



Alpha EEG asymmetry, childhood maltreatment, and problem behaviors: A pilot home-based study

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ABSTRACT

Background: Child maltreatment, trauma symptoms, and alpha electroencephalography (EEG) asymmetry have been linked to problem behaviors and alcohol use disorders.

Objective: The goal of this pilot study was to clarify the role of alpha EEG asymmetry in the relation of maltreatment and problem behaviors. It was hypothesized that adolescents with more maltreatment, trauma symptoms, and right alpha EEG asymmetry would have more problem behaviors and alcohol use. It was also hypothesized that alpha EEG asymmetry would moderate the association between maltreatment/trauma symptoms and problem behaviors.

Participants and Setting: Participants were 52 adolescents aged 12–14 years. Resting-state alpha EEG asymmetry was measured in this home-based study as a potential moderator in the association of child maltreatment and trauma symptoms to problem behaviors including alcohol use. **Results:** Child maltreatment reports and trauma symptoms were significantly associated with problem behaviors ($\beta = 0.259$, $p = 0.037$ and $\beta = 0.594$, $p < 0.001$, respectively). Trauma symptoms were associated with alcohol-use (*Incidence Rate Ratio* = 1.048, $p = 0.032$). Right alpha EEG asymmetry moderated the positive association of trauma symptoms and problem behaviors ($\beta = -0.383$, $p = 0.024$). However, this was not the case for left alpha EEG asymmetry.

Conclusions: Neural correlates associated with individuals' affective-behavioral profiles may play a role in the susceptibility for problem behaviors among adolescents exposed to higher levels of childhood trauma. This could be useful in developing targeted assessments and interventions to prevent or treat these problems in adolescents.

1. Introduction

A large and diverse section of the developmental literature focuses on those who experience some form of adverse life event as children (for a review, see De Venter, Demyttenaere, & Bruffaerts, 2013). One specific domain of adversity is child maltreatment, which is defined as a parent or caretaker's action or inaction (abuse or neglect) that leads to any kind of harm, death, or risk of harm to a child (US Department of Health & Human Services, 2011). Recent estimates report that 6.3 million children were reported as victims of maltreatment in the United States in 2012, but this number likely underestimates the problem due to underreporting (US

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Department of Health & Human Services, 2013). Child maltreatment puts victims at a greater immediate and long-term risk for negative effects in many developmental domains, including cognitive function (De Bellis, Hooper, Spratt, & Woolley, 2009; De Bellis, Woolley, & Hooper, 2013; Nikulina & Widom, 2013), peer relationships (Kim & Cicchetti, 2010), physical health (Springer, Sheridan, Kuo, & Carnes, 2007), and problem behaviors (Kim & Cicchetti, 2010), as well as adverse brain development (De Bellis, 2001).

Problem behaviors include thoughts or actions that may be disruptive in nature, represent an error in judgment, or relate to worry or low mood (Manly, Cicchetti, & Barnett, 1994; Vachon, Krueger, Rogosch, & Cicchetti, 2015). Vachon et al. (2015) found similar patterns of problem behaviors across all types of maltreatment, and across gender and race. These problem behaviors can lead to common mental health problems in children and adolescents, including anxiety, depression, attention deficit hyperactivity disorder (ADHD), oppositional defiant disorder (ODD), and substance use disorders (SUD; De Bellis, 2001; Lee, Humphreys, Flory, Liu, & Glass, 2011; Mesman & Koot, 2001).

The current pilot study examines the increased risk of alcohol use following maltreatment. As demonstrated by the seminal Adverse Childhood Experiences (ACE) study, adversity in childhood, particularly child maltreatment, contributes to alcoholism in adulthood (Dube et al., 2006; Felitti, 1998). Adults who reported more ACEs as children were found to have an increased likelihood of early first alcohol use in early- and mid-adolescence, and alcohol abuse as adults, regardless of family history of alcohol use (Dube, Anda, Felitti, Edwards, & Croft, 2002, 2006). Early age of onset of alcohol and marijuana use was seen in a longitudinal study by Proctor et al. (2017) that focused specifically on individuals with documented child maltreatment histories from Child Protective Services (CPS). Children who experienced maltreatment started using substances, including alcohol, at an earlier age, and were more likely to abuse them as adults (for a review see De Bellis, 2001). Taken together, these studies demonstrate that exposure to childhood maltreatment is associated with increased and persistent patterns of alcohol misuse throughout the lifespan, including the development of alcohol use disorders (Dube et al., 2002; Kilpatrick et al., 2000).

Identifying child maltreatment after mental health symptoms emerge typically means that an individual has suffered impairment (Cicchetti & Olsen, 1990). Therefore, it is important to identify mechanisms of child maltreatment risk and resilience earlier to prevent mental health problems, including alcohol- and substance-use disorders (Brown, Cohen, Johnson, & Salzinger, 1998). Resilience is defined as a healthy adjustment in response to adversity (Masten, 2011); for example, a maltreated child who did not show internalizing or externalizing problem behaviors following abuse could be considered resilient (Kim-Cohen, 2007). Recent research has examined neural mechanisms, such as functional or structural differences in the brain, which may underlie risk and resilience for developing problem behaviors in maltreated children. Some structural differences found to result from experiencing trauma symptoms following maltreatment include reduced myelination and grey matter volume, particularly in brain regions involved in emotion processing, decision-making, and working memory (De Bellis et al., 2015; McLaughlin, Sheridan, & Lambert, 2014; Morey, Haswell, Hooper, & De Bellis, 2016; Thomaes et al., 2010).

An electrophysiological measure that has been linked to risk and resilience of problem behaviors among maltreated children is alpha electroencephalography (EEG) asymmetry (e.g., Curtis & Cicchetti, 2007; Tang et al., 2018), which measures the lateralization of electrical brain activity at rest. Patterns of alpha EEG asymmetry are thought to reflect one's pattern of emotional and behavioral responses to the environment; individuals with right EEG asymmetry have been found to have bias towards negative emotions and withdraw-related behaviors. In contrast, individuals with left EEG asymmetry have been found to have bias towards positive emotions and approach-related behaviors (Davidson, 1994; Fox, 1991).

Increased right EEG asymmetry is most commonly associated with problem behaviors, such as low mood and social withdrawal in adolescence (Stewart, Towers, Coan, & Allen, 2011). Studies in adults also suggest that right EEG asymmetry is associated with a host of problems including negative emotions, depression, anxiety, impaired extinction of conditioned fear responses, and even reduced immune activity (Coan & Allen, 2003; Davidson, 1994; Hagemann, Naumann, Thayer, & Bartussek, 2002; Harmon-Jones, Gable, & Peterson, 2010; Metzger et al., 2004). In meta-analyses of children exposed to psychosocial risk factors, such as maternal depression and child maltreatment, right frontal alpha EEG asymmetry was significantly associated with psychosocial risk factors with a combined effect size of $d = 0.36$ (Peltola et al., 2014). However, in these meta-analyses, direct and indirect relationships between EEG asymmetry and problem behaviors were not determined.

Other investigations of alpha EEG asymmetry in maltreated children and adolescents have identified right alpha EEG asymmetry as a risk factor for worse outcomes, including depression, PTSD, and elevated inflammation (Hostinar et al., 2017; Miskovic, Schmidt, Georgiades, Boyle, & MacMillan, 2009; Tang et al., 2018). Prior work by Curtis and Cicchetti (2007) also found that maltreated children showed greater right frontal and parietal alpha EEG asymmetry. Among infants exposed to deprivation due to institutional rearing, right frontal alpha EEG asymmetry in infancy predicted more problem behaviors in childhood (McLaughlin, Fox, Zeanah, & Nelson, 2011). Furthermore, these authors found that among maltreated children, those with greater left frontal alpha EEG asymmetry were resilient to PTSD (McLaughlin et al., 2011). While these results from adults and children indicate that alpha EEG asymmetry could be a mechanism or susceptibility marker underlying risk and resilience to mental health and related substance-use disorders among maltreated youth, several important gaps remain in the literature.

First, previous studies show methodological limitations, such as retrospective self-reports of child maltreatment (e.g. Hostinar et al., 2017) and unrepresentative samples which include only girls (e.g., Tang et al., 2018). Second, few studies have examined brain correlates and substance-and alcohol-use in adolescence among youth exposed to maltreatment. Adolescence is an important developmental period in which substance- and alcohol-use first emerges and can have lasting deleterious effects on brain functioning (Benjet, Borges, & Medina-Mora, 2010; Medina, Schweinsburg, Cohen-Zion, Nagel, & Tapert, 2007; Tapert et al., 2003). Thus, identifying neural correlates that may underlie risk for substance and alcohol use is important for developing preventive interventions before serious use patterns emerge (Dube et al., 2006; Medina et al., 2007).

In the current home-based pilot study of adolescents, we examined the role of resting alpha EEG asymmetry as a neuro-

Table 1
Descriptive Statistics for Covariates.

	N	%	Range	M	SD
Age	52		12–14	13.02	0.860
WASI FSIQ Composite	52			89.29	14.00
Sex	49				
Female	21	42.86			
Male	28	57.14			
Race/Ethnicity	51				
White Non-Hispanic	9	17.65			
White Hispanic	10	19.61			
African American	30	58.82			
Asian	0	0			
American Indian	0	0			
More than one	2	3.92			
Income	49				
< \$10,000	15	30.61			
\$10,000–14,999	9	18.37			
\$15,000–24,999	4	8.16			
\$25,000–34,999	7	14.29			
\$35,000–49,999	7	14.29			
\$50,000–74,999	5	10.20			
\$75,000–99,999	1	2.04			
> \$100,000	1	2.04			

mechanism in the relationship between maltreatment and problem behaviors, including underage alcohol-use in a high-risk group of adolescents. This research used an ecologically valid sample and design, including a substantial portion of families from disadvantaged social backgrounds, ethnic minority, and a home-based design. We tested the following hypotheses: 1) Adolescents with more child maltreatment and trauma symptoms would have more problem behaviors and alcohol abuse symptoms. 2) Adolescents with more right alpha EEG asymmetry (measured during the resting-state) would have more problem behaviors and alcohol abuse symptoms. 3) Alpha EEG asymmetry would moderate the association of child maltreatment and trauma symptoms with problem behaviors and alcohol abuse symptoms, such that child maltreatment experiences and trauma symptoms would be associated with worse outcomes among those with right alpha EEG asymmetry.

2. Method

2.1. Participants

Participants include 52 youth aged 12–14 years (M age = 13.02; SD = 0.86; 22 female) who were recruited from the local Department of Social Services (DSS). Exclusion criteria included serious medical conditions and/or perinatal complications, including contraindications to EEG (e.g., epilepsy), chronic medical illness, neoplasia, premature birth, neonatal intensive care unit (NICU) treatment, leukomalacia, encephalopathy, neurological disorders, loss of consciousness or history of traumatic brain or bodily injury. This sample was predominately African American (59 %), with 18 % being white and non-Hispanic and 20 % being white and Hispanic. The sample was predominately low income, with 31 % of the sample reporting an annual household income of less than \$10,000 per year and 49 % reporting less than \$15,000 per year (see Table 1). Procedures in this study were approved by the university's Institutional Review Board. Standard consent procedures were followed such that consent was obtained from the parent/legal guardian of the adolescent and assent was obtained from the adolescent. This pilot study is the first part of a longitudinal home-based study. Thus cross sectional results are reported here.

2.2. Procedures

This study, including EEG, was conducted in participant's homes. Upon arrival at the participant's home, parents and children completed surveys separately on an encrypted, firewall-protected online neuroimaging database called Collaborative Informatics and Neuroimaging Suite (COINS; Scott et al., 2011). Data in COINS were kept confidential, in accordance with the Health Insurance Portability and Accountability Act (HIPAA). As part of the procedure, adolescents completed questionnaires, one of which was the Childhood Trauma Questionnaire (CTQ). The CTQ was checked for reports of child abuse. If abuse/neglect were reported, the principal investigator (PI), who is a licensed psychologist, notified Child Protective Services (CPS) as required by mandated reporting laws. According to reporting laws and IRB regulations, when CPS reports were made, parents were not notified, as this is not required; this procedure did not affect study participation in this longitudinal home-based study (i.e., no drop-out or withdrawals). After completion of surveys, adolescents completed a general intelligence test followed by resting-state EEG. All study measures were completed with study staff in a quiet area of the home (where electronic media and family members were not distractors). Following study completion, parents and adolescents received monetary compensation at an IRB approved rate.

Table 2

Descriptive Statistics for Independent and Dependent Variables, N = 52.

	CTQ	CPS Reports	TSC	CBCL/YSR	AUDIT	Alpha EEG Asymmetry
Mean	26.86	1.47	25.47	43.75	0.36	0.002
SD	7.41	1.93	17.94	20.70	1.03	0.339
Lower Range	20	0	0	4	0	−0.504
Upper Range	48	9	76	80.5	6	1.170

Note. CTQ = Child Trauma Questionnaire; CPS = Child Protective Services; TSC = Trauma Symptom Checklist; CBCL = Child Behavior Checklist; YSR = Youth Self-Report; AUDIT = Alcohol Use Disorders Identification Test.

2.3. Measures

2.3.1. Childhood trauma questionnaire – short form (CTQ - SF; Bernstein et al., 2003)

The CTQ is a 28-item Likert-type self-report questionnaire that assesses abuse and neglect. Internal consistencies for subscales (Cronbach's $\alpha = 0.79\text{--}0.94$) as well as for the overall questionnaire ($\alpha = 0.94$) were shown to be excellent. Scores were computed by summing the scores for the physical, emotional, and sexual abuse and physical neglect categories of the CTQ. Scores for each of these subscales range from 5 to 25, where five indicates no abuse or neglect, six indicates at least one instance of abuse or neglect, and 25 was the maximum number of instances for each category. The total score can range from 20 to 100, where 20 indicates no abuse or neglect. The obtained range for our participants can be seen in Table 2.

2.3.2. Modified maltreatment classification system

The Modified Maltreatment Classification System (MMCS; Barnett, Manly, Cicchetti, & Toth, 1993; English & Longscan Investigators, 1997) was used to code the adolescents' CPS case records. The MMCS is an empirically validated coding system for child maltreatment reports. We included MMCS guidelines pertaining to physical abuse, sexual abuse, neglect, and drugs and alcohol. For each of these categories, we coded the number of instances of the maltreatment, following the MMCS criteria. Coders were trained to achieve 90 % congruence with their trainer in the MMCS systems before they were permitted to code CPS case records. For the analyses, a total score comprised of a simple count of instances of abuse or neglect was used that summed across types of abuse.

2.3.3. Trauma symptom checklist for children (TSC-C; Briere, 1996)

The TSC is a 54-item scale for children to report on their trauma symptoms and the effects of trauma that they have experienced. Items were measured on a 4-point Likert-type scale ranging from 0 (never) to 3 (almost all the time). This measure showed excellent reliability for subscales (Cronbach's $\alpha = 0.81\text{--}0.88$) and good validity as compared to other measures of child outcomes (Briere, 1996). The TSCC total score was used in the current study. A score was considered clinically significant if it was above a T score of 65 on any subscale (Briere, 1996).

2.3.4. Child behavior checklist (CBCL; Achenbach, 1991)

The CBCL is a 118-item measure of problem behaviors in children. Parents reported on their child's behavior on a 3-point Likert-type scale from 0 to 2, with the options "Not True", "Somewhat or Sometimes True", and "Very True or Often True". In this pilot study, the total score was used as a behavioral outcome measure of problem behaviors. Since internalizing and externalizing scores were highly colinear ($r = 0.94$, $p < 0.001$), the total problems score was used. The CBCL was shown to possess excellent validity and reliability (Nakamura, Ebesutani, Bernstein, & Chorpita, 2009).

2.3.5. Youth self report (YSR; Achenbach & Rescorla, 2001)

The YSR is a 112-item self-report of problem behaviors in children and adolescents. It has similar properties as the CBCL but was made for children and adolescents ages 11–18 years to report on themselves. In the current study, the total score was used as a behavioral outcome measure for problem behaviors. Internalizing and externalizing scores were highly colinear ($r = 0.91$, $p < 0.001$) and for this reason the total score was used. The YSR was shown to possess excellent validity and reliability (Cronbach's $\alpha = 0.88$) in adult and youth populations (Ebesutani, Bernstein, Martinez, Chorpita, & Weisz, 2011).

A composite score of youth self-reported and parent-reported youth problem behaviors was created by calculating the mean across the two measures (CBCL and YSR), since they were correlated ($r = 0.84$, $p = 0.006$). This composite measure of youth behavior problems was used in all analyses.

2.3.6. Alcohol use disorders identification test (AUDIT; Saunders, Aasland, babor, de la fuente, & Grant, 1993)

This is a 10-item self-report that measures alcohol use, related problem behaviors, and dependency. It is also used clinically to identify alcohol use disorder symptoms. A higher score represents more alcohol use and a higher likelihood for dependence. Cut-off scores for identifying adolescents at risk of alcohol use disorder is a score of 3 and above (Babor, Higgins-Biddle, Saunders, & Monteiro, 1992). Items were rated on a Likert-type scale from 0 ("never") to 4 ("daily or almost daily"). The total score was used as a measure of alcoholism and risk behaviors. This scale was shown to demonstrate high reliability (Cronbach's $\alpha = 0.81\text{--}0.93$) and validity in adult (Saunders et al., 1993) and adolescent populations (Knight, Sherritt, Harris, Gates, & Chang, 2003).

2.3.7. Wechsler abbreviated scale of intelligence (WASI; Wechsler, 1999)

This is a comprehensive intelligence measure that provides a full-scale intelligence quotient (FSIQ). The current study uses the Vocabulary and Matrix Reasoning subtests to assess an FSIQ for each subject. The two-subscale FSIQ possesses good reliability (Cronbach's $\alpha = 0.81\text{--}0.97$) and validity with other measures of intelligence ($r = 0.88$; Stano, 2004; Wechsler, 1999). The FSIQ score for each participant was included as a covariate, as previous research has shown evidence for differences in intelligence and academic achievement between maltreated (with or without psychopathology) and non-maltreated children (Cicchetti & Rogosch, 1997; De Bellis et al., 2009, 2013).

2.3.8. EEG data recording and analysis

EEG data were recorded from 8 electrodes placed according to the international 10–20 system using a g.Nautilus g.Ladybird Electroencephalogram (EEG) system and MATLAB Simulink library and g.Nautilus software (g.tec® medical engineering GmbH, Austria). The reference electrode was placed on the right earlobe. Data were sampled at 250 Hz and electrode impedances were kept below 100 k Ω . Participants completed a six-minute resting state period of three minutes with eyes open and three minutes with eyes closed.

EEG data were processed offline using EEGLab toolbox (Delorme & Makeig, 2004) and MATLAB scripts. Data were filtered using 0.5 Hz high-pass and 50 Hz low-pass filters. EEG data were then segmented into 2 s epochs with 1 s (50 %) overlap. Epochs containing artifact were removed from the analysis using a voltage threshold ($\pm 150\mu\text{V}$) rejection. After artifact rejection, epoched data were re-referenced to an average of all channels. After preprocessing, participants with less than 30 artifact-free epochs were excluded from further asymmetry analysis.

2.3.9. EEG alpha asymmetry computation

The artifact-free epoched data were spectrally analyzed using a Fast Fourier transform (FFT) with a 2 s Hanning window. Absolute power (μV^2) was computed for alpha (8–13 Hz) band and for the 1–40 Hz frequency band. Relative alpha power was calculated by dividing mean absolute alpha power by mean absolute total power (1–40 Hz). Relative alpha power for EEG asymmetry was obtained for P3 and P4 electrodes overlying the left (P3) and right (P4) parietal scalp sites according to the international 10–20 system. These were the only parallel hemispheric electrodes available on the 8-channel G.Nautilus cap used. Relative alpha power was used to compute asymmetry because relative power is considered as a more reliable measure of EEG power than absolute power (Fernández et al., 1993). These analyses were performed separately for the eyes open and eyes closed data. The power values for the P3 and P4 electrodes were then log transformed in IBM SPSS Statistics Version 25. Because the log-transformed power values for eyes open and eyes closed conditions were highly correlated (r 's > 0.8) at both sites, they were averaged into one resting state power value for each site as recommended by Tomarken, Davidson, Wheeler, and Kinney (1992). This yielded a combined power value for each of P3 and P4, respectively. Alpha EEG power is inversely associated with electrical brain activity, which is important for correctly interpreting resulting power values (Tomarken et al., 1992). As is customary in the literature, the log-transformed alpha power value of the left electrode (P3) was subtracted from the right (P4) to yield a parietal alpha EEG asymmetry value (Curtis & Cicchetti, 2007; Hagemann et al., 2002; Hostinar et al., 2017; Metzger et al., 2004; Stewart et al., 2011; Tang et al., 2018). Negative values reflect greater relative right parietal activity and positive values reflect greater left parietal activity.

2.4. Data analyses

Linear regression and negative binomial regression were performed to examine study constructs of child maltreatment, trauma symptoms, problem behaviors, alcohol use scores, and EEG asymmetry according to the stated hypotheses. To probe moderation effects, simple slopes analyses examining the moderator's values (± 1 SD) were conducted using Kristopher Preacher's methodology (Preacher, Curran, & Bauer, 2006). We accounted for sex, age, race, ethnicity, parental income, and youth intelligence in all regression analyses.

3. Results

Descriptive statistics for the covariates as well as the variables of interest for the models can be found in Tables 1 and 2. Eighteen percent of participants reported childhood trauma symptoms that were higher than normed averages, with 4 % being in the clinical cutoff range (Briere, 1996). Thirty-three percent of participants had scores above the clinical cutoff (T-score of 65) on the CBCL, and 22 % had scores above the same clinical cutoff on the YSR. Only one participant (2 %) reported an AUDIT total score above the clinical cutoff for adolescents. None of the covariates (i.e., age, gender, ethnicity, SES and IQ) contributed significantly (p 's > 0.4) to any of the models, so the results presented below are shown without covariates.

Some participants could not participate in the EEG due to situational or technological problems ($n = 23$). After preprocessing, four subjects did not have enough resting state data to be analyzed. There were no differences in age, gender, SES, IQ or in the means and standard deviations of the model variables for those who did or did not do EEG (p 's > 0.4); except for a difference in race/ethnicity, where more African American participants were missing EEG data than other participants ($p < 0.05$). There were no race/ethnic differences among the other covariates for the participants who did complete the EEG (p 's > 0.6). This yielded a final count for alpha EEG asymmetry scores of 28. Fifteen of these participants had positive alpha EEG asymmetry values, showing relative left alpha EEG asymmetry, one participant showed no alpha EEG asymmetry, and 12 participants had negative alpha EEG asymmetry values, showing relative right alpha EEG asymmetry.

Table 3
Beta Coefficients and Incidence Ratio Ratios from Regression Analyses.

Hypothesis	Independent Variables	CBCL/YSR		AUDIT	
		β	SE	IRR	SE
1: Main effects	CTQ	0.037	0.325		
	CPS	0.259*	1.265		
	TSC	0.594**	0.149	1.048*	0.022
2: Main effects	Alpha EEG Asymmetry	0.248	11.339	1.452	0.621
3: Interaction effects	CPS X Alpha EEG Asymmetry	-0.041	11.294		
	TSC X Alpha EEG Asymmetry	-0.383*	0.657	0.939	0.041

Note. Beta coefficients are presented from multiple linear regression analyses and Incidence Rate Ratios (IRR) are presented from negative binomial and Poisson regression analyses (AUDIT column). * $p < 0.05$, ** $p < 0.01$. SE = standard error.

3.1. Maltreatment, trauma symptoms, and behavioral outcomes

Beta coefficients and incidence rate ratios for variables in all regressions conducted can be found in Table 3. The overall model was significant ($F(3,42) = 9.44$, $p < 0.001$), such that maltreatment and trauma symptoms explained 36 % of variance in youth problem behaviors. The CTQ was not a significant individual variable. CPS summary was significant individually ($p = 0.04$) and explained approximately 7 % of variance in youth problem behaviors. The TSC was a significant individual variable ($p < 0.001$) and explained approximately 35 % of variance in youth problem behaviors. The association between TSC and CBCL/YSR composite can be found in Fig. 1.

Because the AUDIT is zero-inflated, a negative binomial regression was conducted with both maltreatment variables (CTQ summary and CPS summary) and TSC total score as independent variables and the AUDIT total score as the outcome variable. Because neither the CTQ or CPS variables contributed significantly to the model ($p = 0.88$ and $p = 0.91$, respectively), the model was conducted with only the TSC as an independent variable. The TSC was significantly associated with alcohol use ($p = 0.03$) and the Incidence Rate Ratio (IRR) was 1.048, meaning that trauma symptoms and not trauma experiences increased the rate of AUDIT scores (for a one-unit change in TSC scores, the AUDIT score was increased by a factor of 1.048).

3.2. Alpha EEG asymmetry and behavioral outcomes

A linear regression was conducted with alpha EEG asymmetry scores as the independent variable and the CBCL/YSR composite as the outcome variable. Alpha EEG asymmetry scores were not significantly associated with youth problem behaviors ($F(1,26) = 1.701$, $p = 0.20$).

A negative binomial regression was conducted to test the association of alpha EEG asymmetry as the independent variable with AUDIT total score as the outcome variable. Convergence criteria was never met for the negative binomial regression. Since it failed to converge, the next most appropriate approach is Poisson. Alpha EEG asymmetry was not significantly associated with alcohol use ($\chi^2(1) = 0.361$, $p = 0.55$).

3.3. Alpha EEG asymmetry as a moderator

A linear regression was conducted with CPS summary, alpha EEG asymmetry, and the interaction term between the two as independent variables, and the CBCL/YSR composite as the outcome variable. The interaction between the CPS summary and alpha EEG asymmetry was not significant ($F(3,24) = 0.662$, $p = 0.58$), so the moderation was not probed.

To test moderation, a linear multiple regression was conducted with the TSC and alpha EEG asymmetry scores entered as

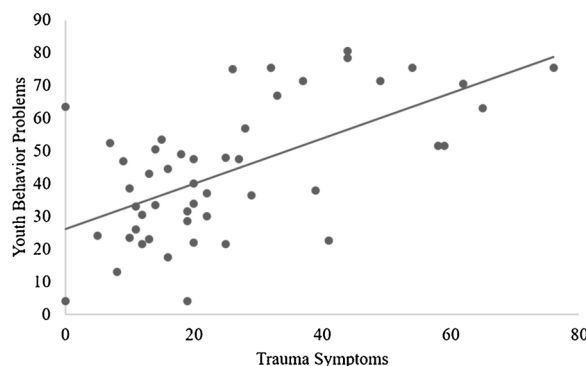


Fig. 1. Scatterplot of trauma symptoms (TSC total score) and youth problem behaviors (composite average of CBCL and YSR total scores). $N = 49$.

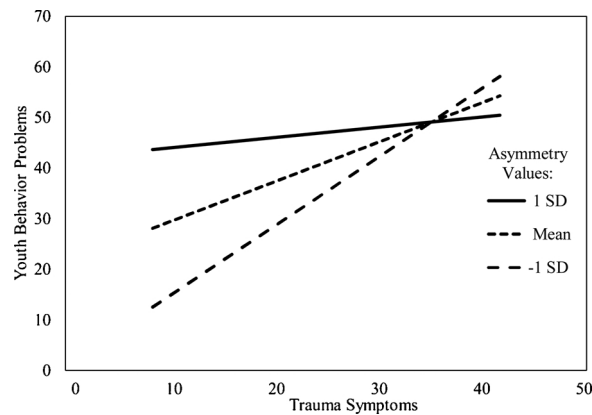


Fig. 2. Alpha EEG asymmetry as a moderator of the relationship between trauma symptoms (TSC total score) and youth problem behaviors (composite average of CBCL and YSR total scores). -1 SD of asymmetry represents relative right alpha EEG asymmetry, whereas $+1$ SD represents relative left alpha asymmetry.

independent variables in the first block, and then the interaction term between the TSC and alpha EEG asymmetry scores entered in the second block. The dependent variable was youth problem behaviors (CBCL/YSR composite). Trauma symptoms, alpha EEG asymmetry, and the interaction term were significantly associated with youth problem behaviors ($F(3,22) = 6.844, p = 0.002$). The interaction term was a significant individual variable ($\beta = -0.383, p = 0.02$). This overall model accounted for approximately 41 % of the variance in youth problem behaviors. The interaction term accounted for approximately 14 % of the variation.

In probing the interaction, we found that at alpha EEG asymmetry values below 1 SD (i.e., relative right alpha EEG asymmetry), the association between trauma symptoms and youth problem behaviors was significantly positive. This association was not significant at alpha EEG asymmetry values above 1 SD (i.e., relative left alpha EEG asymmetry). A visual representation of this moderation effect can be seen in Fig. 2.

Finally, to assess whether alpha EEG asymmetry moderated the effect of trauma symptoms on alcohol use, a negative binomial regression was conducted with the TSC, alpha EEG asymmetry, and the interaction term between the two as independent variables, and the AUDIT total score as the outcome variable. The interaction term between the TSC and alpha EEG asymmetry was not significant ($p = 0.12$), so there was no evidence suggesting alpha EEG asymmetry moderated the association between the TSC and AUDIT.

4. Discussion

The aim of this study was to examine alpha EEG asymmetry measured in the parietal region of the cerebral cortex as it relates to child maltreatment, trauma symptoms, and problem behaviors and alcohol misuse. In support of our hypotheses, our results indicated that child maltreatment and trauma symptoms were significantly associated with problem behaviors. Trauma symptoms, but not CPS and self-reported child maltreatment, were associated with alcohol use. Furthermore, we found that alpha EEG asymmetry in the parietal region was not directly associated with either problem behaviors or alcohol use outcomes. Instead, alpha EEG asymmetry moderated the association of trauma symptoms with problem behaviors, such that greater problem behaviors and alcohol use was evidenced among youth with a combination of high childhood trauma and relative right parietal alpha EEG asymmetry. These findings suggest that neural correlates may play a role in the susceptibility for problem behaviors among adolescents exposed to higher levels of childhood trauma.

The finding showing that CPS reports of child maltreatment and trauma symptoms were associated with youth problem behaviors replicated previous findings of maltreatment and negative outcomes (Twardosz & Lutzker, 2010). However, we found no evidence suggesting alpha EEG asymmetry moderated the association between CPS reports of maltreatment and youth problem behaviors. Trauma symptoms were associated with alcohol abuse symptoms. This is reflective of previous research indicating that youth who have experienced maltreatment but do not report trauma symptoms have fewer problem behaviors than those who experience maltreatment and report trauma symptoms (e.g., Jaycox, Ebener, Damesek, & Becker, 2004). The present study offers further support for the developmental traumatology model which states that it is not maltreatment alone that results in adverse outcomes but the trauma symptoms following maltreatment that confer vulnerability of youth to problem behaviors and adverse brain development (De Bellis, 2001; De Bellis et al., 2015; Morey et al., 2016).

CPS reports of child maltreatment was a significant independent variable for youth problem behaviors. However, maltreatment as assessed by adolescent self-report was not significantly associated with any outcomes, which may be due to adolescents' reluctance to report abuse victimization (National Research Council, 2014). It was expected that child maltreatment as assessed by both sources would be associated with these outcomes; yet, the fact that one type of maltreatment assessment was associated with problem behaviors whereas the other was not highlights the importance of assessing child maltreatment using multi-informant methods to avoid reporter-bias (e.g., Lau et al., 2005). Each reporting source or assessment method can contain unique information, as evidence

by prior findings of low concordance between self-reported and CPS reports of maltreatment (e.g., [Negri, Schneiderman, & Trickett, 2017](#)). Therefore, a strength of the current study was the multifaceted assessment of maltreatment using both self-report and CPS records and also assessing trauma symptoms.

While the direct link between alpha EEG asymmetry and problem behaviors was not supported, we found support suggesting that alpha EEG asymmetry played a moderating role in the relation between childhood trauma and problem behaviors. As hypothesized, adolescents with more right parietal alpha EEG asymmetry had a steeper slope in the significant positive association between trauma symptoms and youth problem behaviors. Although it may seem as though those with higher right alpha EEG asymmetry scores report fewer problem behaviors overall when compared to those with more left alpha EEG asymmetry, the CBCL/YSR means for the left and right asymmetry groups did not significantly differ. The positive linear association between trauma symptoms and problem behaviors was significant at both negative (right alpha EEG asymmetry) and some positive (left alpha EEG asymmetry) values. However, the positive association between trauma symptoms and problem behaviors was stronger for right asymmetry; it flattened for left alpha EEG asymmetry values. This finding supports previous research, which found that relative right alpha EEG asymmetry was associated with worse outcomes in maltreated children ([Curtis & Cicchetti, 2007](#); [Hostinar et al., 2017](#); [Miskovic et al., 2009](#); [Tang et al., 2018](#)). The present findings pertaining to trauma symptoms and problem behaviors give further support for examining alpha EEG asymmetry as a moderator rather than examining as just an independent variable.

4.1. Limitations

While the present pilot study had many strengths, including being a home-based study with a mobile EEG system, which strengthened the ecological validity of the research in a high-risk sample, several limitations are worth noting. One limitation is the small sample size which limits power due to EEG data that could not be collected and low levels of alcohol problems, which is common in this adolescent age group. It is possible that additional factors could be related to this type of research, including youth school maladjustment. We took careful steps to minimize this, in keeping with the literature for high-risk maltreated samples, by accounting for these factors with exclusion criteria as well as statistically in analyses. Even with these limitations, it is useful to study this population because it is an under-studied group that is in dire need of further research to inform targeted prevention and treatment efforts. It is also worth noting that EEG technology has limitations related to the electrodes in the cap needing to make contact with the scalp to obtain a signal. While these limitations are analogous to limitations such as braces preventing some adolescents from participating in magnetic resonance imaging research, improved EEG technology that could improve ability of electrodes to make contact with the scalp is warranted.

Another limitation is that we were not able to collect EEG with many electrodes due to the use of mobile EEG. Part of this was intentional to the study design as having fewer electrodes helped ensure that EEG data quality stayed high in the field, which it did for this study; the quality of the data and artifact rejection were well within acceptable rates for lab-based EEG. Yet, it limited the EEG analyses that could be done. This being said, achieved power for analyses was quite high, at 0.99 for child maltreatment and trauma symptoms as independent variables for problem behaviors, 0.99 for trauma symptoms as an individual predictor, and 0.79 for the interaction term for the significant moderation. In addition, the results of this study were conducted with a number of regressions, each tested at an alpha level of 0.05, which could lead to Type I error inflation. Applying a Bonferroni correction at the level of each hypothesis by dividing the alpha level of 0.05 by the number of regressions yields new alpha levels of 0.025, 0.025, 0.017, and 0.006 for each hypothesis, respectively. Although Type I error inflation should be considered when several regression models are run in a study, many have suggested that the Bonferroni correction is too strict and not appropriate for planned comparisons or pilot work like the present study (e.g., [Perneger, 1998](#)). Using alpha correction, CPS reports would no longer be individually significantly associated with youth problem behaviors, trauma symptoms would no longer be significantly associated with alcohol use, and the interaction term between trauma symptoms and alpha EEG asymmetry on alcohol use would no longer be significant. This study had planned hypotheses/comparisons and is a pilot study, so correction was not warranted ([Rothman, 1990](#)). Further analyses replicating these findings and examining changes over time are ongoing and needed before the results of the present study can be applied with confidence.

It is also important to point out that this is a cross sectional study; results presented here are not longitudinal in nature. The consequences of maltreatment may have bidirectional and cyclical effects with the outcomes and measures studied here. Causality and directionality will be better assessed by a longitudinal design. The current pilot study is part of a three-year longitudinal project, so future results from this sample may shed more light on the directionality of these effects. This pilot study aims to begin to disentangle the relationships between study variables, so that it can guide and inform future research.

4.2. Implications

Our results showed that trauma symptoms are a predictor of problem behaviors and may also be related to functional brain changes associated with risk. It is important to screen children at risk for trauma symptoms and provide evidence-based trauma treatment to prevent long-term mental health and substance use problems. Right alpha EEG asymmetry may function as a neural correlate underlying risk for problem behaviors in adolescents exposed to trauma and maltreatment. While the results of the current study are not conclusive, they provide some support for further study in this area to try to identify risk factors linking maltreatment to trajectories of risk and resilience. Identifying such neurobiological risk factors in the field could be useful for identification of maltreated adolescents that may be at risk for mental health problems as well as for developing interventions aimed at targeting neurological profiles of maltreated adolescents who have mental health problems. For example, maltreated adolescents with right

versus left alpha EEG asymmetry may require different treatments and interventions. This home-based pilot study is the first step in teasing out these types of questions because it is able to reach maltreated adolescents who may not be able to come in for lab-based studies.

While some research has identified anatomical and functional brain changes pertaining to child maltreatment such as cortical gray matter and hippocampal volume decreases (De Bellis et al., 2015 and Carrion & Wong, 2012, respectively), these changes have typically been assessed with magnetic resonance imaging (MRI). While MRI is valuable, EEG is also useful due to it being comparatively inexpensive, mobile, and can involve less contraindications common to adolescents (e.g., braces) compared to MRI-based approaches. Another advantage of the present EEG study, which is mobile, is that it could be brought into schools and other settings to best serve maltreated youth (Zwaanswijk, Verhaak, Bensing, Van der Ende, & Verhulst, 2003). This is especially important for adolescents who spend much of their waking hours at school and involved in extracurricular activities.

The role of alpha EEG asymmetry in maltreated adolescents may have important implications for treatment and intervention going forward. This is especially true for an ethnically diverse, low SES sample like the one in the current study, as this population is commonly underrepresented in research (Cottler et al., 2013), is at a higher risk for experiencing maltreatment and resulting psychopathology, including substance use disorders (Stith et al., 2009), and often has less access to health and mental health resources (Berger, 2004). Mobile EEG studies such as this one have the potential to fill critical gaps both in the diversity of adolescent samples as well as in the scope of research aimed at reducing child maltreatment sequelae.

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Declaration of Competing Interest

There are no conflicts of interest.

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