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Belief Updating, Childhood Maltreatment, and Paranoia in Schizophrenia-Spectrum Disorders

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***Background and Hypothesis*: Exposure to childhood maltreatment—a risk factor for psychosis that is associated with paranoia—may impact one's beliefs about the world and how beliefs are updated. We hypothesized that increased exposure to childhood maltreatment is related to volatility-related belief updating, specifically higher expectations of volatility, and that these relationships are strongest for threat-related maltreatment. Additionally, we tested whether belief updating mediates the relationship between maltreatment and paranoia. *Study Design*: Belief updating was measured in 75 patients with schizophrenia-spectrum disorders and 76 nonpsychiatric controls using a 3-option probabilistic reversal learning (3PRL) task. A Hierarchical Gaussian Filter (HGF) was used to estimate computational parameters of belief updating, including prior expectations of volatility (μ^0_3). The Childhood Trauma Questionnaire (CTQ) was used to assess cumulative maltreatment, threat, and deprivation exposure. Paranoia was measured using the Positive and Negative Syndrome Scale (PANSS) and the revised Green et al. Paranoid Thoughts Scale (R-GPTS). *Results*: Greater exposure to childhood maltreatment is associated with higher prior expectations of volatility in the whole sample and in individuals with schizophrenia-spectrum disorders. This was specific to threat-related maltreatment, rather than deprivation, in schizophrenia-spectrum disorders. Paranoia was associated with both exposure to childhood maltreatment and volatility priors, but we did not observe a significant indirect effect of volatility priors on the relationship between maltreatment and paranoia. *Conclusions*: Our study suggests that individuals with schizophrenia-spectrum disorders who were exposed to threatening experiences during childhood expect their environment to be more volatile, potentially facilitating aberrant belief updating and conferring risk for paranoia.**

Key words: threat/deprivation/volatility/decision-making/computational modeling

Introduction

Childhood maltreatment is a well-documented, transdiagnostic risk factor for psychopathology, including psychosis and schizophrenia.[1–5] Childhood maltreatment has been associated with the onset of psychotic experiences and psychotic disorders. A higher prevalence of childhood maltreatment is also found across psychosis stages including clinical high-risk, first-episode, and chronic populations.[6–9] This is clinically relevant because individuals with psychosis with a history of maltreatment exhibit greater functional impairment, more severe symptoms, poorer treatment response, and higher rates of suicidality.[10–12]

There is a growing body of evidence investigating the mechanisms underlying the pathway from child maltreatment to psychosis. Cognitive models suggest that childhood adversity leads to psychosis through cognitive distortions and dysfunctional information processing,[11,13–15] such that prior experiences prime expectations of the world and shape how new information is integrated. Early adversity has been related to maladaptive cognitive processes, which contribute to impaired decision-making in adulthood.[16,17] This process of integrating prior expectations and new observations to adjust beliefs and behavior is referred to as belief updating. Disturbances in belief updating processes are implicated

in the development and maintenance of psychotic symptoms.[18,19] Within this framework, delusions are thought to result from an overweighting of high-level prior expectations in the face of new observations, leading to false beliefs resistant to change[20]; furthermore, it has been suggested that individuals experiencing high paranoia may demonstrate greater resistance to changing beliefs.[18]

Computational psychiatry illuminates a mechanistic understanding of belief updating using Bayesian learning models, in which prior expectations are strengthened over time through experience.[21] One prior expectation is that of environmental volatility, which reflects how much change an individual anticipates in their environment. Higher volatility priors reflect the belief that the environment will change more frequently, impacting decision-making.[22,23] Previous work has demonstrated higher prior expectations of environmental volatility and more choice switching in individuals with schizophrenia, clinical high-risk samples, and people endorsing paranoia.[18,19,23,24] Furthermore, higher prior beliefs about volatility are specifically associated with increased paranoia in nonclinical samples and individuals with schizophrenia.[25,26] Yet, the question of why these higher volatility beliefs developed remains largely unanswered.[27]

Childhood maltreatment fosters a more unpredictable and volatile developmental environment[28,29] and is commonly associated with increased levels of paranoia.[30,31] We therefore hypothesize that exposure to childhood maltreatment contributes to higher prior expectations of volatility, conferring greater risk for paranoia. Croft et al found significant associations between childhood trauma, abnormal belief updating, and psychotic experiences, but found little evidence to support a mediation model in a large, population-based cohort.[32] While abnormal belief updating has been hypothesized to mediate the relationship between childhood adversity and psychotic experiences, particularly paranoia, no studies to date have looked at these relationships in clinical populations.[33]

Finally, while previous work has predominantly supported a model of global cumulative adversity,[15,30,34] there has been a recent shift toward investigating dimensional models of adversity. For example, the Dimensional Model of Adversity and Psychopathology, suggests that 2 discrete forms of adverse childhood experiences—deprivation and threat—are associated with partially distinct developmental outcomes.[35–40] Deprivation is the absence of expected environmental inputs (ie, neglect) and is associated with cognitive difficulties, including executive functioning, whereas threat is the presence of harmful environmental inputs (ie, abuse) and is associated with information and emotional processing difficulties.[39–41] Furthermore, it has been suggested that threatening and unpredictable environments are associated with cognitive distortions, facilitating the development of psychopathology,[13] including psychotic experiences.[42] Given that threat beliefs are at the core of paranoia,[43] we hypothesized that higher volatility priors would show a stronger association with threat-related maltreatment.

This study aims to investigate how childhood maltreatment relates to volatility-related belief updating and, in turn, paranoia in individuals with schizophrenia-spectrum disorders and nonpsychiatric controls. We hypothesize that increased exposure to childhood maltreatment is associated with higher prior expectations of volatility across the entire sample, and that this relationship is specific to threat-related maltreatment, not deprivation. Additionally, we test whether belief updating mediates the relationship between childhood maltreatment and paranoia.

Methods

Participants

A total of 82 individuals with a schizophrenia-spectrum disorder and 78 healthy control participants were recruited across 2 studies. To eliminate outliers, the win-switch rate was winsorized at the 5th and 95th percentiles. Nine total outliers were identified and excluded from further analysis. The final sample size for all analyses was 75 participants with schizophrenia-spectrum disorders and 76 healthy control participants.

Individuals ages 18–55 years were identified from the Vanderbilt University Medical Center Psychotic Disorders Program and Vanderbilt Psychiatric Hospital. Data included were collected as part of 2 studies conducted in the same laboratory at Vanderbilt University Medical Center under different IRB protocols (IRB# 201489 or IRB# 202462). Inclusion and exclusion criteria were the same across both studies, except that one was focused on schizophrenia-spectrum participants who were recently discharged from an inpatient setting (within the past 2 months) whereas the other study focused on stable outpatients with schizophrenia-spectrum disorders.

All participants were free of present or past physical or neurological illness, a history of significant head injury, and all had an estimated premorbid intelligence quotient of >79 (as determined by the Wechsler Test of Adult Reading[44]). Diagnoses were determined by either a Structured Clinical Interview of the DSM-IV-TR or DSM-5 completed by a trained rater and signed off in a consensus meeting (IRB# 201489) or through review of the participant's electronic medical record, with a schizophrenia-spectrum disorder as their most recent diagnosis made by their treating physician (IRB# 202462). The group with schizophrenia-spectrum disorders included 35 individuals with schizophrenia, 18 with schizoaffective disorder, 21 with schizophreniform disorder, and 1 with psychotic disorder not otherwise specified. Healthy control participants did not have a first-degree relative with a psychotic disorder or any current psychotropic medication use. Healthy control participants with a history of a mild or moderate depressive episode, past mild substance use disorder (alcohol or cannabis), or past

anxiety disorder (not meeting criteria in the past 6 months) were allowed to participate under IRB# 202462. All other controls were free of any lifetime mental health diagnoses. Study protocols were approved by the Vanderbilt Institutional Review Board, and informed consent was provided by all research participants before study participation. Given some of the differences in samples across the pooled studies, the study was included as a covariate in our analyses. Of note, the subset of data from IRB# 201489 on relationships between belief updating and paranoia has been previously reported.[25,45]

Study Measures

Childhood Maltreatment Childhood maltreatment was measured using the Childhood Trauma Questionnaire—Short Form (CTQ-SF),[46] a 28-item self-report measure that retrospectively assesses childhood maltreatment. Items on the CTQ-SF are rated on a 5-point, Likert scale with response options ranging from Never True to Very Often True. The CTQ-SF provides scores on 5 subscales (physical abuse, physical neglect, emotional abuse, emotional neglect, and sexual abuse) as well as a cumulative maltreatment score calculated by summing all 5 subscales. The CTQ-SF has been shown to have a replicable factor structure as well as good sensitivity and convergent validity in both clinical and community samples.[47]

For analyses looking at dimensions of maltreatment, the threat dimension of maltreatment was measured using the physical, emotional, and sexual abuse CTQ-SF subscales, and the deprivation dimension of maltreatment was measured using the physical and emotional neglect CTQ-SF subscales, in line with previous work.[48] To account for the different number of subscales in each dimension creating different ranges in scores, each dimension was defined as the average of the subscales within it.

For categorical analyses, exposure to maltreatment was based on the subscale cutoff scores previously defined in the CTQ manual.[47] For each subscale, the cutoff scores indicate which of the following groups a score falls into none-to-low exposure, low-to-moderate exposure, moderate to severe exposure, and severe to extreme exposure. Exposure to threat-related maltreatment was defined as at least one of the 3 CTQ abuse subscale scores reaching or surpassing low-to-moderate exposure, and no exposure was defined as all 3 CTQ abuse subscale scores falling within the none-to-low exposure range. Exposure to deprivation-related maltreatment was defined as at least one of the 2 CTQ neglect subscale scores reaching or surpassing low-to-moderate exposure, and no exposure was defined as both scores falling within the none-to-low exposure range.

Paranoia Self-reported paranoia was measured across all participants using the revised Green et al. Paranoid Thoughts Scale (R-GPTS),[49] which contains a 10-item subscale measuring persecutory ideation (R-GPTS-Part B) that was used as our measure of paranoia. Items are measured on a 5-point Likert scale and total scores range from 0 to 40.

Interview-rated paranoia was also assessed in the schizophrenia group using the Suspiciousness/Persecution item (P6) of the Positive and Negative Syndrome Scale (PANSS).[50] This scale includes 30 items scored on a 7-point scale to measure the severity of positive (7 items), negative (7 items), and general (16 items) symptoms, and is considered a reliable and comprehensive measure of psychotic symptoms.[51] Higher P6 scores reflect more severe persecutory delusions.

Cognitive Impairment Cognitive impairment was measured using the Screen for Cognitive Impairment in Psychiatry (SCIP),[52] a brief screening tool comprised of 5 sub-tests: working memory, immediate verbal memory, delayed verbal memory, verbal fluency, and processing speed. SCIP raw scores were converted to *z* scores using published normative data.[52]

Anxiety Anxiety was measured using the Beck Anxiety Inventory, a self-report measure of anxiety that has shown high internal consistency and test-retest reliability.[53]

Behavioral Task (3PRL)

Belief updating was measured using a nonsocial 3-option probabilistic reversal learning (3PRL) task (supplementary figure S1A). Participants were presented with 3 decks of cards on a computer screen and were told that each deck contained a mix of winning (+100 points) and losing (−50 points) cards in differing amounts. They were instructed to find the best deck (the deck with the most winning cards, or the highest probability for reward) to win as many points as possible. Participants were informed that the best deck might change at any time and that, if they believed it had, they were to find the new, best deck. Unknown to the participant, the task was designed such that the best deck changed every time the participant selected it in 9 out of 10 consecutive trials (reversal events).[54] This reversal learning task creates an expectation of environmental volatility, as the participant is aware that the best deck might change but is unaware of when or how frequently that change might occur. Participants completed 160 trials divided into 4 blocks, with a break between each block.

Additionally, unbeknownst to the participant, and to increase the experience of volatility, the contingencies of the 3-deck choices changed halfway through the task, while the probability of a reversal event occurring remained the same. During blocks 1 and 2, the win contingencies of the 3 decks were 90% reward, 50% reward, and 10% reward; in blocks 3 and 4, these contingencies

Table 1. Participant Demographics

	Healthy Control Participants, $n = 76$	Schizophrenia Participants, $n = 75$	Statistic
Age, y, mean (SD)	30.6 (7.1)	27.9 (6.6)	$t_{148} = 2.35$, $P = .02$
Sex, F/M/Other	28/47/1	20/54/1	$X3 = 3.81$, $P = .28$
Race, Black/White/Other	15/55/6	23/44/7	$X5 = 4.36$, $P = .50$
Personal education, y, mean (SD)	17.2 (2.4)	14.4 (2.5)	$t_{149} = 6.97$, $P < .001$
Parental education, y, mean (SD)	15.2 (2.6)	14.8 (2.7)	$t_{138} = 0.80$, $P = .42$
Premorbid IQ, mean (SD)	114.4 (9.1)	104.8 (13.0)	$t_{132} = 5.27$, $P < .001$
SCIP, total *z* score, mean (SD)	0.2 (0.8)	−0.8 (1.1)	$t_{137} = 6.59$, $P < .001$
Duration of illness, y, mean (SD)	—	7.1 (6.7)	—
PANSS Positive, mean (SD)	—	16.3 (5.8)	—
PANSS Negative, mean (SD)	—	14.4 (6.0)	—
PANSS General, mean (SD)	—	30.6 (8.8)	—

Note: F, female; IQ, intelligence quotient; M, male; PANSS, Positive and Negative Syndrome Scale; SCIP, Screen for Cognitive Impairment in Psychiatry.

changed to 80% reward, 40% reward, and 20% reward. This transition halfway through the task introduced additional volatility to the task environment and made it more difficult for participants to distinguish between probabilistic errors and errors that signify a reversal event.

Behavioral Analysis The 2 behavioral measures of interest were win-switch and lose-stay rates. The win-switch rate indicates how frequently a participant selected a winning card (+100 points) from 1 deck and subsequently chose a different deck on the next trial. Win-switch rates were calculated as the number of win-switch decisions divided by the total number of trials in which the participant selected a winning card. Lose-stay rate indicates how frequently a participant selected a losing card (−50 points) from 1 deck and subsequently chose the same deck on the next trial. Lose-stay rates were calculated as the number of lose-stay decisions divided by the number of trials in which the participant selected a losing card.

Computational Modeling

Computational modeling was performed on 3PRL task data using the Hierarchical Gaussian Filter (HGF) toolbox v5.3.1[55,56] in MATLAB (version 2020b; The MathWorks, Inc.) (supplementary figure S1B). The model consists of 3 hierarchical belief layers about the reversal learning task that are depicted as probabilities encoding content and uncertainty about beliefs. The first layer represents reward beliefs (What was the outcome of the last trial?); the second layer represents contingency beliefs (What are the current values of the deck options?); and the third layer represents volatility beliefs (How do the values of my options change over time?).[26] Based on previous literature looking at these parameters in schizophrenia[23] and relationships with paranoia,[25,26,54] our primary computational parameters of interest were μ^0_3, κ, and ω_3. μ^0_3 was our main parameter of interest, as it estimates volatility priors, or how volatile the participant believes the task environment is before encountering any evidence. Higher μ^0_3 indicates an expectation that the task will shift more erratically, or that the environment is unstable. We were also interested in κ, which estimates the sensitivity to perceived task volatility, or how the participant uses unexpected changes to update their beliefs. ω_3 estimates the meta-volatility learning rate, or how quickly the participant adjusts their beliefs about the task volatility. Higher ω_3 indicates a faster learning rate about the volatility of the task. Previous work has suggested that paranoia is associated with the following pattern: higher μ^0_3, higher κ, and lower ω_3.[23,25,54]

As previously described,[25,26] belief updating parameters were estimated separately for each reward contingency (90–50–10 and 80–40–20) and then averaged. The deck choice (deck 1, 2, or 3) and outcome (win or loss) were entered as separate column vectors for each block. We used the autoregressive 3-level HGF multi-arm bandit configuration for the perceptual model, paired with the softmax-μ^0_3 decision model. Scripts used in the current analysis are publicly available at https://github.com/JuliaSheffield/CogMech_delusions.

Parameter recovery was performed, and results can be found in supplementary figure S2. Recovered and actual parameters were significantly correlated for all parameters, across the whole group (Ps < .008) and within the schizophrenia group (Ps < .03).

Data Analysis

Data analysis was conducted in Rstudio (version 4.2.1). The final sample size for all analyses was 76 healthy control participants and 75 participants with schizophrenia-spectrum disorders. Participant demographics were compared between groups (table 1).

A Shapiro-Wilk test was used to test for normality of childhood maltreatment, belief updating measures, and paranoia. No variables were normally distributed; therefore, nonparametric association tests were used to examine relationships between childhood maltreatment, belief updating, and paranoia. Mann-Whitney tests were used to evaluate group differences. Relationships between

Table 2. Group Differences

	Controls	Schizophrenia	*P* of *U* Test
Childhood maltreatment			
Cumulative, median	29	38	<.001
Deprivation, median	11	16	<.001
Threat, median	17	22	<.001
Computational parameters			
μ^0_3, median	−0.57	−0.05	.02
κ, median	0.46	0.47	.35
ω_3, median	−0.75	−0.80	.69
Behavior			
Win-switch rate, median	0.02	0.07	<.001
Lose-stay rate, median	0.27	0.11	.002
Paranoia			
GPTS-B, mean (SD)	1.36 (2.6)	6.97 (11.6)	.002
P6, mean (SD)	—	3.07 (1.4)	—

Note: GPTS, Green Paranoid Thoughts Scale; PANSS, Positive and Negative Syndrome Scale.

childhood maltreatment and belief updating measures were analyzed using partial Spearman correlations, controlling for age, sex, study, and, in whole-group analyses, diagnostic group. Additionally, deprivation-related maltreatment was controlled for in all partial Spearman correlations with threat-related maltreatment, and vice versa, to examine the specificity of maltreatment dimensions.

Indirect effect models with the same covariates were used to test whether belief updating mediated the relationship between childhood maltreatment and paranoia. These models were conducted using the "mediation" R package for causal mediation analysis, which uses 1000 bootstraps to determine 95% CIs.[57] This method decomposes the total effect into the average causal mediation effect (ACME) and average direct effect.

A priori associations between cumulative maltreatment, threat-related maltreatment, μ^0_3, and paranoia were uncorrected for multiple comparisons. Additional analyses examining relationships with deprivation-related maltreatment, ω_3, κ, task behavior, and paranoia were Bonferroni corrected for multiple comparisons.

Results

Group Differences

Group differences in childhood maltreatment, computational parameters, and task behavior are presented in table 2.

Childhood Maltreatment Individuals with schizophrenia-spectrum disorders reported greater cumulative exposure to childhood maltreatment ($P < .001$), which included greater exposure to both threat and deprivation dimensions of maltreatment (Ps < .001).

3PRL Performance There was no significant difference in performance, measured by the final score achieved during the task, between the 2 groups (Cohen $d = -0.16$, $P = .37$), suggesting no difference in how well individuals with schizophrenia-spectrum disorders and healthy controls understood and performed the task. Individuals with schizophrenia-spectrum disorders exhibited significantly more win-switch ($P < .001$) and less lose-stay ($P = .002$) behavior. Individuals with schizophrenia-spectrum disorders demonstrated higher μ^0_3 compared with healthy control participants ($P = .02$), but there were no significant group differences in κ or ω_3. Based on these findings, in addition to our a priori hypotheses regarding volatility priors (μ^0_3) we focus the presentation of our analyses on μ^0_3. Analysis of κ and ω_3 is presented in Supplementary Materials.

Paranoia Individuals with schizophrenia-spectrum disorders endorsed greater self-reported paranoia compared with healthy control participants ($P = .002$).

Cumulative Childhood Maltreatment and Belief Updating

In the whole group, there were no significant relationships between childhood maltreatment and behavioral measures (neither win-switch nor lose-stay behaviors). Similarly, childhood maltreatment was not significantly associated with behavior in the schizophrenia group. We therefore did not investigate these associations further.

Across the whole sample, greater cumulative exposure to childhood maltreatment was significantly associated with higher μ^0_3 ($\rho = 0.21$, $P = .01$; figure 1A). We then investigated the diagnostic groups separately to determine whether these relationships were similar across groups or were specific to 1 diagnostic group. In the schizophrenia group, greater cumulative exposure to childhood maltreatment was associated with higher μ^0_3 ($\rho = 0.29$, $P = .01$; figure 1B) but this relationship did not reach significance in the healthy control cohort ($\rho = 0.11$, $P = .37$).

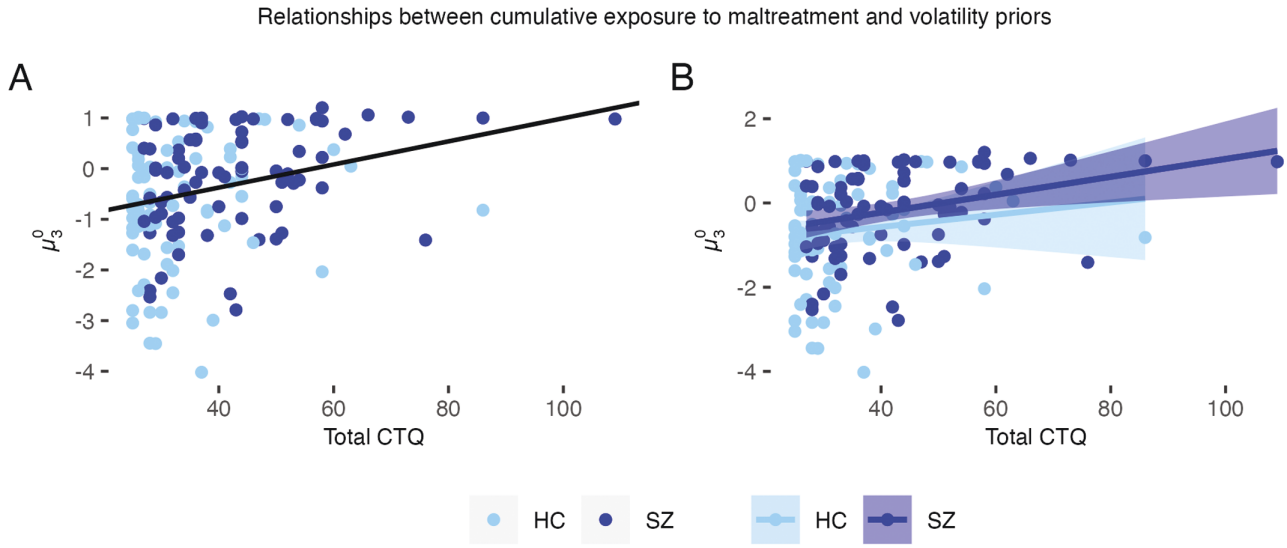

Fig. 1. Greater cumulative exposure to childhood maltreatment was significantly associated with higher μ^0_3 (A) across the entire sample ($\rho = 0.21$, $P = .01$) and (B) in individuals with schizophrenia-spectrum disorders ($\rho = 0.29$, $P = .01$).

Cumulative Childhood Maltreatment and Paranoia

Across the whole sample, cumulative exposure to childhood maltreatment was associated with self-reported paranoia ($\rho = 0.27$, $P = .001$). In the schizophrenia group, interviewer-rated paranoia was associated with cumulative maltreatment ($\rho = 0.26$, $P = .02$).

Belief Updating and Paranoia

Across the whole sample, self-reported paranoia was associated with μ^0_3 ($\rho = 0.20$, $P = .02$), such that more intense paranoia was associated with greater volatility priors. In the schizophrenia group, interviewer-rated paranoia was also associated with μ^0_3 ($\rho = 0.28$, $P = .02$).

Indirect Effect Models

Given significant associations between cumulative childhood maltreatment, μ^0_3, and self-reported paranoia in the whole group, we conducted an indirect effects analysis to determine whether μ^0_3 explained a significant proportion of the variance in the relationships between maltreatment and paranoia. Results revealed that there was not a significant indirect effect of μ^0_3 (ACME: 0.001, 95% CI [−0.02, 0.02], $P = .86$) on the relationship between childhood maltreatment and paranoia in the whole sample. The same was true when looking only within the schizophrenia group (ACME: 0.005, 95% CI [−0.001, 0.01], $P = .10$).

Dimensions of Maltreatment: Threat and Deprivation

We conducted the above analyses examining associations with threat and deprivation. In the whole group, μ^0_3 was not significantly associated with either exposure to threat- or deprivation-related maltreatment (Ps > .05). In the schizophrenia group, greater exposure to threat-related maltreatment ($\rho = 0.27$, $P = .02$), but not deprivation-related maltreatment ($P > .05$), was associated with higher μ^0_3 (figure 2).

We also considered maltreatment categorically to investigate whether exposure to threat- and deprivation-related maltreatment was associated with differences in volatility priors in the schizophrenia group. We separated the schizophrenia group into 2 groups: no exposure to threat-related maltreatment ($n = 31$) and exposure to threat-related maltreatment ($n = 44$). We found that the 2 groups significantly differed in μ^0_3 (Cohen $d = -0.65$, $P = .005$; figure 3A), with the threat-maltreatment group showing higher volatility priors. Additional analyses examining group differences in duration of illness and symptom severity are presented in Supplementary Materials. We then separated the schizophrenia group into 2 groups: no exposure to deprivation-related maltreatment ($n = 35$) and exposure to deprivation-related maltreatment ($n = 40$). We found that the 2 groups did not significantly differ in μ^0_3 (Cohen $d = -0.36$, $P = .21$; figure 3B).

Full results on threat and deprivation dimensions are presented in supplementary table S1. We also present exploratory analyses looking at specific subtypes of maltreatment (eg, sexual abuse, physical abuse) and belief updating (supplementary table S2).

Sensitivity Analyses

We also explored relationships between maltreatment and the parameters of κ and ω_3. In the schizophrenia group, greater cumulative exposure to childhood maltreatment was significantly associated with lower ω_3

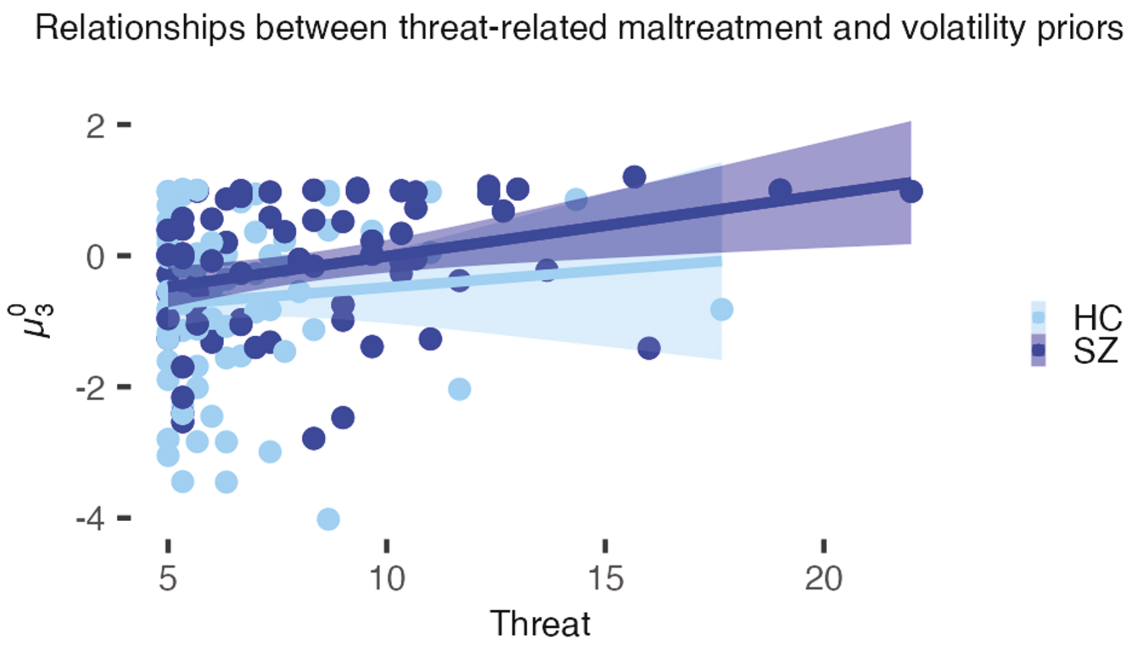

Fig. 2. In individuals with schizophrenia-spectrum disorders, greater exposure to threat-related maltreatment was associated with higher μ^0_3 ($\rho = 0.27$, $P = .02$). This relationship was not significant in the healthy control group ($\rho = 0.02$, $P = .85$).

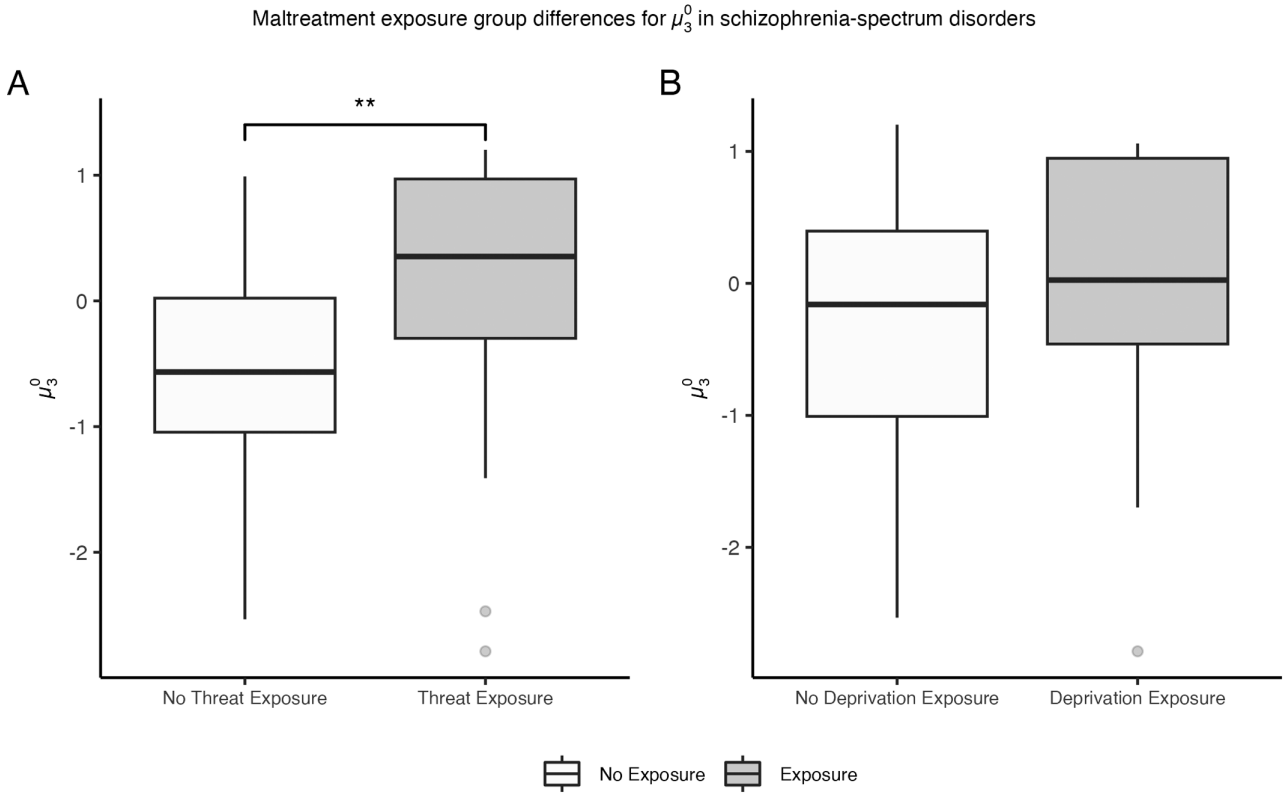

Fig. 3. In individuals with schizophrenia-spectrum disorders, (A) exposure to threat-related maltreatment was associated with higher μ^0_3 and (B) exposure to deprivation-related maltreatment was not associated with differences in μ^0_3. $^{**}P < .01$.

($\rho = -0.41$, $P_{corrected} < .001$) after correcting for multiple comparisons. Full analyses are presented in Supplementary Materials.

Given prior work suggesting childhood maltreatment contributes to cognitive deficits, and belief updating is a cognitive task, we explored whether the observed

relationships remained when controlling for total cognitive ability, as measured by the SCIP. We found that all significant relationships remained significant; these results are presented in supplementary table S3.

Additionally, prior work has implicated atypical belief updating in anxiety disorders.[18] Thus, we conducted sensitivity analyses to examine the impact of anxiety symptoms on observed relationships between volatility priors and childhood maltreatment. We found that all significant relationships remained significant; in the whole group, μ^0_3 remained significantly associated with cumulative childhood maltreatment ($\rho = 0.22$, $P = .01$) and, in schizophrenia, μ^0_3 remained significantly associated with both cumulative maltreatment ($\rho = 0.31$, $P = .01$) and threat-related maltreatment ($\rho = 0.30$, $P = .01$) when controlling for anxiety symptoms.

Discussion

This study assessed whether exposure to childhood maltreatment was associated with atypical belief updating, and whether belief updating had a significant indirect effect on the relationship between childhood maltreatment and paranoia. We found that individuals with schizophrenia-spectrum disorders have both higher expectations of volatility and report greater exposure to childhood maltreatment, consistent with prior literature.[5,23,42] We further reveal that greater exposure to childhood maltreatment was associated with higher expectations of volatility (that the environment is frequently changing). This relationship was observed across the whole sample and in individuals with schizophrenia-spectrum disorders but did not reach significance in the nonpsychiatric controls alone. Finally, we offer preliminary findings that associations between volatility priors and maltreatment in schizophrenia-spectrum disorders may be stronger for threat-related maltreatment. Supplemental results revealed that these relationships were robust to individual differences in cognitive ability and extended to the parameter of meta-volatility learning rate (ω_3). This latter finding suggests that maltreatment is related to slower learning about environmental volatility, possibly due to a more rigid prior expectations about volatility. Our findings suggest that exposure to maltreatment during childhood, particularly threat-related maltreatment, may promote greater expectations that one's own environment is volatile, impacting decision-making and conferring risk for paranoia.

Greater exposure to childhood maltreatment was associated with greater prior expectations of volatility and a slower meta-volatility learning rate in people with schizophrenia-spectrum disorders. Additionally, we found that these relationships were stronger for threat-related maltreatment than deprivation-related maltreatment. Taken together, exposure to childhood maltreatment, specifically threat-related maltreatment, may contribute to higher expectations of volatility in adulthood, which, in turn, influences decision-making. Critically, childhood maltreatment fosters a more unpredictable and volatile developmental environment.[28,29] Past literature has associated childhood adversity with altered decision-making in adulthood; for instance, childhood maltreatment has been associated with impaired decision-making in emerging adulthood via executive attention difficulties[17] and with maladaptive risk-taking behaviors and judgments in adulthood via altered reward processing.[16] Here, we show for the first time that greater exposure to childhood maltreatment is associated with higher volatility priors during a decision-making task, thus suggesting another pathway through which childhood maltreatment may contribute to altered decision-making in adulthood. Longitudinal data are needed to determine whether this relationship is causal.

Additionally, we found that exposure to childhood maltreatment is associated with self-reported paranoia across our whole sample. In people with schizophrenia-spectrum disorders, threat-related maltreatment, but not deprivation, was significantly associated with clinician-rated persecutory beliefs. The relationship between cumulative childhood adversity and paranoia has been previously established in nonclinical and clinical samples.[58–60] It has been suggested that maladaptive cognitive, emotional, and behavioral responses to suspicious or mistrustful thoughts may contribute to the pathogenesis of psychopathology,[61] including the endorsement of persecutory delusions.[62] Additionally, prior work has suggested that events involving psychological threats (eg, emotional abuse) may be associated with paranoia in individuals with schizophrenia and, more broadly, that exposure to hostile or threatening experiences may contribute to the onset of psychotic experiences and disorders in some individuals.[8,30,42,59] Here, we show that exposure to threatening experiences in childhood is associated with persecutory beliefs in adults with schizophrenia. Importantly, one pathway that harmful experiences in childhood may confer risk for psychopathology is through paranoid thoughts and one's response to them. However, future longitudinal data are needed to elucidate the temporal and causal interactions.

Finally, childhood maltreatment, volatility priors, and paranoia were interrelated both in the whole group and in individuals with schizophrenia-spectrum disorders. These findings are consistent with previous work that has implicated atypical belief updating—specifically higher volatility priors—in paranoid thinking, in both nonclinical and clinical samples.[25,26,54] Here, we have demonstrated that exposure to childhood maltreatment, particularly threat-related maltreatment, may be one factor that contributes to those higher volatility priors, suggesting that individuals with a history of maltreatment may expect their environment to be more volatile and experience elevated paranoia. Recent literature has also suggested that

unpredictability may serve as a third, distinct dimension of childhood maltreatment, which was not independently considered within the scope of this project, as it is not measured by the CTQ, but has been associated with mental health outcomes and may be particularly relevant for volatility-related belief updating.[39,63–65]

Importantly, we did not find evidence to support a cross-sectional mediation model, similar to the only other study to date that has examined relationships between these 3 variables.[32] While it is possible that belief updating processes may not be implicated in the mechanism linking childhood adversity and paranoia, it is also possible that we were not able to capture the complexity of these relationships in the present study. For example, unpredictability may be the dimension of childhood maltreatment most integral to this model, and the measures used in the present study did not capture this dimension distinctly. Furthermore, prior work has suggested that childhood maltreatment leads to psychosis, including paranoia, via maladaptive schemas,[30,66] and it is possible that aberrant belief updating processes interact with those schemas thereby contributing to the onset and maintenance of psychosis, but that belief updating alone is not enough. Lastly, our study focused on belief updating as a potential mechanism explaining the association between childhood maltreatment and paranoia, to follow closely from published work demonstrating specific associations between volatility-related belief updating and paranoia.[25] As noted in our supplement, however, elevated childhood trauma is associated with higher positive symptoms overall, in line with recent work from our group.[67] Therefore, although research on volatility suggests specific relationships with paranoia, a broader investigation between childhood maltreatment, volatility, and multiple schizophrenia-spectrum symptoms may be warranted in the future.

Our findings should be interpreted in the context of certain limitations. First, we must acknowledge the limitations of utilizing the CTQ, a retrospective self-report, to assess for exposure to childhood maltreatment. First, it is possible that the measure did not accurately capture participants' experiences due to nondisclosure or impaired memory of maltreatment experiences.[68] Second, it did not include a comprehensive assessment of all types and dimensions of maltreatment experiences in this study; abuse and neglect are only 2 indicators of exposure to threat and deprivation, respectively, and unpredictability remains largely understudied in the context of psychopathology, including in the present study. Third, this measure of maltreatment did not assess the age of the child at the time when the exposure occurred. A wealth of research shows that experiencing adversity can have different effects based on the age of the child and that trauma during specific critical periods of neurodevelopment can be particularly deleterious.[69] Future research should aim to examine how exposure to different dimensions of childhood maltreatment at specific stages of development contributes to differences in belief updating and positive symptoms of psychosis.

Another limitation is that we utilized the SCIP, a brief screening tool, to assess for cognitive deficits; a more comprehensive cognitive battery may reveal other associations between individual differences in belief updating and cognition. For example, social cognition, which is not assessed by the SCIP, may be an important factor influencing the association between maltreatment and paranoia. Thus, future studies may aim to utilize a more comprehensive assessment of cognition to provide more robust conclusions. Additionally, we utilized nonparametric tests that did not allow for the test of interactions and reduced our ability to examine specificity more definitively in linear relationships. Finally, making inferences about a developmental process in the context of cross-sectional data in adults is limited. Future longitudinal research, for instance in youth at clinical high risk for psychosis, is needed to truly elucidate these relationships.

Despite these limitations, our findings highlight childhood maltreatment as a potential contributing factor to higher prior expectations of volatility in schizophrenia-spectrum disorders, conferring risk for paranoia. This relationship may be particularly strong or perhaps even specific to threat-related maltreatment, such that individuals with schizophrenia-spectrum disorders who were exposed to harm during childhood expect their environment to be more volatile, potentially facilitating aberrant belief updating. Understanding the implications of early adversity, and how discrete dimensions of adversity contribute to different symptoms and outcomes, is critical to inform the development of effective interventions. Volatility priors, eg, may serve as a potential treatment target for individuals exposed to childhood maltreatment to prevent the onset or attenuate the severity of psychotic symptoms, including paranoid thinking.

Supplementary Material

Supplementary material is available at https://academic.oup.com/schizophreniabulletin/.

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