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ORIGINAL ARTICLE

The Lasting Effects of Early Adversity and Updating Ability on the Tendency to Develop PTSD Symptoms Following Exposure to Trauma in Adulthood

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Abstract

Background Adverse childhood experiences (ACEs) serve as a risk factor for developing posttraumatic stress disorder (PTSD) in those who experience additional adult trauma. However, while some individuals with ACEs develop severe PTSD symptoms following exposure to additional adult trauma, others do not. We propose that updating prior knowledge in the face of new inconsistent information may account for these individual differences. This notion is based on prior work showing that for individuals with a reduced ability to update negative-to-positive outcome associations, greater trauma is correlated with elevated PTSD symptoms. On the other hand, individuals with flexible updating do not develop such symptoms. **Objective.** Here, we tested whether reduced updating moderates the relationship between ACEs and PTSD symptoms following additional adult trauma.

Methods Firefighters (N = 123, *M*age = 28.02, *SD*age = 4.69) were assessed for childhood adversity and PTSD symptoms and completed a performance-based learning paradigm to evaluate reduced updating.

Results We predicted and found strong associations between ACEs and PTSD symptoms for individuals with reduced updating of negative–but not positive–outcomes.

Conclusions The results may serve as a first step toward improving mental health outcomes in individuals with ACEs and protecting them from the aversive effect of exposure to additional adult trauma.

Keywords Childhood adversity · Adult trauma · PTSD symptoms · Updating · Firefighters

Introduction

Adverse childhood experiences (ACEs) refer to a wide range of circumstances or events that pose a serious threat to a child's physical or psychological well-being and are one of the most consistent risk factors associated with adult mental disorders (Agbaje et al., 2021; Bellis et al., 2015; Bryant et al., 2020; Cleare et al., 2018; McLaughlin et al., 2013; Nelson et al., 2020; Sareen et al., 2013; Trotta et al., 2015). The primary aim of the current study is to test the moderating role of cognitive flexibility on the tendency of individuals with different levels of exposure to ACEs to develop posttraumatic stress disorder (PTSD) following exposure to additional trauma in adulthood. As a secondary aim, the study compares this moderating role of cognitive flexibility on the tendency to develop PTSD symptoms in those who experienced adversity in childhood, adolescence, and adulthood.

One central facet of cognitive flexibility is updating – the ability to adequately update previous beliefs, cognitions, and behaviors when new, inconsistent information is provided (Dajani & Uddin, 2015). Individuals with PTSD symptoms show a reduced ability to update previous knowledge when new inconsistent information is available. Specifically, they

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struggle to use positive information to update expectations regarding negative outcomes associated with traumatic stimuli (Levy-Gigi et al., 2014). For example, someone who was in an abusive romantic relationship may ignore or misinterpret positive affection from new potential partners. In recent studies of individuals with a reduced ability to update outcome expectations from negative to positive (i.e., learning that a stimulus associated with a loss was now associated with a gain), greater trauma exposure was associated with elevated PTSD symptoms (Levy-Gigi et al., 2014, 2015). This effect was not evident in individuals with reduced updating of positive-to-negative associations (i.e., a stimulus associated with a gain was now associated with a loss) (Levy-Gigi et al., 2014). Moreover, recent evidence points to associations between aversive events, updating, and PTSD symptoms (see Sopp et al., 2022), serving as a proof of concept for the associations between these variables.

In a framework that examined ACEs' impact on affective development, Callaghan and Tottenham (2016) proposed that children who have been neglected show faster development of affective regulation compared to those who have not experienced neglect. However, such accelerated development comes at the cost of more rigid regulation, which may persist into adulthood. Thus, adults with ACEs may be less flexible when updating negative expectations, even when presented with unambiguously positive information. Moreover, it was found that ACEs affect the development of certain brain regions, such as the amygdala and hippocampus, and the amygdala-prefrontal circuitry, which may be correlated with impaired updating (Andersen et al., 2008; Herzog & Schmahi, 2018; Teicher et al., 2016; Tomoda et al., 2012) and decreased cognitive control (for a review, see, McLaughlin et al., 2020). Relatedly, Weiss et al. (2019) found that individuals with a history of childhood trauma succeeded more in positive-to-negative but not negative-to-positive updating conditions. Critically, not all adults with ACEs show deficits in cognitive flexibility. Research indicates that approximately a third of children with ACEs exhibit clinically significant cognitive flexibility deficits (Fay-Stammbach & Hawes, 2019). These findings reflect a substantial variability in ACE-related deficits in cognitive flexibility, which could be linked to different outcomes in adult psychopathology. In support of this assumption, previous studies have shown that cognitive flexibility moderates the association between ACEs and emotion regulation, well-being, depression, and anxiety (Amédée et al., 2022; Davich, 2022; Fu & Chow, 2016). However, to date, no study has tested the moderating effect of cognitive flexibility – as reflected in updating performance – on the link between ACEs and PTSD symptoms following exposure to trauma in adulthood.

Since the developmental process by which individuals learn to update expectations extends well into adolescence (Weiss et al., 2021), adversity occurring either during childhood or adolescence might result in reduced updating in adulthood. However, given that early disruption of neurophysiological development is assumed to result in more detrimental outcomes, adversity should have a greater impact on updating if it occurs during childhood than during adolescence (Hodel, 2018). It is thus important to investigate the moderating effect of updating on the association between ACEs and PTSD symptoms separately for ACEs occurring during childhood and adolescence.

Based on prior findings, we hypothesize that individuals with ACEs and reduced updating experience more PTSD symptoms after additional adult trauma exposure than individuals with ACEs and intact updating. In line with prior research, we assume these effects should be evident only for negative-to-positive updating and not for positive-to-negative updating (Levy-Gigi et al., 2014). Moreover, while we expect to find that adversity across all life phases and reduced negative-to-positive updating interact to predict PTSD symptoms, we predict that the link between reduced updating and PTSD symptoms would be more pronounced for individuals who experienced adversity in childhood rather than in adolescence and adulthood (Zlotnick et al., 2008; McLaughin et al., 2012). To address these hypotheses, the current study used a performance-based learning paradigm that assesses the ability to update positive and negative stimulus-outcome associations (Levy-Gigi et al., 2014; see Fig. 1) in a sample of trauma-exposed firefighter trainees. Whereas these individuals differ in the level of ACEs they experienced, they were all exposed to similar traumatic events in adulthood. To assess the robustness of updating as a moderator in the relationship between ACEs and PTSD symptoms, we examined its influence above and beyond the following correlations with PTSD symptoms: age (Liu et al., 2017), education (Vilaplana-Pérez et al., 2020), military combat exposure (Phillips et al., 2018), and adversity in all life phases (Keinan et al., 2012; Vrana & Lauterbach, 1994). These variables have been shown to correlate with PTSD symptoms and are often controlled for in the context of updating tasks such as the current one (Leeson et al., 2009).

Methods

Participants

We used G*Power software to calculate the required sample size, which revealed a need for at least 107 participants to detect a medium-size effect ($f^2 = 0.15$) (Faul et al., 2007) given an alpha of 5%, with 95% power (1-β) (for a related study, see Haim-Nachum & Levy-Gigi, 2021). The Power analysis was based on finding a significant association in a linear multiple regression model with two main predictors:

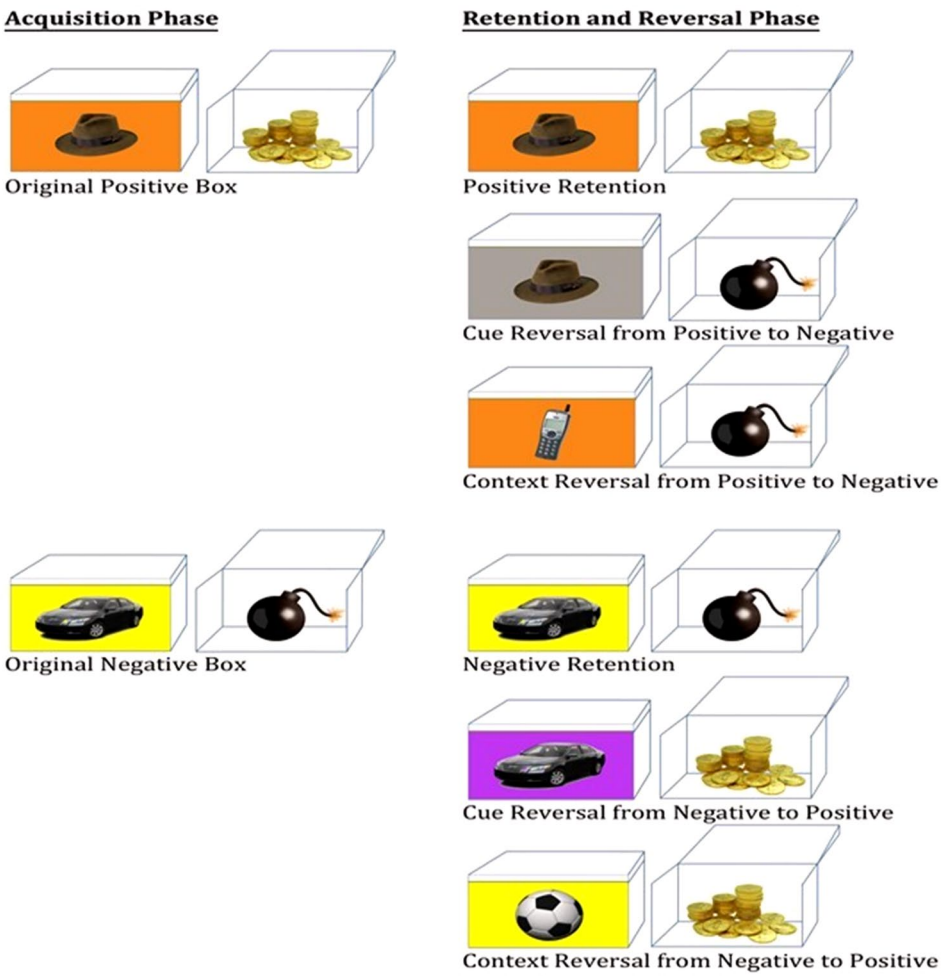

Fig. 1 *Example of Acquisition, Retention, and Updating Trials in the Two Phases of the Cue-Context Reversal Learning Paradigm.* Note: This Figure is being reproduced with the permission of the copyright holder Neuropsychology. Reference of the original source: Levy-Gigi et al. (2015). Reduced hippocampal volume is associated with overgeneralization of negative context in individuals with PTSD. *Neuropsychology 29*(1),151–161

ACEs and updating. The sample size was increased by 15% to account for potential equipment failure. We, therefore, recruited 123 trainee firefighters. Participants were all male and recruited at the end of an eight-month introductory firefighters' course in which they have experienced six weeks of extensive exposure to duty-related potential traumatic events, including fires, car accidents, spilling of toxic/combustion substances, gas leaks, breaking in due to fear of a lost life, and missile attacks. We used the Structured Clinical Interview for the *Diagnostic and Statistical Manual for Mental Disorders–Fourth Edition* Axis I Disorders (First et al., 1996) to exclude individuals with psychiatric disorders other than PTSD. Additional exclusion criteria were history of head injury, alcohol dependence, danger or harm to self or others, and color-blindness. The Institutional Review Board of Bar-Ilan University approved all procedures performed in the study (Reference #65). After an explanation of the objectives and methods of the study, informed consent was obtained from all of the participants. At the end of the study, participants were debriefed.

Measurements

The Cue-Context Reversal Learning Paradigm

In this paradigm (Levy-Gigi et al., 2014, 2015), participants observe several boxes on a computer screen. On each box, the image of a target object (e.g., a hat) is placed against a background context (different colors, e.g., orange). Participants can decide 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 results in either a gain or a loss of 25 points, respectively (Fig. 2). The paradigm includes an *acquisition phase* followed by a *retention and updating phase* (Fig. 1). In the acquisition phase, each box is unique, and the participants learn by trial and error to open positive and skip negative boxes. The outcome of each box is counterbalanced across participants. To complete the acquisition phase and start the retention and updating phase, participants must achieve six consecutive correct

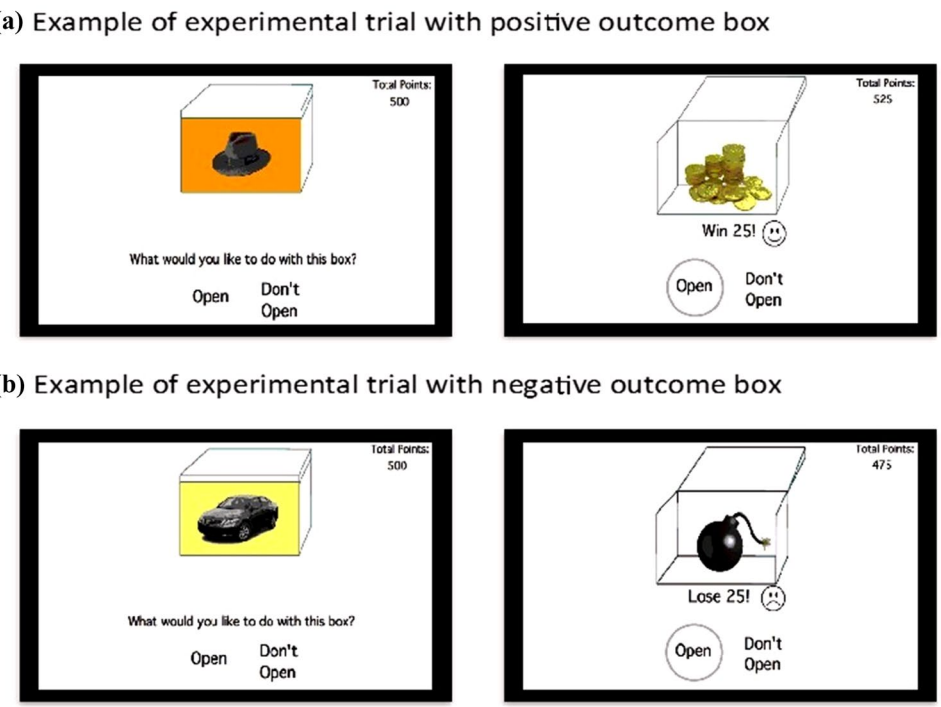

Fig. 2 *Example of Experimental Trials with Different Outcomes.* Note: This Figure is being reproduced with the permission of the copyright holder Neuropsychology. Reference of the original source: Levy-Gigi et al. (2015). Reduced hippocampal volume is associated with overgeneralization of negative context in individuals with PTSD. *Neuropsychology 29*(1),151–161

responses within a minimum of 40 trials. If they fail to do so, they get another 16 trials, and if they fail again, they are opted out of the experiment. Once accomplished, the retention and updating phase starts immediately.

In this phase, participants see the original boxes (retention trials, e.g., a *hat* on an *orange* background has *gold* inside) in addition to two new types of boxes that share either target (e.g., a *hat* on a gray background) or context (e.g., a phone on *orange* background) with an original box (Fig. 1), but have an opposite outcome (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 a *bomb* inside and vice versa). To successfully learn these new associations, participants need to reverse and update the association rule of either the original target or the original context. Boxes in the *retention and updating phase* are presented in 10 blocks of 12 boxes each (two boxes from each of the following conditions: positive/negative retention, positive/negative target updating, positive/negative context updating). Boxes in each block are randomly presented with a total of 120 trials, 20 trials per condition. The task allows measuring both positive-to-negative and negative-to-positive updating while differentiating between cue and context-related information. In the current study, there were no differences as a function of the information type. Hence, they were collapsed to simplify the report.

Assessment of Adversity Exposure and Clinical Measures

Exposure to adversity experiences was measured using a 10-item scale designed by the PI research group to cover adverse and potentially traumatic events related to different developmental phases. The scale allows us to differentiate between distinct life periods (childhood, adolescence, and adulthood) in addressing our particular hypotheses. Participants were screened for common adverse events, including, for example, loss of a parent, death of a sibling/parent, divorce of parents, chronic illness in the family, severe economic difficulties, a personal serious injury/accident/disease, having a mentally or physically disabled sibling, and domestic violence. Additionally, there was an open-ended question about exposure to 'any other' traumatic event. Participants were instructed to indicate whether the event occurred to them and when: during childhood (age < 10; range in this sample = 0–3), adolescence (10 < age < 18; range = 0–3), or adulthood (age > 18; range = 0–8). The total score of these events was computed separately for each life period.

PTSD symptomology. We used the *Posttraumatic Stress Disorder Checklist for DSM-IV (PCL-IV;* Weathers et al., 1993*)*, a 17-item self-report questionnaire, to evaluate PTSD symptoms during the past month. Symptoms are rated on a scale of 1 = "not at all" to 5 = "extremely" ($M = 21.37$, $SD = 4.22$, range in this sample = 17–37). This measure has

good reliability and validity scores (Blanchard et al., 1996). We used the total symptom severity score for our analyses.

Additional Control Measures

Several studies have found correlations between PTSD symptoms and age (Liu et al., 2017), education years (Vilaplana-Pérez et al., 2020), military combat exposure (Phillips et al., 2018), and adversity in different life phases (Keinan et al., 2012; Vrana & Lauterbach, 1994). Here we sought to control for the potential effect of these variables on symptoms and test the moderating role of updating in explaining individual differences in PTSD symptoms in individuals with ACEs and additional adult trauma exposure.

Data Analyses

Descriptive statistics were computed to show the variables' means and standard deviations for all measures. We examined Pearson correlation coefficients to evaluate the associations between adversity, updating, and PTSD symptoms. In addition, we used hierarchical multiple regression analyses to investigate updating performance as both a predictor and outcome of PTSD symptoms. We additionally tested the role of updating as a moderator of the association between adversity and PTSD symptoms while accounting for the effects of socio-demographic variables (age, education years, and military combat exposure) and adversity in all life phases. Similar to previous studies, we decomposed the hypothesized interaction effect by examining the slope of childhood adversity at different levels of negative-to-positive updating: 1 *SD* below average, average, and 1 *SD* above average (Haim-Nachum & Levy-Gigi, 2021). The alpha level was set to 0.05 for all analyses. Analyses were conducted using SPSS Statistics version 25 and R.

Results

Descriptive Statistics

Firefighters were 28.02 years old on average ($SD = 4.69$) and reported 12.54 years of education ($SD = 1.25$). All had attended military service, and 57.72% had been involved in combat during service. Participants reported exposure to adversity in childhood ($M = 0.47$, $SD = 0.73$), adolescence ($M = 0.49$, $SD = 0.73$), and/or adulthood ($M = 1.52$, $SD = 1.65$). Task performance was medium-to-high for negative-to-positive ($M = 65.11\%$, $SD = 24.18$) and positive-to-negative ($M = 80.09\%$, $SD = 14.44$) updating, indicating sufficient understanding and task compliance. Participants showed significantly higher performance rates for positive-to-negative than for negative-to-positive updating, $t(122) = 5.78$, $p > 0.001$.

Correlation Analyses

Zero-order correlations are reported in Table 1. Analyses did not yield any significant correlations between ACEs and PTSD symptoms, nor between ACEs and updating patterns (all $ps > 0.05$). Unsurprisingly, different forms of adversity were positively correlated: A medium-sized correlation emerged between adversity during childhood and adolescence ($r = 0.32$, $p < 0.001$). Moreover, large correlations emerged between adversity during childhood and adulthood ($r = 0.72$, $p < 0.001$) and adolescence and adulthood ($r = 0.69$, $p < 0.001$). In addition, we found inverse significant correlations between PTSD symptoms and updating, $r = -0.27$, $p = 0.003$; $r = -0.29$, $p = 0.001$; for negative-to-positive and positive-to-negative updating, respectively. That is, greater positive-to-negative and negative-to-positive updating were linked to fewer PTSD symptoms.

Hierarchical Regression Analyses

To examine the moderating effect of updating on the association between ACEs and PTSD symptoms following additional trauma in adulthood, we conducted a series of

Table 1 Zero-order correlations between adversity experiences, PTSD symptoms and updating

Variables	1	2	3	4	5	6
1. Childhood adversity	1					
2. Adolescence adversity	.32***	1				
3. Adulthood adversity	.72***	.69***	1			
4. PTSD symptoms	.09	.01	-.01	1		
5. Neg-to-pos updating	−.10	−.14	.10	−.27**	1	
6. Pos-to-neg updating	−.05	.09	.04	−.29***	.10	1

**p ≤ .01, ***p ≤ .001

Table 2 Hierarchical regression analyses for negative-to-positive updating

	Baseline model			+Negative-to-Positive Updating			+Interaction Childhood Adversity × Negative-to-Positive Updating			+Interaction Adolescence Adversity × Negative-to-Positive Updating			+Interaction Adulthood Adversity × Negative-to-Positive Updating		
Predictors	Estimates	*CI*	*p*	Estimates	*CI*	*p*	Estimates	*CI*	*p*	Estimates	*CI*	*p*	Estimates	*CI*	*p*
(Intercept)	26.64	18.44 – 34.84	**<.001**	27.89	19.85 – 35.92	**<.001**	28.47	20.53 – 36.42	**<.001**	27.74	19.66 – 35.83	**<.001**	28.07	19.96 – 36.18	**<.001**
Age	− 0.11	− 0.32 – 0.09	.277	− 0.11	− 0.31 – 0.09	.292	− 0.11	− 0.30 – 0.09	.289	− 0.10	− 0.30 – 0.11	.341	− 10	− 0.30 – 0.10	.326
Education	− 0.18	− 0.89 – 0.54	.626	− 0.05	− 0.75 – 0.65	.885	− 0.10	− 0.79 – 0.60	.784	− 0.06	− 0.77 – 0.64	.862	− 0.08	− 0.80 – 0.64	.826
Combat Exposure	0.33	− 0.43 – 1.10	.392	0.23	− 0.52 – 0.98	.543	0.35	− 0.40 – 1.10	.354	0.23	− 0.52 – 0.98	.541	0.27	− 0.50 – 1.04	.494
Adversity – Childhood (AC)	1.36	− 0.30 – 3.03	.107	1.27	− 0.35 – 2.90	.122	1.04	− 0.58 – 2.65	.205	1.36	− 0.30 – 3.02	.108	1.28	− 0.34 – 2.91	.121
Adversity – Adolescence (AAdo)	0.49	− 1.08 – 2.06	.538	0.31	− 1.23 – 1.84	.694	0.26	− 1.25 – 1.77	.734	0.23	− 1.34 – 1.80	.774	0.23	− 1.36 – 1.81	.777
Adversity – Adulthood (AAdu)	− 0.54	− 1.53 – 0.46	.286	− 0.55	− 1.51 – 0.42	.266	− 0.41	− 1.37 – 0.55	.402	− 0.57	− 1.54 – 0.41	.249	− 0.52	− 1.50 – 0.45	.289
Neg-to-Pos (NtP)				− 0.04	− 0.07 – 0.01	**.008**	− 0.05	− 0.08 – 0.02	**.004**	− 0.04	− 0.07 – 0.01	**.009**	− 0.04	− 0.07 – 0.01	**.008**
AC × NtP							− 0.84	− 1.64 – 0.03	**.041**						
AAdo × NtP										− 0.19	− 0.94 – 0.57	.626			
AAdu × NtP													− 0.18	− 1.03 – 0.67	.678
R^2 / R^2 adjusted	0.054 / 0.005			0.111 / 0.056			0.143 / 0.082			0.112 / 0.050			0.112 / 0.050		

$p < .05$ is highlighted in bold

Neg-to-Pos = Negative-to-Positive

hierarchical regression analyses with PTSD symptoms as a dependent variable. In the baseline model, socio-demographic variables (age, education years, and combat exposure) were entered as predictors along with exposure to adversity during childhood, adolescence, and adulthood. In a subsequent step, we added updating performance as a predictor and examined the increase in explained variance. Our first models focused on reduced negative-to-positive updating (see Table 2). Introducing reduced negative-to-positive updating as a predictor led to a significant increase in variance explained by the model, $F(1,115) = 7.36$, $p = 0.008$. In line with our assumptions, reduced negative-to-positive updating was associated with higher PTSD symptom levels. In a second step, we examined whether the interaction between updating and adversity in different life phases further increased the portion of explained variance. While interactions involving adversity during adolescence and adulthood did not result in an increase of explained variance, the interaction between reduced negative-to-positive updating and adversity during childhood significantly increased the portion of accounted variance, childhood: $F(1,114) = 4.26$, $p = 0.041$; adolescence: $F(1,114) = 0.24$, $p = 0.626$; adulthood: $F(1,114) = 0.17$, $p = 0.678$. We additionally run these analyses without covariates and found the same pattern of results (See Supplementary Tables 1 and 2).

To further decompose this interaction effect, we examined the slope of childhood adversity at different levels of negative-to-positive updating. While a negative link between adversity during childhood and PTSD symptoms was evident in those with below-average negative-to-positive updating (mean − 1 *SD*; $b = 1.59$, *SE.* $= 0.67$, $t = 2.38$, $p = 0.02$), no significant link emerged for those with average (mean; $b = 0.76$, *SE.* $= 0.59$, $t = 1.27$, $p = 0.21$) and above-average negative-to-positive updating (mean + 1 *SD*; $b = -0.08$, *SE.* $= 0.76$, $t = 0.11$, $p = 0.92$). In a more in-depth analysis, we examined the region of significance for the slope of childhood adversity for continuous levels of negative-to-positive updating. For z-standardized negative-to-positive updating scores below −0.52 (range of observed values: −2.73 – 1.40), a significant slope of childhood adversity was evident (see Fig. 3).

In a separate set of models, we examined positive-to-negative updating as a predictor and moderator of PTSD symptoms (see Table 3). First, we introduced positive-to-negative updating into the baseline model to examine its effects as a predictor of PTSD symptoms. Contrary to our assumptions and previous research indicating that only reduced negative-to-positive updating is linked to PTSD symptoms, we found that introducing reduced positive-to-negative updating as a predictor increased the portion of explained variance; $F(1,115) = 8.28$, $p = 0.005$. Reduced positive-to-negative updating was linked to higher PTSD symptoms. In a second step, we investigated incremental variance accounted for by the interaction between adversity and updating. Three consecutive models examining adversity during childhood, adolescence, and adulthood did not yield any significant increases in the portion of explained variance, childhood: $F(1,114) = 1.17$, $p = 0.283$; adolescence: $F(1,114) = 1.36$,

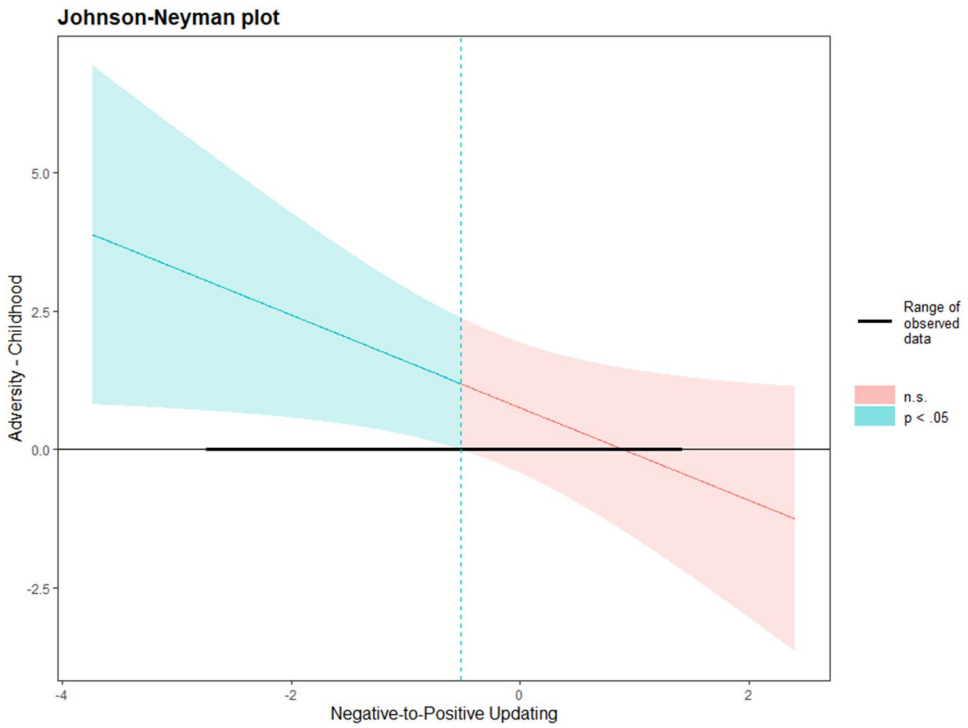

Fig. 3 An Illustration of the Region of Significance for the Interaction Between Childhood Adversity and Negative-to-Positive Updating on PTSD Symptoms

Table 3 Hierarchical regression analyses for positive-to-negative updating

	Baseline model			+Positive-to-Negative Updating			+Interaction Childhood Adversity × Positive-to-Negative Updating			+Interaction Adolescence Adversity × Positive-to-Negative Updating			+Interaction Adulthood Adversity × Positive-to-Negative Updating		
Predictors	Estimates	*CI*	*p*	Estimates	*CI*	*p*	Estimates	*CI*	*p*	Estimates	*CI*	*p*	Estimates	*CI*	*p*
(Intercept)	26.64	18.44 – 34.84	**< .001**	31.43	22.82 – 40.04	**< .001**	31.59	22.98 – 40.20	**< .001**	32.13	23.45 – 40.81	**< .001**	32.09	23.45 – 40.73	**< .001**
Age	− 0.11	− 0.32 – 0.09	.277	− 0.09	− 0.29 – 0.11	.350	− 0.08	− 0.28 – 0.12	.427	− 0.09	− 0.29 – 0.11	.382	− 0.07	− 0.27 – 0.14	.512
Education	− 0.18	− 0.89 – 0.54	.626	− 0.10	− 0.80 – 0.59	.771	− 0.16	− 0.87 – 0.54	.648	− 0.18	− 0.88 – 0.53	.624	− 0.23	− 0.95 – 0.49	.527
Combat Exposure	0.33	− 0.43 – 1.10	.392	0.04	− 0.73 – 0.81	.918	0.06	− 0.71 – 0.83	.872	0.06	− 0.70 – 0.83	.870	0.06	− 0.71 – 0.83	.877
Adversity – Childhood (AC)	1.36	− 0.30 – 3.03	.107	1.22	− 0.40 – 2.84	.137	1.09	− 0.54 – 2.73	.187	1.30	− 0.32 – 2.92	.114	1.28	− 0.33 – 2.89	.119
Adversity – Adolescence (AAdo)	0.49	− 1.08 – 2.06	.538	0.67	− 0.86 – 2.20	.387	0.56	− 0.98 – 2.10	.472	0.72	− 0.81 – 2.25	.352	0.58	− 0.95 – 2.10	.455
Adversity – Adulthood (AAdu)	− 0.54	− 1.53 – 0.46	.286	− 0.54	− 1.51 – 0.42	.265	− 0.44	− 1.42 – 0.54	.373	− 0.60	− 1.56 – 0.37	.223	− 0.53	− 1.49 – 0.43	.278
Pos-to-Neg Updating (PtN)				− 0.08	− 0.13 – 0.02	**.005**	− 0.08	− 0.13 – 0.02	**.006**	− 0.08	− 0.13 – 0.02	**.005**	− 0.08	− 0.13 – 0.02	**.006**
AC × PtN							− 0.41	− 1.16 – 0.34	.283						
AAdo × PtN										-0.45	− 1.22 – 0.32	.246			
AAdu × PtN													− 0.49	− 1.21 – 0.23	.181
R^2 / R^2 adjusted	0.054 / 0.005			0.117/0.063			0.126 / 0.065			0.128 / 0.066			0.131 / 0.070		

$p < .05$ is highlighted in bold

Note. Pos-to-Neg = Positive-to-negative

$p = 0.246$, adulthood: $F(1,114) = 1.81$, $p = 0.181$. Hence, the interactive effect between adversity and updating was selective to negative-to-positive updating and adversity during childhood.

Finally, given the study's cross-sectional nature, we additionally sought to test the main model with PTSD symptom severity as the independent variable and updating as the outcome (See Supplementary 3).

Discussion

The study's primary aim was to examine the interactive effect of ACEs and reduce updating on the tendency to develop PTSD symptoms among individuals exposed to additional trauma in adulthood. As predicted, and in line with previous studies, we found a significant main effect of reduced negative-to-positive updating on PTSD symptoms (Haim-Nachum & Levy-Gigi, 2019; Levy-Gigi et al., 2015; Zabag et al., 2020). This effect demonstrates the type of updating that is required after trauma and the obstacle that trauma-exposed individuals often face. Individuals associate neutral but trauma-associated stimuli within their posttraumatic environments with danger or negative reminders of the traumatic event. They, therefore, struggle to learn that trauma-associated stimuli can predict safety when presented in a harmless environment. These results are in line with the predictive processing framework (Kube et al., 2020); according to this framework, traumatic experiences may affect individuals' prior hypotheses about the world and the relative precision attributed to these hypotheses. Traumatized individuals tend to have strong, danger-related hypotheses about their environments. Conversely, they lack the ability to use disconfirmatory information within their harmless environments to update these hypotheses. This may facilitate PTSD symptoms, especially intrusive re-experiencing, which triggers the re-selection of these maladaptive hypotheses and thoughts.

Interestingly, in contrast to our prediction, a similar significant main effect on PTSD symptoms was found for reduced positive-to-negative updating. Specially, these symptoms were correlated with a struggle to learn that a previously positive outcome could be later associated with a negative outcome, even when new contradictive information was presented. This finding may reflect a broader learning difficulty, suggesting that individuals with PTSD symptoms react in a similar manner independent of the updating valence. However, in line with previous findings (see, e.g., Levy-Gigi et al., 2014, 2015; Levy-Gigi & Richter-Levin, 2014), only reduced updating of negative-to-positive associations was correlated with ACEs to predict PTSD symptoms. Hence, we focused on this type of updating in the current study.

Moreover, we did not find significant correlations between ACEs and updating. This finding is in line with another study comparing children who had experienced abuse or neglect to controls and found no group differences in inhibitory control and cognitive flexibility (Augusti & Melinder, 2013). However, there are inconsistent findings in the literature with other studies showing the opposite pattern. For example, one study found correlations between child maltreatment and poor inhibitory control and cognitive flexibility (Fay-Stammbach & Hawes, 2019). Moreover, Weiss et al. (2019) found inverse associations between ACEs and updating. More research is needed to clarify the relationship between these variables.

Most importantly, we predicted and found a significant interaction between ACEs and reduced negative-to-positive updating on PTSD symptoms. These results extend previous research by signifying that for individuals with exposure to childhood adversity, reduced updating may be correlated with a tendency to develop PTSD symptoms following additional exposure to trauma in adulthood. Although preliminary and cross-sectional, these findings may additionally explain the inconsistent link between ACEs and PTSD symptoms (Stanley et al., 2021). Moreover, whereas prior work indicates that ACEs serve as a risk factor for PTSD following additional exposure to trauma during adulthood, our results suggest that this risk might be especially applicable to those who have reduced updating. This could shed light on the ongoing debate regarding how vulnerability versus resilience may emerge following trauma. That is, while some individuals might be vulnerable and show maladaptive outcomes such as PTSD symptoms following exposure to aversive and traumatic incidents (Bryant et al., 2015; for a review, see Bryant, 2019), others may experience resilience and post-traumatic growth (Bonanno, 2004; Martin-Soelch & Schnyder, 2019; for a review, see, Galatzer-Levy et al., 2018).

Furthermore, we found that the effect of adversity was significant only when it was experienced in childhood – but not in adolescence or adulthood. One possible explanation is that during the first years of life, the brain undergoes its most rapid development. Experiencing different levels of exposure to adversity during this period may have a profound impact on the limbic regions, which are important to adaptively cope with future trauma (Luby et al., 2019; Tottenham, 2020). Such alterations may not be evident if adversity occurs later in life (Luby et al., 2019; for further support, see animal studies, e.g., Richter-Levin & Jacobson-Pick, 2010; for reviews, see Tryon et al., 2021; Verbitsky et al., 2020). The findings stress the importance of differentiating between the effects of adversity in childhood compared to that in adolescence and adulthood. Ignoring this distinction could result in a failure to detect important associations of maladaptive adult outcomes. Future studies

may further address this point by comparing the effects of adversity experienced in childhood, adolescence, and adulthood on PTSD symptoms in populations who additionally experience adult trauma.

Our findings highlight possible leads for a cognitive intervention aiming to improve updating skills. Such an intervention could be particularly beneficial for children, as plasticity occurs more readily in their brains than in adults, and updating developmental processes decline in later life (Uddin et al., 2021). Future investigations may aim to train those who have experienced ACEs to increase their negative-to-positive updating skills to improve their coping with additional adult trauma and overall mental health. Furthermore, the results stress the importance of detecting updating patterns following ACEs among those likely to face adult trauma as part of their daily routines. It is possible that training individuals to increase their negative-to-positive flexible updating may buffer the deleterious effects of early adversity and adult trauma on PTSD symptoms.

Several limitations should be noted. First, the present study utilized an unpublished scale to assess adversity. Despite certain advantages of the scale, which allows the assessment of adverse and potentially traumatic events in relation to different developmental phases, future studies should consider using established instruments such as the Maltreatment and Abuse Chronology of Exposure scale (Teicher & Parigger, 2015) and/or the Child Trauma Questionnaire (Bernstein et al., 1994). Relatedly, we used a self-report measure to capture diverse aversive childhood experiences. Such scales are influenced by memory biases and have been found to be less accurate (for a review, see Baldwin et al., 2019). However, this is currently the most frequently used method to assess ACEs (see Bethell et al., 2017).

Additionally, future studies should aim to differentiate between distinct types and severity levels of ACEs (see McLaughlin & Sheridan, 2016; Negriff, 2020). This could improve our understanding of vulnerability to ACEs and inform PTSD diagnosis. In addition, due to the timing of the study, PTSD symptoms were assessed using the PCL-IV according to the DSM-IV criteria for PTSD, which does not include negative alterations in cognitions and mood. Future studies should seek to replicate our results with DSM-5 PTSD criteria. Furthermore, whereas the current demographic allows for the generalization of the findings to more segments of society, future examinations may test the relationship between ACEs and PTSD symptoms in one specific segment—clinically diagnosed individuals—and assess whether updating influences specific PTSD symptom clusters. Relatedly, further investigation would benefit from exploring this relationship among a more balanced sample, including both men and women, and a wider age range. Finally, the cross-sectional design of this study does not allow causal inferences regarding the relationship between reduced updating, ACEs, and PTSD symptoms. Specifically, while reduced updating could accelerate PTSD symptom development following ACEs and additional adult trauma, it is also possible that the presence of PTSD symptoms may impair updating performance. That is, the performance on the updating task may be the result of third variables related to or caused by PTSD symptoms such as reduced concentration, neuropsychological impairment, or attentional processes (Aupperle et al., 2012; Hayes et al., 2012; Sherin & Nemeroff, 2011; Summer et al., 2017). While this study serves as an important step in investigating possible PTSD mechanisms and paves the way for further research, future research should use longitudinal designs to assert the direction of these findings and to further confirm the specific updating index (general negative to positive and not context-related deficit; Levy-Gigi et al., 2015), that was not pre-defined prior to the current data collection.

To conclude, our findings highlight the role of reduced negative-to-positive updating in developing PTSD symptoms in individuals with different levels of ACE history and additional adult trauma exposure. The results provide an extension of the predictive processing framework (Kube et al., 2020) by suggesting that the ability to update information after trauma may interact with past experiences. That is, traumatic exposure alone may not be sufficient to alter predictive processing in a way that facilitates PTSD development. Rather, early adverse experiences may constitute a critical vulnerability factor that interacts with predictive processing upon trauma exposure in a way that results in the occurrence of PTSD symptoms. Hence, our findings suggest that preventing PTSD symptoms could be improved by identifying individuals with ACEs and reducing negative-to-positive updating. Such individuals should be the target population for preventive interventions, especially after adult trauma. The findings imply that increasing individuals' negative-to-positive updating skills may help reduce PTSD symptoms and improve current PTSD treatments. Such treatments could help buffer the deleterious effects of ACEs and adult trauma on individuals' mental health.

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Declarations

Conflict of Interest Haim-Nachum, Sopp, Bonanno and Levy-Gigi have not disclosed any competing interests.

Informed Consent Informed consent was obtained from all the participants included in the study.

Animal Rights Statements No animal studies were carried out by the authors for this article.

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