Interactive Effect of Stressful Life Events and the Serotonin Transporter *5-HTTLPR* Genotype on Posttraumatic Stress Disorder Diagnosis in 2 Independent Populations

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Abstract

Context: The *5-HTTLPR* polymorphism in the promoter region of the serotonin transporter gene *(SLC6A4)* has been found to moderate several categories of emotional response after stressful life events. Previous studies generally focused on its effect on depressive symptoms; little is known about its moderation of the development of post-traumatic stress disorder (PTSD).

Objective: To examine the effects of childhood adversity, adult traumatic events, *5-HTTLPR* genotypes, and gene×environment interactions on the etiology of PTSD.

Design: A cross-sectional study in which participants in several studies investigating the genetics of substance dependence were also screened for lifetime PTSD. The triallelic system of *5-HTTLPR* was genotyped. Logistic regression modeling was used in the analyses.

Setting: General community.

Participants: Five hundred eighty-two European American and 670 African American individuals who reported experiences of childhood adversity, adult traumatic events, or both.

Main Outcome Measure: Diagnosis of PTSD, defined by *DSM-IV* diagnostic criteria and assessed through the Semi-Structured Assessment for Drug Dependence and Alcoholism interview.

Results: Childhood adversity and adult traumatic events both predicted PTSD. Although the *5-HTTLPR* genotype alone did not predict the onset of PTSD, it interacted with adult traumatic events and childhood adversity to increase the risk for PTSD, especially for those with high rates of both types of trauma exposure (European American: odds ratio [OR], 2.86; 95% confidence interval [CI], 1.50-5.45; *P*=.002; African American: OR, 1.88; 95% CI, 1.04-3.40; *P*=.04; pooled: OR, 2.31; 95% CI, 1.50-3.56; *P*<.001).

Conclusions: Participants who had both childhood adversity and adult traumatic events were more likely to develop lifetime PTSD compared with those who experienced either type of adverse event. The risk was increased in individuals with 1 or 2 copies of the *S′* (*S*) allele compared with the *L′* (*L*) homozygotes. Our study provides additional direct evidence that PTSD is influenced by the interactive effect of environmental and genetic factors.

Posttraumatic stress disorder (PTSD) is a complex and multifactorial anxiety disorder. According to the *DSMIV*, it requires the presence of symptoms from each of 3 clusters, reexperiencing, avoidance, and increased arousal, that occur following exposure to a life-threatening traumatic event. While 40% to 70% of the US population have experienced high-level traumatic events,[1,2] the lifetime prevalence for PTSD is 8% in adult Americans based on community epidemiological studies (*DSM-IV*). Several risk factors, including those that characterize the traumatic exposure as well as those that characterize traits of the individual, have been identified for PTSD. Among the former, traumatic events that involve the infliction of harm by others (eg, rape, physical assault, military combat) carry higher risks for PTSD than other traumas (eg, natural disasters).[3] Female sex, preexisting psychiatric disorders, and premorbid personality characteristics such as neuroticism have also been shown to increase risk for PTSD.[4,5]

Childhood adversity, including sexual and physical abuse, neglect, and other traumas, has received considerable attention from researchers in the studies of the etiology of PTSD. Neurobiological consequences of early life stress can be severe in that they cause enduring changes in brain structure and function.[6] These physical changes could influence the response to adult traumas, triggering a cascade of biological events that may ultimately lead to the occurrence of mental disorders. Meanwhile, childhood adversity is associated with an increased risk for behavior problems,[7] which, in turn, expose the person more to traumatic events. Numerous studies have shown that childhood adversity is associated with a range of mental disorders, such as major depression,[8] antisocial disorder, substance use disorder,[9] and PTSD. [10] Although most studies of early life stress and mental disorders have focused on childhood abuse or neglect, other traumatic events, such as involvement in a serious accident or witnessing events causing death or serious injury, also constitute an important part of a broad view of early life stress.

In addition to the obvious effect of environmental factors, PTSD has a heritable component. A twin study based on the Vietnam War veteran sample indicated that genetic factors account for approximately 30% of the variance in PTSD symptoms.[11] A more recent study outside the context of military trauma showed similar findings.[12] Although the idea that PTSD is affected by both environmental and genetic factors has been widely accepted, there have been relatively few molecular genetic studies of PTSD. Association studies have identified a small number of possible susceptibility genes, but the results are inconsistent.[13] The difficulty in identifying PTSD-related genes may be due to their low to moderate effect sizes, with consequent insufficient statistical power of many studies, and other methodological shortcomings.[14]

Study of gene×environment effects on mental disorders has been of great interest recently. This approach is especially promising for investigating the etiology of PTSD, which requires exposure to a traumatic event and has a genetic component. The serotonin transporter gene (*SLC6A4*) has been shown to moderate several categories of emotional response. In the brain,

the serotonin transporter is involved in the rapid reuptake of serotonin following neuronal stimulation; it is thus a key regulator of serotonergic neurotransmission. A common polymorphism (*5-HTTLPR*) in the promoter region of *SLC6A4* was found to regulate gene expression. In vitro studies of *SLC6A4* expression in human lymphoblastoid cells and placental choriocarcinoma cell lines consistently showed that the long variant of the polymorphism (*L*) (16 repeats) produced 2- to 3-fold higher levels of messenger RNA than that of the short variant (14 repeats), resulting in reduced serotonin reuptake.[15,16] In vivo studies of messenger RNA level in human postmortem tissue sections, however, yielded inconsistent results.[17,18] One possible explanation for this inconsistency between in vitro and in vivo studies is that under normal physiological conditions, the expression level of *SLC6A4* may be regulated by many other factors. However, when stressful life events occur, which increases the serotonin release at targeted brain regions,[19] the *S* allele may be less efficient than the *L* allele at up-regulating the expression level of the serotonin transporter and keeping the extracellular serotonin at a normal level. Studies of humans and rhesus macaques showed that the presence of the *S* allele interacts with environmental factors to produce effects on behavior and measures of central nervous system function.[20-22] Although the most common alleles at *5-HTTLPR* in most populations have either 14 or 16 repeated elements, other alleles, generally with more repeated elements (18 or 20 repeats), occasionally occur.[23] However, transcriptional efficiencies of these rare *5-HTTLPR* alleles are unknown. More recently, an A/G single-nucleotide polymorphism (SNP) (rs25531) in the repeats region was found to be functional; rs25531 is mostly found in the *L* variant, further dividing it into L_A and L_G.[24] L_G and *S* alleles have equivalent expression levels, which are about half of that of the L_A allele; L_G and *S* are thus reclassified as *S'* and *L*, as *L'*.[25] A Although PTSD, like depression, can be considered to reflect a maladaptive response to stressful events, few studies have examined the possible role of *5-HTTLPR* in moderating the influence of traumatic events on PTSD risk.

In the present study, gene×environment interaction was examined to explore its effect on the development of PTSD. We recruited a large number of patients in the course of studies investigating the genetics of drug and alcohol dependence, disorders that are associated (perhaps causally) with high rates of PTSD,[26,27] and administered the Semi-Structured Assessment for Drug Dependence and Alcoholism (SSADDA), a comprehensive polydiagnostic instrument that includes assessment of PTSD.[28,29] The SSADDA covers a wide range of traumatic events and contains additional items related to childhood adversity. Using these environmental data and the triallelic system (L_A/L_G/*S*) for *5-HTTLPR*, individual and interactive effects of genetic and environmental factors were investigated.

METHODS

SAMPLE COLLECTION AND DEMOGRAPHIC INFORMATION

Samples in this study were a subgroup of 1793 European American and African American individuals who participated in linkage studies focused on the genetics of substance dependence (and were recruited as members of families, each of which included at minimum an affected sibling pair for cocaine or opioid dependence),[30,31] as well as more recently recruited subjects, substance dependence cases and unaffected controls, related and unrelated, all of whom were recruited and ascertained with similar methods. The participants were recruited at 4 sites: Yale University School of Medicine, University of Connecticut Health Center, Medical University of South Carolina, and McLean Hospital of Harvard Medical School. Written informed consent was obtained from all participants. The institutional review board at each of the participating sites approved the study protocol. All subjects were interviewed using the SSADDA, which provides diagnostic criteria for a variety of psychiatric and substance use disorders, as well as information on childhood environment.[32,33] Since the purpose of the present study was to explore the factors affecting the risk for PTSD when

individuals face traumatic events, 510 people who reported never having experienced childhood adverse events or adult traumatic events were excluded. In addition, 31 individuals with rare *5-HTTLPR* alleles were excluded from the study, leaving 1252 informative subjects.

The mean (SD) age of the 1252 participants (52% male) was 38.9 (11.0) years, ranging from 17 to 79 years. To derive ancestry information from each individual, a panel of 41 ancestry-informative markers was genotyped, including FY and 36 short tandem repeats markers described in our previous studies,[34,35] and augmented by 4 highly ancestry-informative SNPs, rs1540771 (6p23.5), rs1805007 (*MC1R*), rs12896399 (*SLC24A4*), and rs1426654 (*SLC24A5*), which are all associated with hair, eye, and/or skin pigmentation.[36,37] These ancestry-informative markers were analyzed by a Bayesian cluster model using STRUCTURE software.[38-40] We used admixture and allele frequencies–correlated models and 500 000 Markov chain Monte Carlo repeats after 500 000 burn-in repetitions.

DIAGNOSIS OF PTSD AND ADULT TRAUMATIC EVENTS INDEX

Sample collection and diagnostic interviews were performed by trained interviewers. Interviewing methods and the diagnostic reliability of the SSADDA, including the PTSD section (which showed interrater reliability and test-retest reliability [κ] of 0.59 and 0.76, respectively), have been described previously.[32,33] In the SSADDA PTSD section, 12 separate types of traumatic events are assessed. These events are experienced direct combat in a war; seriously physically attacked or assaulted; physically abused as a child; seriously neglected as a child; raped; sexually molested or assaulted; threatened with a weapon; held captive or kidnapped; witnessed someone being badly injured or killed; involved in a flood, fire, or other natural disaster; involved in a life-threatening accident; suffered a great shock because one of these events happened to someone close to you; and other. Participants were asked to list up to 3 traumatic events and their age when these events happened. Those reporting traumatic experiences were then interviewed for potential PTSD symptoms. After all of the data were scored, a PTSD diagnosis was generated based on *DSM-IV* criteria requiring symptoms from each of 3 clusters, reexperiencing, avoidance, and increased arousal, that occur following the events.

CHILDHOOD ADVERSITY INDEX

Although childhood physical abuse and neglect are ascertained in the PTSD section of the SSADDA, we used the Environment section as the main instrument to assess participants' childhood experiences. All of the participants were asked whether they had witnessed or experienced a violent crime or been sexually abused, physically abused, or neglected by age 13 years. Since neglect is more subjective than the other childhood adversities, participants were asked 3 questions to assess it: "whether the person you were closest to was usually available to you when you needed him or her," "whether you felt you could confide in this person when necessary," and "whether this person was aware of who your friends were." Respondents who answered "no" to any of the 3 questions were considered to have been neglected.

GENOTYPING

DNA was extracted from whole blood or immortalized cell lines. Polymerase chain reaction amplification was used to differentiate the short allele from the long allele of the *5-HTTLPR* polymorphism. Polymerase chain reaction conditions are described in detail elsewhere.[23] To genotype the additional SNP (rs25531), the polymerase chain reaction product was digested by *Msp*I and size-fractionated on agarose gel.[41]

Detailed genotyping methods and characteristics for 37 of the 41 ancestry-informative markers were described previously.[34] The remaining 4 SNPs were genotyped by the TaqMan technique

using the ABI PRISM 7900 Sequence Detection System (Applied Biosystems Inc, Foster City, California).

STATISTICAL ANALYSIS

Based on the levels of transcriptional efficiency, the triallelic geno-types were reclassified: L_A/L_A was reclassified as $L'L'$; L_A/S and L_A/L_G were reclassified as $L'S'$; and L_G/L_G, L_G/S, and S/S were reclassified as $S'S'$. We used logistic regression models to examine the association between the PTSD diagnosis and the potential explanatory variables. In the first model, the effects of *5-HTTLPR* geno-type (coded as 0 for $L'L'$, 1 for $L'S'$, and 2 for $S'S'$), childhood adversity (coded as 0 for none, 1 for exposure), adult traumatic events (coded as 0 for none, 1 for exposure), gene×childhood adversity, and gene×adult traumatic events were explored. In the second model, we focused on the participants who experienced both childhood and adulthood traumas. Exposure to dual stressful event types (both childhood and adulthood) was coded as 1, and exposure to either type of stressful events was coded as 0. The interactive effect of gene×stressful events was calculated. After that, in the third model, we analyzed the dual stressful events linearly: exposure to adulthood trauma and 1 type of childhood adversity was coded as 1, adulthood trauma and 2 types of childhood adversity was coded as 2, adulthood trauma and 3 or more types of childhood adversity was coded as 3, and exposure to either type of stressful events was coded as 0. In the first 2 models, we first analyzed each population, European American individuals and African American individuals, separately, using sex and age as covariates. Then we combined the data across the 2 populations using sex, age, and ancestry proportion scores as covariates. In the third model, since the group of dual stressful events was already small, dividing it into 3 groups further decreased the sample size. To increase the statistical power, only analyses with combined data (sex, age, and ancestry proportion scores were used as covariates) were performed. In addition, generalized estimating equations (GEE)[42] were applied to fit the logistic regression model to take into account the potential dependence of the data from individuals within the same nuclear family. An exchangeable correlation structure was used in this logistic GEE regression model. Since many previous *5-HTTLPR*×stressful events studies did not include rs25531, analyses using the diallelic *L-S* classification were also performed. Comparisons between groups of categorical variables were made using χ^2 tests. All analyses were performed by SAS 9.1 (SAS Inc, Cary, North Carolina).

RESULTS

DEMOGRAPHICS

Approximately one-fifth of the 1252 participants (n=229; 18.3%) who experienced childhood adverse events and/or adult traumatic events met the criteria for lifetime PTSD. The mean (SD) age of participants developing PTSD was 39.3 (9.6) years, which was similar to those without a diagnosis of PTSD (mean [SD], 38.9 [11.3] years). Table 1 presents information on the prevalence of PTSD by sex and population. Among women, 22.3% received a lifetime diagnosis of PTSD, which was significantly higher than for male participants (14.6%) (χ^2_1=12.3; *P*<.001). The rate of PTSD among European American individuals (19.6%) and African American individuals (17.1%) was statistically indistinguishable (χ^2_1=1.3; *P*=.26). In addition, many psychiatric disorders were observed to be comorbid with PTSD (eTable, http://www.archgenpsychiatry.com).

EFFECT OF ADULT TRAUMATIC EVENTS ON RISK OF PTSD

Eight hundred eighty of the 1252 participants (70.3%) reported that they had experienced 1 or more traumatic events as adults. Among them, 21.5% (n=189) met criteria for lifetime PTSD. In contrast, only 10.7% of the participants who never experienced adult traumatic events

developed PTSD. Using a logistic GEE regression model, after adjusting for age, sex, ancestry proportion score, *5-HTTLPR* genotype, and childhood adversity, adult traumatic events were significantly associated with an increased risk for PTSD (OR, 3.57; 95% CI, 2.43-5.25; *P<*.001) (Table 2).

EFFECT OF CHILDHOOD ADVERSITY ON RISK OF PTSD

Four types of childhood adversities, namely witnessing or experiencing a violent crime, sexual abuse, physical abuse, or neglect, were assessed in this study. Most of the participants (n=924; 73.8%) experienced at least 1 type of childhood adversity. Among them, 64.4% (n=595) experienced 1 type of adverse event; 23.8% (n=220) experienced 2 types; and 11.8% (n=109) experienced 3 or 4 types of childhood adversities. The percentage of participants with a lifetime diagnosis of PTSD increased from 8.8% in individuals with no childhood adversity to 15.4% in those with 1 type, 28.6% in those with 2 types, and 40.5% in those with 3 or 4 types of childhood adversity (Figure 1). Using the same logistic GEE regression model described previously, a significant effect of childhood adversity on PTSD development was observed (OR, 4.30; 95% CI, 2.81-6.60; *P<*.001) (Table 2).

EFFECT OF *5-HTTLPR* GENOTYPES ON RISK OF PTSD

In European American individuals, the frequency of the long allele was 56.3% and the short allele, 43.7%. The genotype distribution was 31.1% *LL*, 50.3% *LS*, and 18.6% *SS*. The minor allele frequency of rs25531 was 7.1%. After reclassification, the genotype frequencies were 23.5% *L′L′*, 51.2% *L′S′*, and 25.3% *S′S′*. In African American individuals, the frequencies for the long and short alleles were 77.8% and 22.2%, respectively, and the genotype distribution was 61.0% *LL*, 33.6% *LS*, and 5.4% *SS*. The minor allele frequency of rs25531 was 22.5%. After reclassification, the genotype distribution was 32.2% *L′L′*, 46.1% *L′S′*, and 21.6% *S′S′*. The allele frequencies of the *5-HTTLPR* polymorphism were consistent with previous studies, [21,23,24] and all were in Hardy-Weinberg equilibrium.

After adjusting for age, sex, childhood adversity, and adult traumatic events, logistic GEE regression analysis showed no significant association between *5-HTTLPR* genotype and PTSD diagnosis in either European American or African American individuals (European American: OR, 1.24; 95% CI, 0.91-1.69; *P=*.17; African American: OR, 1.22; 95% CI, 0.91-1.63; *P=*.18); the association in the combined sample, in which ancestry proportion score was entered as a covariate, was not statistically significant (OR, 1.22; 95% CI, 0.99-1.51; *P=*.07). The use of diallelic genotypes, which include only the *L* and *S* alleles of the *5-HTTLPR* polymorphism, in the logistic regression analysis also showed that *5-HTTLPR* genotypes were not associated with PTSD (OR, 0.95; 95% CI, 0.67-1.35; *P=*.77). In addition, none of the psychiatric disorders that were found to be comorbid with PTSD were associated with *5-HTTLPR* genotypes (eTable).

5-HTTLPR GENOTYPES INTERACTED WITH CHILDHOOD ADVERSITY AND ADULT TRAUMATIC EVENTS TO INCREASE RISK FOR DEVELOPING PTSD

We first tested two 2-way interactions, genotype×adult traumatic events and genotype×childhood adversity, as predictors in the model. After adjusting for all the main effects, including age, sex, genotype, childhood adversity, and adult traumatic events, the genotype×adult traumatic events interaction was significantly associated with risk for PTSD in both European American and African American individuals separately (European American: OR, 2.60; 95% CI, 1.19-5.66; *P=*.02; African American: OR, 2.06; 95% CI, 1.02-4.14; *P=*.04) (**Figure 2**A and B), with the combination of the 2 populations providing stronger evidence of association (OR, 1.93; 95% CI, 1.17-3.17; *P=*.01). The genotype×childhood adversity interaction was found to be significantly associated with risk for PTSD in European American individuals, but not in African American individuals (European American: OR, 3.29; 95% CI,

1.17-9.22; *P*=.02; African American: OR, 1.71; 95% CI, 0.81-3.61; *P*=.16) (Figure 2C and D). When all the participants were combined together, the interactive effect of genotype×childhood adversity was significant (OR, 1.81; 95% CI, 1.01-3.24; *P*=.046).

Because in our study the participants reported experiencing at least 1 type of trauma, and many of them experienced both childhood adversity and adult traumatic events, we then investigated how the high rates of both types of trauma exposure interacted with *5-HTTLPR* to influence risk for PTSD. Five hundred fifty-two of the 1252 participants (44.1%) experienced both childhood adversity and adult traumatic events. Among this group, 29.0% (n=160) received a lifetime diagnosis of PTSD. In contrast, only 9.9% of participants who experienced either (but not both) childhood adversity or adult traumatic events developed PTSD. Moreover, among European American participants who experienced both stressful events, 41.0% with the *S′S′* genotype developed PTSD, compared with 33.1% in the *L′S′* genotype group and only 18.3% in the *L′L′* genotype group. In African American participants, 38.2% of individuals with the *S′S′* genotype, 26.2% with the *L′S′* genotype, and 19.5% with the *L′L′* genotype were diagnosed with PTSD (Figure 3). If we used the dual stressful events as a predictor, and computed the second logistic regression model described in the "Methods" section, after adjusting for all the main effects, the genotype×dual stressful events interaction was significantly associated with risk for PTSD in both European American and African American individuals (European American: OR, 2.86; 95% CI, 1.50-5.45; *P*=.002; African American: OR, 1.88; 95% CI, 1.04-3.40; *P*=.04), with the combination of the 2 populations providing stronger evidence of association (OR, 2.31; 95% CI, 1.50-3.56; *P*<.001) (Table 2). If the *L-S* diallelic classification of the *5-HTTLPR* genotype was used, the results of the genotype×dual stressful events interaction were comparable with those obtained using the triallelic clasification (European American: OR, 2.37; 95% CI, 1.19-4.72; *P*=.01; African American: OR, 2.97; 95% CI, 1.43-6.17; *P*=.003; pooled: OR, 2.64; 95% CI, 1.63-4.27; *P*<.001). In addition, this interactive effect was observed in both male and female participants (triallelic genotypes: male: OR, 2.38; 95% CI, 1.20-4.72; *P*=.01; female: OR, 2.31; 95% CI, 1.31-4.09; *P*=.004; diallelic genotypes: male: OR, 1.99; 95% CI, 1.01-3.92; *P*=.04; female: OR, 3.38; 95% CI, 1.72-6.64; *P*<.001).

Because the number of childhood adversity types was associated with the risk of PTSD, we then modeled the dual stressful events linearly, as was described in the "Methods" section. The interaction further suggested that the effect of life events on the onset of PTSD was stronger among individuals with an *S′* (*S*) allele than among those without (triallelic genotypes: OR, 1.41; 95% CI, 1.20-1.66; *P*<.001; diallelic genotypes: OR, 1.60; 95% CI, 1.32-1.94; *P*<.001) (Figure 4).

DISTRIBUTION OF CHILDHOOD ADVERSITY AND ADULT TRAUMATIC EVENTS BY GENOTYPE GROUPS

As mentioned previously, different traumas influence people differently. Certain life-threatening events may carry higher risk for developing PTSD than others. To exclude the possibility that trauma type was a confounding factor in our study, we examined the distribution of childhood adversity and adult traumatic events across the genotype groups. For childhood adversity, the distribution of events did not differ significantly among the 3 genotype groups (Table 3). Based on the characteristics of the trauma types, and previous studies showing that events involving the element of interpersonal assault are associated with a higher rate of PTSD than events without the element,[4,12] we grouped the 10 types of adulthood adverse events into 3 broad groups, namely, sexual trauma (rape or molestation), physical trauma (physical attack, threatened with a weapon, held captive, or kidnapped), and other trauma (witness, natural disaster, accident, shock, or other qualifying trauma). The distribution of this measure also did not differ significantly among the 3 genotype groups (Table 3).

COMMENT

In this study, we examined the effects of childhood adversity, adult traumatic events, the *5-HTTLPR* polymorphism, and their interactions on the risk of receiving a lifetime diagnosis of PTSD. We found that both childhood adversity and adult traumatic events predicted PTSD. Although the *5-HTTLPR* polymorphism alone did not predict the onset of PTSD, it regulated risk for PTSD in people who experienced childhood adversity and/or adult traumatic events, especially in those who experienced both types of stressful life events, with comparable findings in both European American and African American individuals. We initially based the hypothesis on evidence from prior studies that *SLC6A4* was associated with emotional responses, especially the response to a stressful life event. Indeed, our previous work showed that this locus influenced risk for PTSD-related symptoms in a sample of subjects exposed to a hurricane.[43]

Although the role of serotonergic function in the patho-physiology of PTSD is still unclear, it is believed to regulate a wide array of stress-related processes: anxiety, arousal, depression, aggression, and impulsivity, which are all common symptoms of PTSD. Since the serotonin transporter regulates serotonergic neurotransmission, and is the primary target of efficacious antidepressants such as selective serotonin reuptake inhibitors, *SLC6A4* has received particular attention in research on mood and anxiety disorders. Compared with the *L'* allele, the *S'* allele of the *5-HTTLPR* polymorphism was found to reduce *SLC6A4* expression and function, resulting in decreased serotonin reuptake. Previous studies have shown that presence of the short allele was associated with anxiety-related personality traits[15] and increased amygdala neuronal activity under fearful stimuli[44] and may influence selective serotonin reuptake inhibitor response rate among European American patients.[41] Studies of gene×environment interactions have also provided evidence for a functional link among serotonin, psychosocial stressors, and risk of depression[21,22,45] and an intermediate phenotype of anxiety,[25] although some other studies failed to replicate these findings.[46-48]

Our study provides additional evidence that genetic and environmental factors interact to play a role in psychiatric disorders. Exposure to trauma earlier in life increases risk for PTSD on exposure to subsequent trauma.[49] Our study suggests that this risk is heightened among individuals with 1 or 2 copies of the *5-HTTLPR S'*(*S*) allele. Interestingly, because of the design of our study (people who reported never experiencing traumas were not included), we were unable to ascertain an effect of *5-HTTLPR* genotype on risk for PTSD among persons with either (but not both) childhood maltreatment or adult trauma. It was only in the group of subjects who could be characterized as having had the highest rates of trauma exposure (ie, in both childhood and adulthood) that an impact of *5-HTTLPR* could be detected. This suggests that there may be many neurobiological (including genetically determined) "buffers" to PTSD; only in instances of extreme and/or repeated trauma exposure (which, it should be pointed out, characterizes those trauma "types" with the highest conditional risk for PTSD, eg, domestic violence and military combat), in which these buffers are overwhelmed, can the impact of specific genes such as *5-HTTLPR* be detected. To our knowledge, this is the first study to examine the diagnosis of PTSD as an outcome of a gene×environment interaction. Two previous studies have focused on gene×environment interaction effects on PTSD symptom severity.[43,50] Kilpatrick and colleagues[43] were the first to provide evidence that the *S'* allele of the *5-HTTLPR* polymorphism modulated the influence of hurricane exposure and social support on PTSD symptoms. A limitation of that epidemiologic study is that the number of affected subjects was small (n=19). Further, it focused on 1 specific (and acute) trauma. This decreased the heterogeneity of the trauma experience between patients, enhancing the internal validity of the study but limiting its generalizability. The study by Binder and colleagues[50] showed that 4 SNPs in the *FKBP5* gene interacted with childhood abuse to increase the level of PTSD symptoms. Two of the 4 SNPs in *FKBP5* were previously found to be associated with

peritraumatic dissociation, a well-established risk factor for PTSD, in medically injured children.[51] Binder and colleagues used a PTSD symptom scale score as an outcome measure based on the assumption that it could be used to make inferences about the disorder. Although the score correlates with a diagnosis of PTSD, it remains uncertain as to the relevance of the measured symptoms to the disorder.

In comparison with these previous studies, the current study has several strengths that deserve mention. Instead of using PTSD symptoms as an outcome, participants were directly interviewed by trained interviewers, resulting in a reliable PTSD diagnosis. Consistent with the necessity that PTSD follows exposure to traumatic event(s), we studied only people who reported having had 1 or more extreme adverse experiences in their lives, which increased the statistical power. In addition, we examined a range of childhood adversity and adult traumatic events. These events covered most (although certainly not all) trauma types known to cause PTSD. For the *5-HTTLPR* genotypes, we performed analyses using genotypes based on the triallelic reclassification to compare the results with those using the genotypes from the *L-S* diallelic classification. They were nearly identical. Therefore, this study provided a systematic and clear view of the gene×environment interaction as it contributes to the risk of a PTSD diagnosis.

Different allele frequencies of *5-HTTLPR* in European American and African American individuals have been previously reported[23] and were observed in our study. A series of methods to exclude population stratification as a potential confounder were used in this study. First, a Bayesian clustering method was applied to analyze the genotype data of 41 ancestry-informative markers, dividing the participants into 2 subgroups. Second, statistical analyses were performed separately within the 2 population subgroups. The interaction of *5-HTTLPR* by dual stressful life events was observed to be significantly associated with the PTSD diagnosis in both populations individually. Third, when analyzing the whole sample, ancestry proportion score was used as a covariate in the logistic regression model, although no significant association was observed between PTSD and population. Therefore, the different *5-HTTLPR* allele frequencies between the 2 populations were not likely confounding our analyses.

However, interpretation of this study should consider the following limitation. Retrospective recall of early adverse experiences might be inaccurate or biased, including the potential for there to be bias introduced by a subsequent experience of PTSD. The interval, significance of events, and personal characteristics could cause recall bias. Especially since PTSD rarely occurs alone, an abnormal mental state related to other disorders, such as substance use disorder or major depression, may also cause recall bias. Future gene×environment studies based on a cohort longitudinal design would address this potential bias in recall of life events.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Acknowledgments

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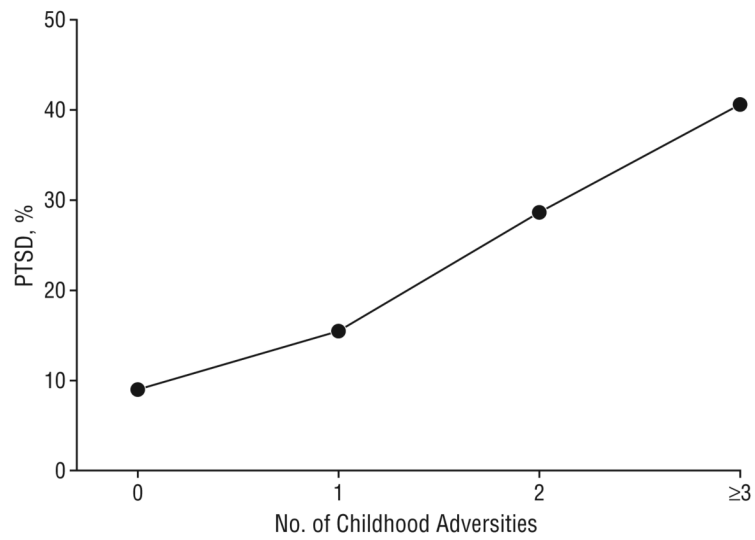
Figure 1.
The number of childhood adversity types is associated with the onset of posttraumatic stress disorder (PTSD).
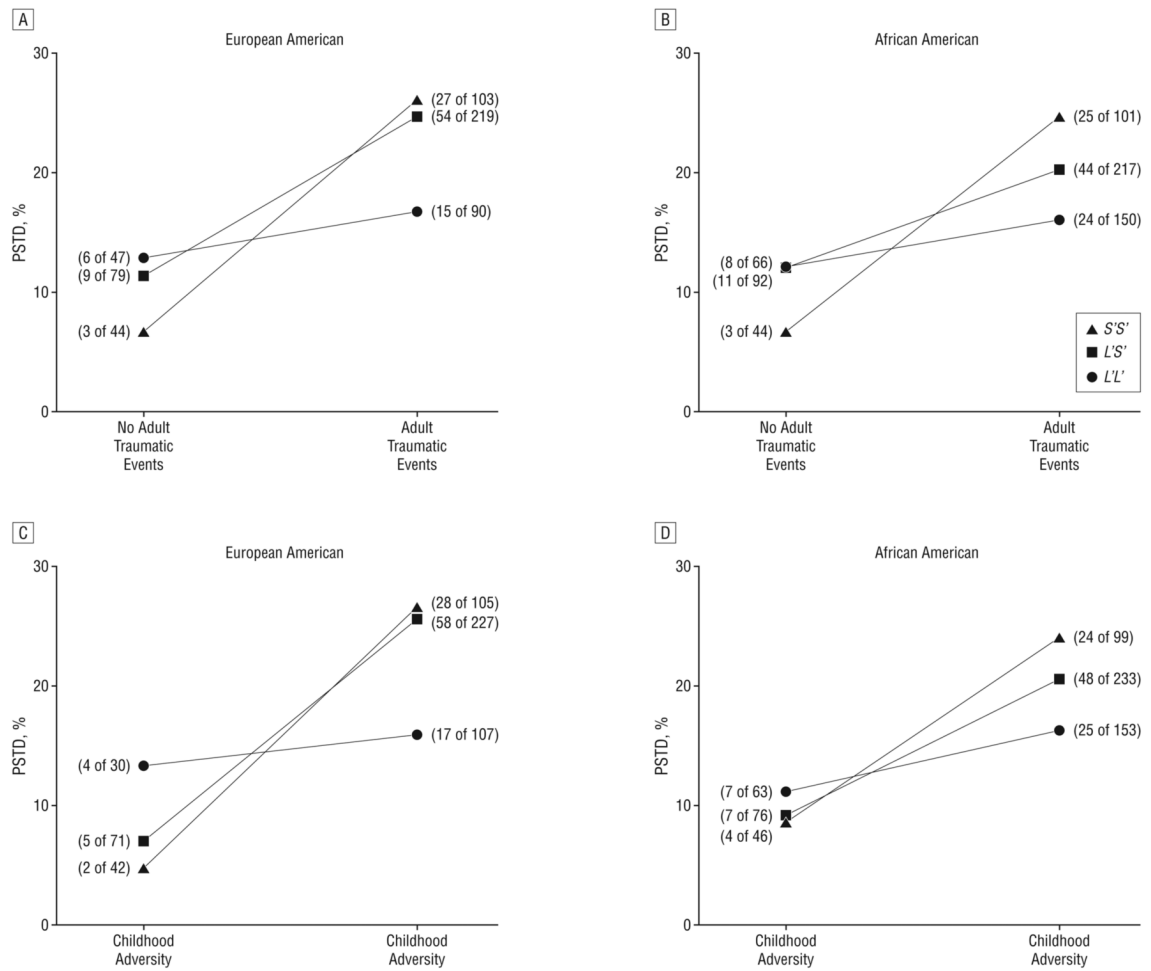
Figure 2.
In European American and African American individuals, *5-HTTLPR* genotype interacted with adult traumatic events (A and B) to increase risk for posttraumatic stress disorder (PTSD). In European American individuals, the genotype also interacted with childhood adversity (C); in African American individuals, the interactive effect was a trend (D). The numbers of patients with PTSD of the total numbers of participants in the group are shown.
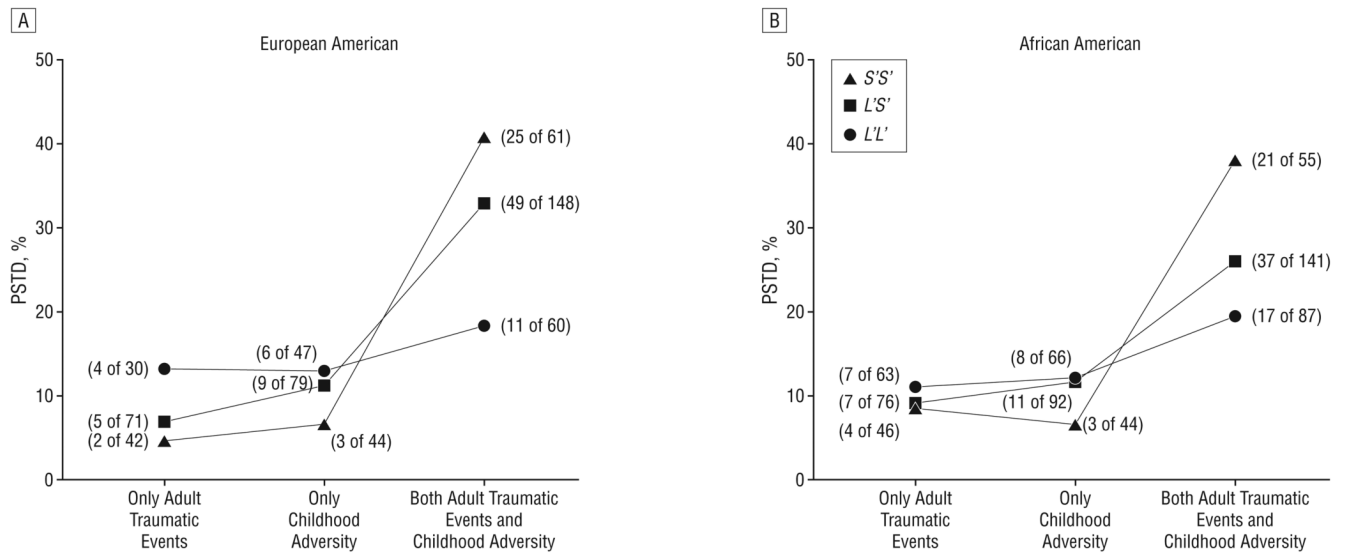
Figure 3.
5-HTTLPR genotype interacted with dual stressful life events to increase the risk for posttraumatic stress disorder (PTSD) in both European American and African American individuals. The numbers of patients with PTSD of the total numbers of participants in the group are shown.
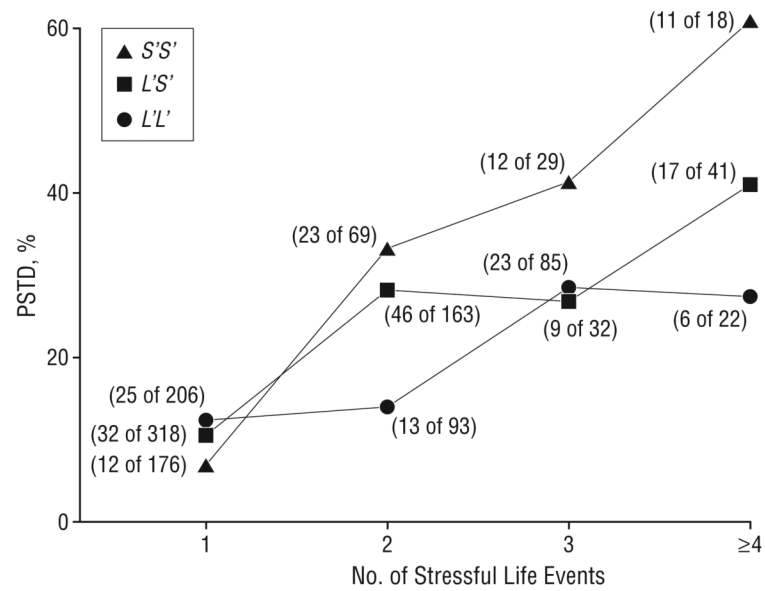
Figure 4.
5-HTTLPR genotype interacted with the number of stressful life events to increase the risk for posttraumatic stress disorder (PTSD) (group 1: exposure to either adult trauma or childhood adversity; group 2: exposure to adult trauma and 1 type of childhood adversity; group 3: exposure to adult trauma and 2 types of childhood adversity; and group 4: exposure to adult trauma and more than 2 types of childhood adversity).

Table 1

Prevalence of PTSD by Sex and Population

Characteristics	PTSD, No. (%)	χ^2_1	P Value
Sex		12.3	<.001
M (n = 656)	96 (14.6)		
F (n = 596)	133 (22.3)		
Population		1.3	.26
EA (n = 582)	114 (19.6)		
AA (n = 670)	115 (17.1)		

Abbreviations: AA, African American; EA, European American; PTSD, posttraumatic stress disorder.

Table 2

Results of Logistic Regression Analyses[a]

	EA		AA		Pooled	
	OR (95% CI)	P Value	OR (95% CI)	P Value	OR (95% CI)	P Value
Sex	0.53 (0.34-0.83)	.005[b]	0.63 (0.42-0.96)	.03[c]	0.58 (0.43-0.79)	<.001[d]
Age,y	1.01 (0.99-1.02)	.58	1.02 (1.00-1.04)	.08	1.01 (1.00-1.02)	.09
Ancestry proportion score					1.12 (0.81-1.55)	.50
Adult traumatic events	4.09 (2.31-7.26)	<.001[d]	3.22 (1.90-5.45)	<.001[d]	3.57 (2.43-5.25)	<.001[d]
Childhood adversity	5.70 (2.89-11.26)	<.001[d]	3.44 (1.98-5.97)	<.001[d]	4.30 (2.81-6.60)	<.001[d]
5-HTTLPR genotype	1.24 (0.91-1.69)	.17	1.22 (0.91-1.63)	.18	1.22 (0.99-1.51)	.07
5-HTTLPR× adult traumatic events	2.60 (1.19-5.66)	.02[c]	2.06 (1.02-4.14)	.04[c]	1.93 (1.17-3.17)	.01[c]
5-HTTLPR× childhood adversity	3.29 (1.17-9.22)	.02[c]	1.71 (0.81-3.61)	.16	1.81 (1.01-3.24)	.046[c]
5-HTTLPR× dual stressful events	2.86 (1.50-5.45)	.002[b]	1.88 (1.04-3.40)	.04[c]	2.31 (1.50-3.56)	<.001[d]

Abbreviations: AA, African American; CI, confidence interval; EA, European American; OR, odds ratio.

[a] Sex, age, adult traumatic events, and childhood adversity were used as covariates in all the models. In addition, ancestry proportion scores were included in the pooled model.

[b] P<.01.

[c] P<.05.

[d] P<.001.

Table 3

Distribution of Childhood Adversity and Adult Traumatic Events by Genotype Groups

	%			
	L′L′	**L′S′**	**S′S′**	*P* **Value**
Childhood adversity				
Neglect	50.4	50.0	51.5	.78
Witnessing or experiencing a violent crime	41.5	42.2	40.7	.91
Sexual abuse	29.6	35.9	31.9	.26
Physical abuse	28.5	24.6	28.9	.36
Adult traumatic events				
Sexual harassment	21.7	20.0	17.6	.57
Physical attack	42.9	46.1	45.6	.72
Accidents	70.8	69.5	70.1	.94