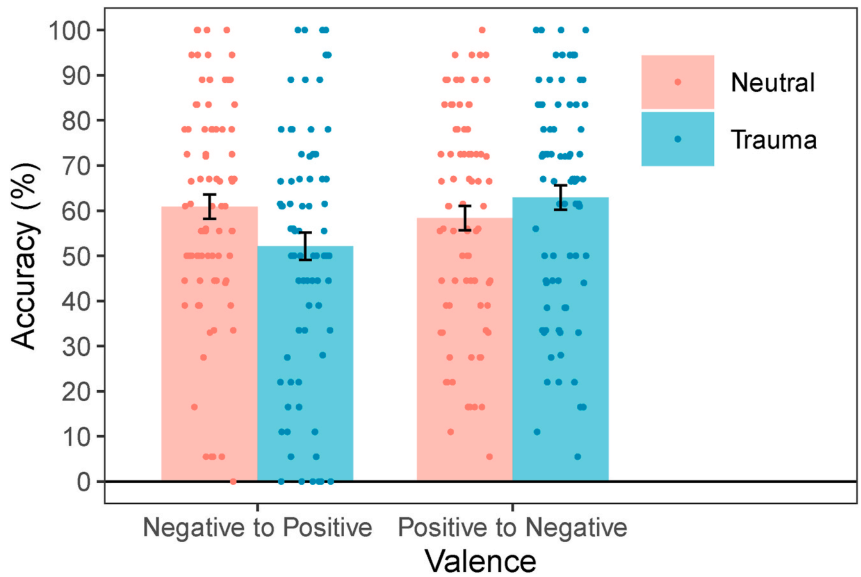

Fig. 3. Illustration of the interaction between Valence and Stimulus Type. Error bars depict ±1 SEM (standard error of the mean). Points represent individual participants. The graphs were made using the ggplot2 library (Wickham, 2016) for R (R Core Team, 2019).

Table 1
Bivariate associations between updating, PTSD symptoms, and covariates.

Measures	1	2	3	4	5	6	7	8	9	10	11	12
1. N-to-P trauma ACC	–	.45**	.78**	.73**	.22*	.41**	-.23*	-.09	.16	.00	-.15	.07
2. N-to-P neutral ACC	–	–	.51**	.16	.71**	.65**	-.11	.03	.11	.10	.03	.05
3. N-to-P Target – trauma ACC	–	–	–	.14	.51**	.17	-.23*	-.19	.12	-.05	-.10	.02
4. N-to-P Context – trauma ACC	–	–	–	–	-.21	.45**	-.11	.07	.13	.06	-.12	.08
5. N-to-P Target – neutral ACC	–	–	–	–	–	-.07	-.08	-.04	.19	.16	.05	-.07
6. N-to-P Context – neutral ACC	–	–	–	–	–	–	-.07	.08	-.05	-.03	-.01	.15
7. PCL-5	–	–	–	–	–	–	–	.04	.08	.04	.53**	.03
8. AT - Childhood	–	–	–	–	–	–	–	–	.41**	.78**	.31**	.11
9. AT - Adolescence	–	–	–	–	–	–	–	–	–	.71**	.04	-.01
10. AT - Adulthood	–	–	–	–	–	–	–	–	–	–	.28*	.08
11. BDI	–	–	–	–	–	–	–	–	–	–	–	.03
12. Verbal IQ	–	–	–	–	–	–	–	–	–	–	–	–

Table 2
Hierarchical regression analyses for negative-to-positive updating for traumatic content.

	PCL			PCL			PCL		
Predictors	*B*	*CI*	*p*	*B*	*CI*	*p*	*B*	*CI*	*p*
(Intercept)	2.93	2.71–3.14	<.001	3.02	2.80–3.25	<.001	3.02	2.80–3.24	<.001
Verbal IQ	0.00	−0.01–0.02	.682	0.00	−0.01–0.02	.528	0.00	−0.01–0.02	.546
BDI	0.02	0.01–0.03	<.001	0.02	0.01–0.03	<.001	0.02	0.01–0.03	<.001
AT-Childhood	−0.01	−0.08–0.06	.811	−0.02	−0.08–0.05	.654	−0.03	−0.10–0.04	.452
AT-Adolescence	0.06	−0.00–0.12	.065	0.07	0.01–0.13	.027	0.07	0.01–0.13	.026
AT-Adulthood	−0.03	−0.06–0.01	.175	−0.03	−0.06–0.01	.165	−0.02	−0.06–0.01	.201
N ACQ – traumatic ACC	−0.05	−0.23–0.14	.617	−0.09	−0.28–0.09	.306	−0.10	−0.29–0.08	.261
N-to-P – traumatic ACC				−0.14	−0.26–−0.02	.021			
N-to-P Target – traumatic ACC							−0.11	−0.20–−0.03	.010
N-to-P Context- traumatic ACC							−0.02	−0.11–0.07	.650
Model test	$F(6,73) = 6.23$, $p < .001$			$F(7,72) = 6.47$, $p < .001$			$F(8,71) = 5.98$, $p < .001$		
R^2/R^2 adjusted	0.34/0.28			0.39/0.33			0.40/0.34		

Note. BDI = Beck depression inventory, Verbal IQ = verbal intelligence score, N = Negative, ACQ = Acquisition.
N-to-P = Negative to positive, AT = Adversity and traumatic experiences, ACC = Accuracy.

the past month. Finally, in contrast to our hypotheses, we found that traumatic – as compared to neutral content – impaired target rather than context updating. Correspondingly, only impaired negative-to-positive target – and not context – updating for traumatic content predicted PTSD symptoms.

3.1. Alignment of findings with the literature and the predictive processing framework

Our finding concurs with previous research showing that negative-to-positive updating is selectively impaired in trauma-exposed individuals (Levy-Gigi & Richter-Levin, 2014; Levy-Gigi et al., 2014; Radell, Myers, et al., 2017; Zabag et al., 2020). Most importantly, our

Table 3
Hierarchical regression analyses for negative-to-positive updating for neutral content.

	PCL			PCL		
Predictors	*B*	*CI*	*p*	*B*	*CI*	*p*
(Intercept)	2.89	2.67–3.10	<.001	2.97	2.73–3.20	<.001
Verbal IQ	0.00	−0.01–0.02	.670	0.00	−0.01–0.02	.604
BDI	0.02	0.02–0.03	<.001	0.02	0.02–0.03	<.001
AT-Childhood	−0.01	−0.08–0.06	.849	−0.01	−0.08–0.06	.805
AT-Adolescence	0.06	0.00–0.13	.048	0.07	0.00–0.13	.039
AT-Adulthood	−0.03	−0.07–0.01	.139	−0.03	−0.06–0.01	.152
N ACQ – neutral ACC	−0.00	−0.20–0.19	.986	−0.03	−0.23–0.16	.731
N-to-P – neutral ACC				−0.10	−0.23–0.03	.133
Model test	$F(6,73) = 6.17$, $p < .001$			$F(7,72) = 5.71$, $p < .001$		
R^2/R^2 adjusted	0.34/0.28			0.36/0.29		

Note. BDI = Beck depression inventory, Verbal IQ = verbal intelligence score, N = Negative.
ACQ = Acquisition, N-to-P = Negative to positive, AT = Adversity and traumatic experiences.
ACC = Accuracy.left.

study extends previous research in two important ways: Firstly, by contrasting updating performance for neutral and traumatic content, we provide direct support for the assumption that traumatic content is more resistant to updating than neutral content. Secondly, our study is the first to demonstrate a link between reduced updating and PTSD symptoms. This is especially interesting since previous studies demonstrated impaired updating of neutral associations in individuals with repeated traumatic exposure compared to unexposed controls (Levy-Gigi & Richter-Levin, 2014; Levy-Gigi et al., 2014). However, these general updating impairments did not correlate with PTSD symptoms, and hence were considered a hidden price of repeated trauma exposure. The current findings suggest that using traumatic content may capture a direct explicit price of repeated trauma exposure, demonstrated in the level of PTSD symptoms. In line with previous research, our regression analyses consistently showed a significant link between PTSD and depressive symptoms, demonstrating a strong comorbidity between these disorders (Haim-Nachum & Levy-Gigi, 2021). However, by controlling for these effects, we are able to establish that the current results are not related to an overlap between PTSD and depressive symptoms, which is important since depressive symptoms have been linked to reduced belief updating (Kube et al., 2019, 2021).

On a conceptual level, our findings are strongly aligned with the premise of the predictive processing account: Hypotheses that were formed in the context of images relating to occupational trauma of our sample were more resistant to subsequent updating than hypotheses formed in the context of neutral images. Moreover, this resistance was selectively evident for hypotheses predicting negative outcomes for which positive disconfirmatory information was present. This pattern supports the assumption that exposure to trauma results in the formation of hyper-precise priors that bias subsequent precision-weighting processes (Kube et al., 2020). Moreover, these priors do not only appear to make trauma-related hypotheses resistant to change despite disconfirmatory information, they also seem to be linked to PTSD symptoms. These findings converge with recent research on predictive processing in psychopathology (Kube & Rozenkrantz, 2021). That is, individuals with depressive symptoms have been found to struggle with updating self-related beliefs based on positive disconfirmatory feedback, with cognitive immunization being the underlying mechanism (Kube et al., 2019). Moreover, individuals with social anxiety disorder have been found to selectively use negative evaluative feedback to update self-related beliefs in the presence of negative, positive, and neutral feedback (Koban et al., 2017). A recent study further indicates that individuals with high trait anxiety show aberrant belief updating reflected in increased usage of priors independent of the level of sensory uncertainty (Kraus, Niedeggen, & Hesselmann, 2021). Similar study designs could be used to investigate the interplay between priors and disconfirmatory information in PTSD, shedding further light on precision-weighting processes.

3.2. *Lack of alignment of findings concerning target vs. context updating*

Despite the high level of convergence, we found a deviation of our results from the predictive processing framework: Traumatic content affected target rather than context updating. Moreover, target rather than context updating was correlated with PTSD symptoms. This finding appears to be at odds with the assumption that PTSD symptoms specifically emerge because trauma-exposed individuals fail to use disconfirmatory contextual information in their environment to update trauma-related hypotheses (Kube et al., 2020). Moreover, these results contradict previous studies (Haim-Nachum & Levy-Gigi, 2021; Levy-Gigi et al., 2015) showing that context – and not target – updating is specifically impaired in trauma-exposed individuals with PTSD symptoms. A possible explanation for this inconsistency is that previous studies and the current one differed in sample composition. Whereas previous studies examined first responder samples with a wide range of traumatic exposure due to high variance in years of work experience (Levy-Gigi et al., 2014), the current study investigated a homogenous sample of firefighters after an 8-month period of trauma exposure. Hence, effects in our sample may only reflect early responses to work-related trauma whereas effects in previous samples may also reflect long-term adjustment to chronic work-related trauma (Lee et al., 2020). Future research should further investigate this hypothesis by contrasting subsamples with short-term and chronic work-related trauma exposure to assess how this potential moderator influences context and target updating.

Alternatively, it is possible that differences between the current task and the task used by previous studies may account for the fact that we found effects for target rather than context updating. That is, previous tasks used a highly salient context feature (i.e., background color) whereas the current task used complex scenes, which may have altered processing demands and subsequent context updating. Moreover, it is important to note that our task varied neutral and traumatic context pictures, whereas targets were always neutral. Hence, the task features a certain imbalance since traumatic content was only presented as context and never as target. As a result, traumatic context images may have triggered attentional avoidance (Mackintosh & Mathews, 2003; Sagliano et al., 2021), which in turn may have affected participants' ability to learn that the same old targets can predict positive outcomes when presented in new contexts. Moreover, since attentional avoidance has been shown to be greater in individuals with PTSD symptoms (Schoorl, Putman, Van Der Werff, & Van Der Does, 2014), this impairment may have been more pronounced in symptomatic individuals. Future studies may thus aim to include traumatic images of both target and context and investigate their differential impact on updating.

Finally, the lack of alignment between our selective finding for target rather than context updating and the assumption of the predictive processing framework concerning contextual processing may be related to discrepancies between different definitions of context. Specifically, in the task which was utilized in our study, both targets (i.e., a symbol on a door) and contexts (i.e., wall illustration) are processed as parts of a complex scene configuration. According to the predictive updating framework (Kube et al., 2020), these components could thus be considered equally contextual since they are scene details that are processed incidentally without any specific instruction that guides attention. Hence, if transferred to real-life conditions, targets and contexts could both reflect indicators of a harmless posttrauma environment used to update trauma-related hypotheses. Future research may aim to further test the relationship between target and context updating by using top-down instructions, guiding participants to focus their attention on one of the two elements. Such instructions would be more suited to approximate what is considered as contextual by the predictive processing framework (Kube et al., 2020).

3.3. Limitations

Although our results provide important insights, several limitations should be considered. First, presenting traumatic pictures rather than examining updating related to real-life trauma limits the generalization of our findings. However, it is difficult to examine fine-grained processes such as updating during or immediately after real-life trauma. For this reason, using materials that are conceptually related to individual trauma is considered a valid approach to investigate peri- and posttraumatic processes (e.g., Ehring, Kleim, & Ehlers, 2011). Secondly – in line with previous reversal learning tasks – our paradigm did not prevent participants from reaching accuracy rates of zero, which limited us in examining speed-accuracy tradeoffs in the entire sample. Future studies should seek to adapt existing paradigms to be able to capture performance both in terms of accuracy and speed. Another limitation that needs to be considered is that we used the PCL-IV for the assessment of PTSD symptoms based on the DSM-IV PTSD criteria. Future studies should thus seek to replicate our findings using the PCL-5 (Weathers, Litz, et al., 2013). Relatedly, we used an unpublished scale to assess adverse and traumatic life events. Despite certain advantages of the scale, future studies should consider using established instruments such as the Life Events Checklist (Weathers, Blake, et al., 2013).

Moreover, it is important to note that the majority of participants in this study reported subclinical PTSD symptoms. However, investigating samples with a wide range of subclinical symptoms aligns with recent views that promote characterizing mental disorders in terms of varying degrees of dysfunction in general psychological and biological systems rather than limiting observation to dichotomous clinical definitions (e.g., Carcone & Ruocco, 2017; Cuthbert & Kozak, 2013; Insel et al., 2010). Nevertheless, it must be considered that results may differ in a sample of patients with a full PTSD diagnosis, which should be investigated by future research. A further limitation is that our design did not include a non-exposed control group. As a result, we were not able to investigate trauma-related alterations in neutral updating but only alterations in traumatic as compared to neutral updating. Thus, we were not able to directly replicate analyses of previous studies finding reduced neutral updating in trauma-exposed samples (Levy-Gigi & Richter-Levin, 2014; Levy-Gigi et al., 2014; Weiss et al., 2019). Nevertheless, it should be noted that since neutral updating performance did not approach ceiling levels, it is possible that such a reduction also exists in the current sample. Finally, our sample comprised only of male participants who were exposed to occupational trauma, constituting a relatively homogenous population. However, since repeated trauma exposure is pervasive in several settings, our findings may generalize to other populations of first responders (e.g., police officers, medical personnel) and also beyond (e.g., civilians living in war zones, children growing up in abusive families). Finally, it is important to note that the effect sizes we found were mostly in the small-to-medium range. However, this does not necessarily indicate a lack of clinical relevance, since we used an experimental paradigm to model expectation updating. Hence, effects are expected to be larger if assessed in settings with higher ecological validity. Future studies should thus aim to adapt newly emerging paradigms (e.g., Kube et al., 2021) and re-investigate updating in PTSD under conditions that approximate real life.

4. Conclusion and outlook

Despite these limitations, the current findings contribute to the current literature. On the one hand, they support the premise of the predictive processing account of PTSD (Kube et al., 2020) that traumatic stress impacts subsequent updating of trauma-related hypotheses, which is in turn linked to PTSD symptom development. On the other hand, they underline the clinical relevance of updating processes in the context of PTSD. That is, if replicated, our findings indicate that helping traumatized individuals to acquire and maintain adaptive updating patterns may be a promising avenue for promoting resilience after trauma. This view is supported by research showing that cognitive training early after trauma exposure reduces subsequent symptom development (Ben-Zion et al., 2018). Moreover, in symptomatic individuals, training of updating processes may help to reduce existing symptoms: Initial studies examining the effects of cognitive training have shown promising effects both as a standalone treatment (Bomyea, Stein, & Lang, 2015; Larsen et al., 2019) and as adjunctive treatment for PTSD (Crocker et al., 2018). Critically, to the best of our knowledge, no study to date has trained updating of outcome expectations in trauma-exposed individuals to assess effects on PTSD symptoms. Based on the current findings, such research appears both timely and warranted.

Funding statement

This work was supported by the Binational Science Foundation; BSF (Grant #2015_143) to GAB and ELG.

Acknowledgements

MRSs participation in this project was supported by a fellowship from the German Academic Exchange Service (DAAD). SHN is grateful to the Azrieli Foundation for the award of an Azrieli Fellowship. BEWs participation in this project was supported by a Minerva Fellowship of the Minerva Stiftung Gesellschaft fuer die Forschung mbH.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.brat.2022.104098.

References

Acock, A. C. (2014). *A gentle introduction to Stata* (4th ed.). Texas: Stata Press.
Beck, A. T., Steer, R. A., & Brown, G. (1996). *Beck depression inventory–II*. Psychological Assessment.
Ben-Zion, Z., Fine, N. B., Keynan, N. J., Admon, R., Green, N., Halevi, M., … Shalev, A. Y. (2018). Cognitive flexibility predicts PTSD symptoms: Observational and interventional studies. *Frontiers in Psychiatry, 9*, 477.
Blanchard, E. B., Jones-Alexander, J., Buckley, T. C., & Forneris, C. A. (1996). Psychometric properties of the PTSD checklist (PCL). *Behaviour Research and Therapy, 34*(8), 669–673.
Bomyea, J., Stein, M. B., & Lang, A. J. (2015). Interference control training for PTSD: A randomized controlled trial of a novel computer-based intervention. *Journal of Anxiety Disorders, 34*, 33–42.
Breslau, N., Chen, Q., & Luo, Z. (2013). The role of intelligence in posttraumatic stress disorder: Does it vary by trauma severity? *PLoS One, 8*, Article e65391.
Carcone, D., & Ruocco, A. C. (2017). Six years of research on the national institute of mental health's research domain criteria (RDoC) initiative: A systematic review. *Frontiers in Cellular Neuroscience, 11*, 46.
Cohen, J. (1988). *Statistical power analysis for the behavioral sciences* (2. Edition). Hillsdale, NJ: Erlbaum.
Crocker, L. D., Jurick, S. M., Thomas, K. R., Keller, A. V., Sanderson-Cimino, M., Boyd, B., … Jak, A. J. (2018). Worse baseline executive functioning is associated with dropout and poorer response to trauma-focused treatment for veterans with PTSD and comorbid traumatic brain injury. *Behaviour Research and Therapy, 108*, 68–77.

Cuthbert, B. N., & Kozak, M. J. (2013). *Constructing constructs for psychopathology: The NIMH research domain criteria": Correction to Cuthbert and Kozak*, 2013.
Ehlers, A., & Clark, D. M. (2000). A cognitive model of posttraumatic stress disorder. *Behaviour Research and Therapy, 38*(4), 319–345.
Ehring, T., Kleim, B., & Ehlers, A. (2011). Combining clinical studies and analogue experiments to investigate cognitive mechanisms in posttraumatic stress disorder. *International Journal of Cognitive Therapy, 4*(2), 165–177.
Faul, F., Erdfelder, E., Lang, A.-G., & Buchner, A. (2007). G*Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavior Research Methods, 39*(2), 175–191.
First, M. B., Spitzer, R. L., Gibbon, M., & Williams, J. B. W. (1996). *Structured clinical interview for DSM-IV axis I disorders, clinician version (SCID-CV)*. Washington, DC: American Psychiatric Press.
Garfinkel, S. N., Abelson, J. L., King, A. P., Sripada, R. K., Wang, X., Gaines, L. M., et al. (2014). Impaired contextual modulation of memories in PTSD: An fMRI and psychophysiological study of extinction retention and fear renewal. *Journal of Neuroscience, 34*(40), 13435–13443.
Geronazzo-Alman, L., Eisenberg, R., Shen, S., Duarte, C. S., Musa, G. J., Wicks, J., … Hoven, C. W. (2017). Cumulative exposure to work-related traumatic events and current post-traumatic stress disorder in New York City's first responders. *Comprehensive Psychiatry, 74*, 134–143.
Haim-Nachum, S., & Levy-Gigi, E. (2019). A chink in the armor: The influence of training on generalization learning impairments after viewing traumatic stimuli. *Cognition, 193*, 104021.
Haim-Nachum, S., & Levy-Gigi, E. (2021). To Be or Not to Be Flexible: Selective impairments as a means to differentiate between depression and PTSD symptoms. *Journal of Psychiatric Research, 136*, 366–373.
Haim-Nachum, S., Sopp, R., Bonanno, G. A., & Levy-Gigi, E. (2021). The lasting effects of early adversity and updating ability on the tendency to develop PTSD symptoms following exposure to trauma in adulthood. https://doi.org/10.31219/osf.io/2tqd3.
Herzog, P., Barth, C., Rief, W., Brakemeier, E., & Kube, T. (2021). How expectations shape the formation of intrusive memories – an experimental study using the trauma film paradigm. https://doi.org/10.31234/osf.io/ta96q.
Herzog, P., Kaiser, T., Rief, W., Brakemeier, E. L., & Kube, T. (2021). Assessing dysfunctional expectations in posttraumatic stress disorder–Development and validation of the Posttraumatic Expectations Scale (PTES). https://doi.org/10.31234/osf.io/e6g4b.
Insel, T., Cuthbert, B., Garvey, M., Heinssen, R., Pine, D. S., Quinn, K., … Wang, P. (2010). Research domain criteria (RDoC): Toward a new classification framework for research on mental disorders. *American Journal of Psychiatry, 167*(7), 748–751.
Kessler, R. C., Aguilar-Gaxiola, S., Alonso, J., Benjet, C., Bromet, E. J., Cardoso, G., et al. (2017). Trauma and PTSD in the WHO world mental health surveys. *European Journal of Psychotraumatology, 8*(sup5), 1353383.
Kim, M. J., Jeong, Y., Choi, Y. S., Seo, A. R., Ha, Y., Seo, M., et al. (2019). The association of the exposure to work-related traumatic events and work limitations among firefighters: A cross-sectional study. *International Journal of Environmental Research and Public Health, 16*(5), 756.
Koban, L., Schneider, R., Ashar, Y. K., Andrews-Hanna, J. R., Landy, L., Moscovitch, D. A., et al. (2017). Social anxiety is characterized by biased learning about performance and the self. *Emotion, 17*(8), 1144.
Kraus, N., Niedeggen, M., & Hesselmann, G. (2021). Trait anxiety is linked to increased usage of priors in a perceptual decision making task. *Cognition, 206*, 104474.
Kube, T., Berg, M., Kleim, B., & Herzog, P. (2020). Rethinking post-traumatic stress disorder–A predictive processing perspective. *Neuroscience & Biobehavioral Reviews, 113*, 448–460.
Kube, T., Kirchner, L., Lemmer, G., & Glombiewski, J. A. (2021). *How the discrepancy between prior expectations and new information influences expectation updating in depression—the greater, the better?* Clinical Psychological Science, 21677026211024644.
Kube, T., Rief, W., Gollwitzer, M., Gärtner, T., & Glombiewski, J. A. (2019). Why dysfunctional expectations in depression persist–Results from two experimental studies investigating cognitive immunization. *Psychological Medicine, 49*(9), 1532–1544.
Kube, T., & Rozenkrantz, L. (2021). When beliefs face reality: An integrative review of belief updating in mental health and illness. *Perspectives on Psychological Science, 16*(2), 247–274.
Larsen, S. E., Lotfi, S., Bennett, K. P., Larson, C. L., Dean-Bernhoft, C., & Lee, H. J. (2019). A pilot randomized trial of a dual n-back emotional working memory training program for veterans with elevated PTSD symptoms. *Psychiatry Research, 275*, 261–268.
Leeson, V. C., Robbins, T. W., Matheson, E., Hutton, S. B., Ron, M. A., Barnes, T. R., et al. (2009). Discrimination learning, reversal, and set-shifting in first-episode schizophrenia: Stability over six years and specific associations with medication type and disorganization syndrome. *Biological Psychiatry, 66*(6), 586–593.
Levy-Gigi, E., Bonanno, G. A., Shapiro, A. R., Richter-Levin, G., Kéri, S., & Sheppes, G. (2016). Emotion regulatory flexibility sheds light on the elusive relationship between repeated traumatic exposure and posttraumatic stress disorder symptoms. *Clinical Psychological Science, 4*(1), 28–39.
Levy-Gigi, E., & Richter-Levin, G. (2014). The hidden price of repeated traumatic exposure. *Stress: The International Journal on the Biology of Stress, 17*(4), 343–351.
Levy-Gigi, E., Richter-Levin, G., & Kéri, S. (2014). The hidden price of repeated traumatic exposure: Different cognitive deficits in different first-responders. *Frontiers in Behavioral Neuroscience, 8*, 281.
Levy-Gigi, E., Szabo, C., Richter-Levin, G., & Kéri, S. (2015). Reduced hippocampal volume is associated with overgeneralization of negative context in individuals with PTSD. *Neuropsychology, 29*(1), 151.
Liberzon, I., & Abelson, J. L. (2016). Context processing and the neurobiology of post-traumatic stress disorder. *Neuron, 92*(1), 14–30.
Linson, A., & Friston, K. (2019). Reframing PTSD for computational psychiatry with the active inference framework. *Cognitive Neuropsychiatry, 24*(5), 347–368.
Mackintosh, B., & Mathews, A. (2003). Don't look now: Attentional avoidance of emotionally valenced cues. *Cognition & Emotion, 17*(4), 623–646.
McDonald, S. D., & Calhoun, P. S. (2010). The diagnostic accuracy of the PTSD checklist: A critical review. *Clinical Psychology Review, 30*(8), 976–987.
Patterson, G. T. (2001). The relationship between demographic variables and exposure to traumatic incidents among police officers. *Australasian Journal of Disaster and Trauma Studies, 1*, 1174–4707.
Radell, M. L., Beck, K. D., Gilbertson, M. W., & Myers, C. E. (2017). Post-traumatic stress disorder symptom burden and gender each affect generalization in a reward-and punishment-learning task. *PLoS One, 12*(2), Article e0172144.
Radell, M. L., Myers, C. E., Sheynin, J., & Moustafa, A. A. (2017). Computational models of posttraumatic stress disorder (PTSD). *Computational Models of Brain and Behavior, 43*, 43–55.
Rodin, R., Bonanno, G. A., Rahman, N., Kouri, N. A., Bryant, R. A., Marmar, C. R., et al. (2017). Expressive flexibility in combat veterans with posttraumatic stress disorder and depression. *Journal of Affective Disorders, 207*, 236–241.
Ryan, J. J., & Rosenberg, S. J. (1984). Validity of the verbal IQ as a short form of the Wechsler adult intelligence scale-revised. *Journal of Clinical Psychology, 40*(1), 306–308.
Sagliano, L., Conson, M., Saporito, G., Carolei, A., Sacco, S., & Pistoia, F. (2021). Far from the mind": Preliminary evidence of avoidance bias for emotional facial expressions among earthquake victims. *International Journal of Disaster Risk Reduction, 59*, 102273.
Schoorl, M., Putman, P., Van Der Werff, S., & Van Der Does, A. W. (2014). Attentional bias and attentional control in posttraumatic stress disorder. *Journal of Anxiety Disorders, 28*(2), 203–210.
Selya, A. S., Rose, J. S., Dierker, L. C., Hedeker, D., & Mermelstein, R. J. (2012). A practical guide to calculating Cohen's f2, a measure of local effect size, from PROC MIXED. *Frontiers in Psychology, 3*, 111.
Sopp, M. R., Streb, M., Brueckner, A. H., Schäfer, S. K., Lass-Hennemann, J., Mecklinger, A., et al. (2021). Prospective associations between intelligence, working memory capacity, and intrusive memories of a traumatic film: Potential mediating effects of rumination and memory disorganization. *Journal of Behavior Therapy and Experimental Psychiatry, 70*, 101611.
Teoh, K. R. H., Lima, E., Vasconcelos, A., Nascimento, E., & Cox, T. (2019). Trauma and work factors as predictors of firefighters' psychiatric distress. *Occupational Medicine, 69*(8–9), 598–603.
Wang, Y. P., & Gorenstein, C. (2013). Psychometric properties of the Beck depression inventory-II: A comprehensive review. *Brazilian Journal of Psychiatry, 35*(4), 416–431.
Weathers, F. W., Blake, D. D., Schnurr, P. P., Kaloupek, D. G., Marx, B. P., & Keane, T. M. (2013). *The life events checklist for DSM-5* (LEC-5). Instrument available from the National Center for PTSD at www.ptsd.va.gov.
Weathers, F. W., Litz, B. T., Herman, D. S., Huska, J. A., & Keane, T. M. (1993). *The PTSD Checklist (PCL): Reliability, validity, and diagnostic utility*. San Antonio, TX: annual convention of the international society for traumatic stress studies.
Weathers, F. W., Litz, B. T., Keane, T. M., Palmieri, P. A., Marx, B. P., & Schnurr, P. P. (2013). *The PTSD checklist for DSM-5* (PCL-5). Scale available from the National Center for PTSD at www.ptsd.va.gov.
Wechsler, D. (1997). *Wechsler Adult intelligence scale* (3rd ed.). The Psychological Corporation, San Antonio.
Weiss, O., Levy-Gigi, E., Adelson, M., & Peles, E. (2019). Methadone maintenance treatment patients with a history of childhood trauma succeed more in a cognitive paradigm that is associated with a negative reward. *Psychiatry Research, 271*, 381–388.
Whisman, M. A., Perez, J. E., & Ramel, W. (2000). Factor structure of the Beck depression inventory—second edition (BDI-ii) in a student sample. *Journal of Clinical Psychology, 56*(4), 545–551.
Wickham, H. (2016). *ggplot2: elegant graphics for data analysis*. springer.
Zabag, R., Deri, O., Gilboa-Schechtman, E., Richter-Levin, G., & Levy-Gigi, E. (2020). Cognitive flexibility in PTSD individuals following nature adventure intervention: Is it really that good? *Stress: The International Journal on the Biology of Stress, 23*(1), 97–104.