Trauma Exposure and Stress Response: Exploration of Mechanisms of Cause and Effect

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People differ markedly in their risk for developing posttraumatic stress symptoms (PTSS) after exposure to traumatic events. Twin studies suggest that the trauma-PTSS relationship is moderated by genetic and environmental influences. The present study tested for specific types of genetic and environmental interaction effects on PTSS. A sample of 222 monozygotic and 184 dizygotic twin pairs reported on lifetime frequency of assaultive and nonassaultive trauma and associated PTSS. Biometric analyses indicated that in the case of nonassaultive trauma, PTSS were directly affected by environmental factors that also influence exposure to nonassaultive trauma. For assaultive trauma both genetic and non-shared environmental influences jointly affected PTSS, and the number of traumatic events moderated the severity of PTSS. Genetic factors were found to become less important beyond some threshold (e.g., 3 or 4 types of serious trauma) suggesting that genetic factors — which may confer either risk or resilience to PTSS — modify these symptoms within a range of human experience, beyond which environmental effects supervene.

Posttraumatic stress disorder (PTSD) is unique among anxiety disorders in that it is defined in the context of exposure to a traumatic event. PTSD is characterized by a range of symptoms including vivid reexperiencing of the trauma (e.g., intrusive memories, nightmares, flashbacks), phobic avoidance of trauma-related stimuli, emotional numbing (e.g., difficulty experiencing close emotional bonds to other people), and hyperarousal (e.g., hypervigilance, sleep difficulties; American Psychiatric Association, 2000).

Posttraumatic stress symptoms (PTSS) vary on a continuum of severity; in other words, the symptoms arising from severe traumatic events differ quantitatively, not qualitatively, from the symptoms associated with less serious but nonetheless stressful life events (Mol et al., 2005). PTSD represents the upper end of the continuum of symptom severity rather than constituting a qualitatively distinct diagnostic category (Ruscio et al., 2002).

People differ markedly in their risk of developing PTSS after exposure to a traumatic event; traumatic events are relatively common, whereas PTSS and PTSD are comparatively rare (McNally, 2003). Events that involve the element of interpersonal assault (e.g., rape, intimate partner violence, other violent crime) carry higher risks for PTSD than events lacking this element (Taylor, 2006). Although such characteristics of the traumatic stressor have been shown to influence risk for PTSD, these fail to explain much of the variance in PTSD rates among exposed persons. This suggests the importance of individual differences variables, such as genetic factors influencing the severity of stress reactions.

Twin studies have provided support for modest, but significant genetic influences on PTSS. The Vietnam Era Twin Registry (VETR) study evaluated 4029 male–male veteran twin pairs (2224 monozygotic [MZ] and 1818 dizygotic [DZ] pairs; Lyons et al., 1993; True et al., 1993). The estimated heritability of PTSS, after accounting for differences in trauma exposure between twins, was approximately 30%. This research also demonstrated that genetic factors influence trauma exposure (in this study, combat was the sole type of trauma exposure evaluated), highlighting the fact that risk for PTSS is the outcome of two processes: risk for exposure to traumatic events, followed by the risk for PTSS symptoms conditional upon exposure.

Similar findings were reported in a study of general population twin pairs, which examined noncombat-related traumatic events (Stein et al., 2002). The variability in exposure to assaultive trauma (e.g., robbery, sexual assault) was explained by additive genetic ($h^2 = .20$), common environmental ($c^2 = .21$) and unique environmental effects ($e^2 = .58$). In comparison, the variability of exposure to nonassaultive trauma (e.g., motor vehicle accident; natural disaster)
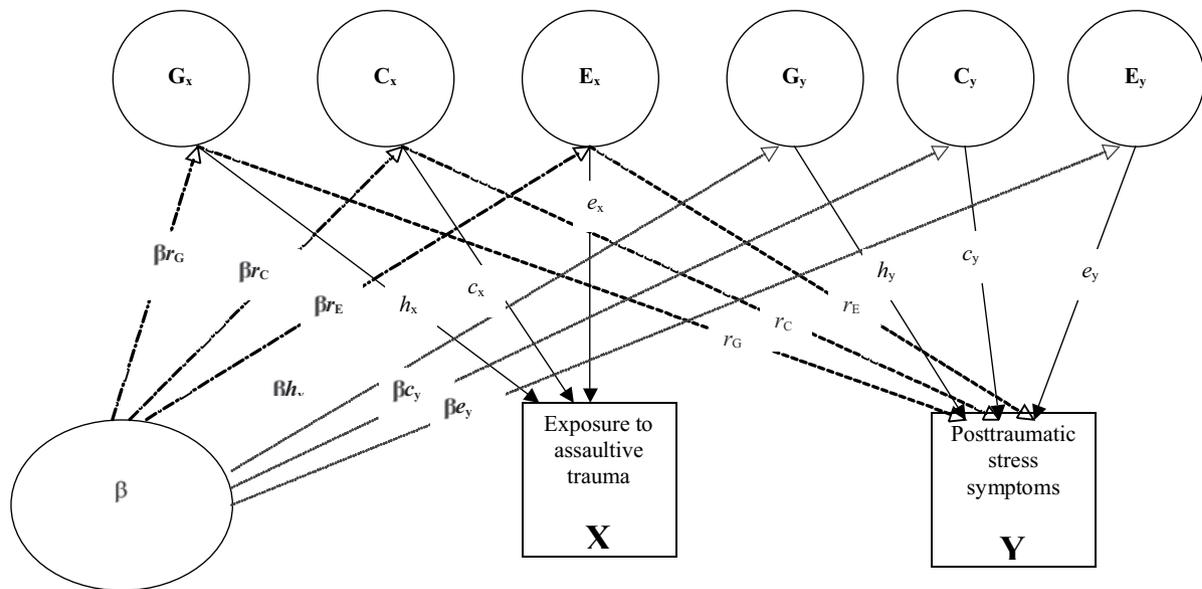
Figure 1

Full model.

Note: Y = intensity of PTSS; X = number of exposure to either assaultive or nonassaultive trauma; G_x and G_y = additive genetic effects passed directly from parents to offspring along the paths marked h_x and h_y; C_x and C_y = shared family environment transmitted to each member of the family along the path marked c_x and c_y; E_x and E_y = nonshared environmental effects (including error) transmitted to each member of the family along paths e_x and e_y; r_G, r_C, and r_E index the degree to which a particular form of exposure and a PTSS are influenced by the same genetic environmental factors; βh_y, βc_y, βe_y, βr_G, βr_C, and βr_E that index the moderation of genetic and environmental effects in common to the moderator and PTSS as described in text.

could be explained entirely by environmental factors ($c^2 = .39$, $e^2 = .61$). This study also reported that PTSS were moderately heritable ($h^2 = .28$ to .36) and showed for the first time that exposure to assaultive trauma and the severity of PTSS are influenced by a common set of genetic factors; the genetic correlations (r_G indexes pleiotropy — the degree to which genetic factors are shared) ranged from .71 to .83, thereby establishing a genetic link between trauma exposure and PTSS. In contrast, the environmental factors that influence trauma exposure appear to be largely distinct from the environmental factors influencing PTSS, as indicated by the low values of r_E (environmental correlations between types of PTSS and assaultive trauma ranged from .16 to .25; environmental correlations between types of PTSS and nonassaultive trauma ranged from .11 to .18).

These relationships need to be examined in more detail. The Stein et al. (2002) findings indicate that exposure to nonassaultive trauma is etiologically distinct from assaultive trauma. This raises the question of whether PTSS associated with nonassaultive trauma may arise from different mechanisms than PTSS associated with assaultive trauma. There are also unanswered questions about the relationship between 'dose' of trauma and the impact of genes. For example, does the role of genetic factors change as a function of the number of traumatic events that a person has experienced? Research indicates that the risk of developing PTSS increases with the dose (severity or frequency) of trauma exposure (see Taylor, 2006, for a review). Thus, given a sufficiently

large dose of trauma exposure, virtually anyone would succumb to PTSS (and PTSD). People who are most likely to develop PTSS in response to comparatively lower doses of trauma may be those individuals who are genetically predisposed to have intense emotional reactions in response to stressors. All of this suggests that, at a population level, there will be an inverse relationship between heritability of PTSS and the number of traumatic events that are experienced. Genetic factors should account for more variance in PTSS for groups of people who have experienced few traumatic events (i.e., genetically vulnerable individuals), compared to people who have experienced a great deal of trauma. The experience of a large number of traumatic events should lead to PTSS regardless of a person's genetic vulnerability. Therefore, the importance of genetic factors (in terms of variance explained in PTSS) should diminish as a function of the number of traumatic events that a person has experienced.

An important step in understanding the trauma-PTSS relationship is to determine the mechanisms that govern how exposure to an event activates and shapes the stress response. In addition to the concept of genetic (r_G) and environmental correlations (r_E) that index the extent to which two variables share a common etiology, another plausible mechanism given that genetic and environmental factors affect both exposure to events and the stress response, is gene–environment interaction or G × E (Plomin et al., 1977) in which environmental conditions (e.g., number of exposures or severity of

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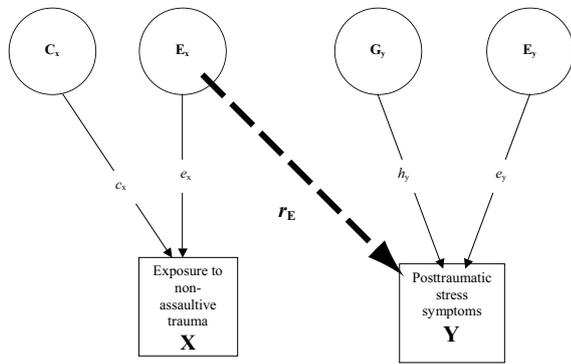
Figure 2

Best-fitting model for nonassaultive trauma.

Note: Y = intensity of PTSS; X = number of exposure to nonassaultive trauma; G_y = additive genetic effects passed directly from parents to offspring along the path marked h_y; C_x = shared family environment transmitted to each family member along the path marked c_x; E_x and E_y = nonshared environmental effects (including error) transmitted to each member of a family along paths e_x and e_y; r_E = the degree to exposure to nonassaultive trauma and a particular form of exposure and a PTSS are influenced by the same nonshared environmental factors.

exposure) moderate genetic factors involved in the stress response. Within the classical twin study, the presence of G × E is demonstrated when heritability for a target behaviour is shown to vary across levels of some environmental condition. For example, Heath et al. (1989) showed that marriage (an environmental condition) reduced the genetic variability in alcohol consumption in females. Across their total sample, for unmarried twins the heritability for alcohol consumption was estimated to be 77%, but was only 59% for married twin pairs. In addition to G × E, there also may be an experience-by-environment interaction (E × E). An example is the finding that some people can live in the most adverse conditions (e.g., extreme poverty), but display no ill effects because the presence of another environmental factor, such as a caring mother who attends to the emotional needs of a child, buffers the effects of poverty (e.g., Leckman & Mayes, 2007).

The purpose of the present study was to simultaneously investigate the interaction of genetic and environmental influences, pleiotropy, and mutual environments on the observed relationship between the exposure to the number of traumatic events and PTSS. Specifically, we investigated interactions between composite measures of self-reported frequency of assaultive and nonassaultive events and severity of the four major groups of PTSS: re-experiencing, effortful avoidance, numbing, and hyperarousal, as identified in previous research (e.g., Asmundson et al., 2004).

Method

Participants

The sample consisted of 222 MZ twin pairs (174 sister pairs aged 34.52 ± 17.29 years; 48 brother pairs

aged 35.99 ± 14.16 years) and 184 DZ pairs (117 sister pairs aged 31.30 ± 17.11 years, 27 brother pairs aged 34.92 ± 14.67 years, and 40 opposite-sex pairs aged 32.08 ± 15.54 years) from the Vancouver area in British Columbia, Canada, who volunteered after media appeals. Zygosity was determined using a highly accurate questionnaire (Kasriel & Eaves, 1976) and examination of recent color photographs. All subjects gave their informed, written consent to participate in this study, which was approved by the Human Subjects Committee of the Faculty of Medicine of the University of British Columbia. Data from a portion of these participants were published previously (Jang et al., 2003; Stein et al., 2002), although the specific aims of this study have not been previously addressed with this dataset. These previous publications established the basic properties of the instruments and yielded preliminary heritability estimates, results that help frame the interpretation of subsequent findings.

Measures and Procedure

Twin pairs completed a packet of questionnaires at home, a common method used by twin studies. Participants were instructed to complete the questionnaires independently of one another in a nondistracting setting. All participants who returned their questionnaires received cash remuneration.

One questionnaire included in the battery was a pencil-and-paper adaptation of questions used in our previous telephone epidemiologic survey of PTSD (Stein et al., 1997). This questionnaire assessed lifetime exposure to 9 different types of traumatic events: robbery; kidnapping; being held captive; being beaten up; sexual assault; other life threat; sudden family death; motor vehicle accident; fire; and tornado, flood, earthquake. Previous factor analyses of the scale yielded two factors: assaultive trauma (robbery, held captive, beaten up, and sexual assault) and nonassaultive trauma (sudden family death, motor vehicle, accident fire, and tornado, flood, earthquake; Stein et al., 2002).[1] A score for assaultive trauma was formed by summing the number of exposures for robbery, held captive, beaten up, and sexual assault; and a score for nonassaultive trauma comprised the sum of reported exposures to sudden family death, motor vehicle, accident fire, and tornado, flood, and earthquake.

Each member of a pair was screened for exposure to either type of traumatic event. In total, both members of 167 MZ (75% of all MZ pairs) and 156 DZ pairs (85% of all DZ pairs) reported experiencing some form of traumatic event. It is important to note that for the present study, a deliberately conservative analytic approach was taken by only including twin pairs in which *both* members had reported exposure to some kind of traumatic event. This approach was taken for two reasons. First, although it is possible to increase the sample and statistical power by including pairs in which only one member had reported exposure to
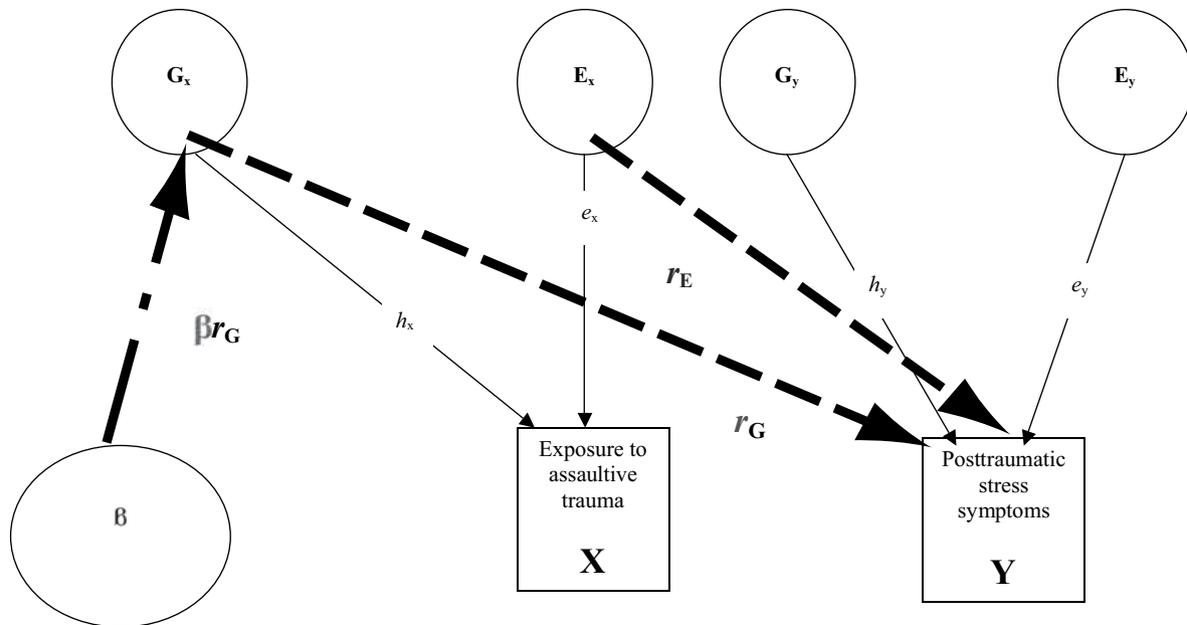
Figure 3

Best-fitting model for assaultive trauma.

Note: Y = intensity of PTSS; X = number of exposure to either assaultive; G_x and G_y = additive genetic effects passed directly from parents to offspring along the paths marked h_x and h_y; E_x and E_y = nonshared environmental effects (including error) transmitted to each member of the family along paths e_x and e_y; r_G and r_E index the degree to which a particular form of exposure and a PTSS are influenced by the same genetic and environmental factors; βr_G indexes the moderation of genetic effects in common to the moderator, assaultative trauma and PTSS as described in text.

some form of trauma, inclusion of such pairs would artificially inflate the differences between members of a pair and the ability to detect gene–environment interplay effects. Second, we felt it was important to adhere to the clinical definition of PTSS/PTSD that one cannot report having PTSS unless one has experienced some form of trauma. Therefore, people who had not experienced a traumatic event were excluded, even if they might have had PTSS-like symptoms arising from nontraumatic stressors. Thus, despite incurring a penalty of reduced sample size, the compensation is increased validity of the results.

The proportions of trauma-exposed individuals are consistent with findings from general population epidemiologic studies, which have clearly demonstrated that trauma exposure is unfortunately common, even in developed countries (e.g., Breslau, 2002). A total of 86 MZ and 71 DZ pairs reported experiencing at least one nonassaultive traumatic event, and 81 MZ and 85 DZ pairs reported experiencing at least one assaultive event. All subsequent analyses were conducted with these selected samples. A total of 37 MZ (22% of all MZ pairs) and 48 DZ (31% of all DZ pairs) pairs reported having experienced at least one assaultive *and* at least one nonassaultive trauma.[2]

PTSS were assessed by a 17-item scale adapted, with permission, from Foa's (1995) Posttraumatic Diagnostic Questionnaire. Participants were instructed that 'Some people have difficulties after a particularly disturbing event. Please recall a period of your life following the disturbing event(s) when you were most troubled or upset. For each question, please tell us whether you would say not at all, a little bit, somewhat, very much or don't know'. Factor analyses of the items have yielded four factors corresponding to the following symptom dimensions: re-experiencing, avoidance, numbing, and hyperarousal (Asmundson et al., 2004). Factor scores were computed for each participant as an index of stress response.

Biometric Model-Fitting

PRELIS 2 was used to estimate co-twin similarity (covariances and Pearson's *r*) for MZ and DZ pairs (Jöreskog & Sörbom, 1993). Figure 1 illustrates the basic model used to simultaneously estimate the degree to which the relationship between frequency of exposure and PTSS is attributable to shared etiology and to interplay effects described by Purcell (2002). The square marked Y represents the intensity of PTSS reported by each individual as a result of exposure to either assaultive or nonassaultive trauma (square marked X). The circles labelled G_x and G_y represent genetic influences that are passed directly from parents to offspring along the paths marked h_x and h_y. The circles labelled C_x and C_y represent the general environment of a family that have an effect, along the paths marked c_x and c_y respectively, of making children within a family more similar (Rowe, 1994). E_x and E_y represent environmental events or conditions that have differential effects transmitted to individual

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Table 1

Model Fitting Statistics for Nonassaultive Trauma

Model (parameters in each model)	χ^2	df	Models tested	$\Delta\chi^2$
Re-experiencing				
1. c_{nasalt}, e_{nasalt}, $h_{rexperiencing}$, $e_{rexperiencing}$, r_E, βh_y, βr_E, βe_y	2928.115	618	—	—
2. c_{nasalt}, e_{nasalt}, $h_{rexperiencing}$, $e_{rexperiencing}$, r_E, βr_E, βe_y	2928.225	619	2 vs. 1	0.110 ns
3. c_{nasalt}, e_{nasalt}, $h_{rexperiencing}$, $e_{rexperiencing}$, r_E, βr_E	2928.269	620	3 vs. 2	0.044 ns
4. c_{nasalt}, e_{nasalt}, $h_{rexperiencing}$, $e_{rexperiencing}$, r_E	**2929.725**	**621**	**4 vs. 3**	**1.456 ns**
5. c_{nasalt}, e_{nasalt}, $h_{rexperiencing}$, $e_{rexperiencing}$	2933.911	622	5 vs. 4	5.642*
Avoidance				
1. c_{nasalt}, e_{nasalt}, $h_{avoidance}$, $e_{avoidance}$, r_E, βh_y, βr_E, βe_y	2409.276	618		—
2. c_{nasalt}, e_{nasalt}, $h_{avoidance}$, $e_{avoidance}$, r_E, βr_E, βe_y	2409.823	619	2 vs. 1	0.547 ns
3. c_{nasalt}, e_{nasalt}, $h_{avoidance}$, $e_{avoidance}$, r_E, βr_E	2410.513	620	3 vs. 2	0.690 ns
4. c_{nasalt}, e_{nasalt}, $h_{avoidance}$, $e_{avoidance}$, r_E	**2410.840**	**621**	**4 vs. 3**	**0.327 ns**
5. c_{nasalt}, e_{nasalt}, $h_{avoidance}$, $e_{avoidance}$	2419.199	622	5 vs. 4	8.359*
Numbing				
1. c_{nasalt}, e_{nasalt}, $h_{numbing}$, $e_{numbing}$, r_E, βh_y, βr_E, βe_y	2852.160	618	—	—
2. c_{nasalt}, e_{nasalt}, $h_{numbing}$, $e_{numbing}$, r_E, βr_E, βe_y	2852.391	619	2 vs. 1	0.231 ns
3. c_{nasalt}, e_{nasalt}, $h_{numbing}$, $e_{numbing}$, r_E, βr_E	2852.708	620	3 vs. 2	0.317 ns
4. c_{nasalt}, e_{nasalt}, $h_{numbing}$, $e_{numbing}$, r_E	**2853.108**	**621**	**4 vs. 3**	**0.400 ns**
5. c_{nasalt}, e_{nasalt}, $h_{numbing}$, $e_{numbing}$	2860.056	622	5 vs. 4	6.948*
Hypervigilance				
1. c_{nasalt}, e_{nasalt}, $h_{hypervigilance}$, $e_{hypervigilance}$, r_E, βh_y, βr_E, βe_y	2927.216	618	—	—
2. c_{nasalt}, e_{nasalt}, $h_{hypervigilance}$, $e_{hypervigilance}$, r_E, βr_E, βe_y	2927.268	619	2 vs. 1	0.052 ns
3. c_{nasalt}, e_{nasalt}, $h_{hypervigilance}$, $e_{hypervigilance}$, r_E, βr_E	2927.291	620	3 vs. 2	0.023 ns
4. c_{nasalt}, e_{nasalt}, $h_{hypervigilance}$, $e_{hypervigilance}$, r_E	**2928.235**	**621**	**4 vs. 3**	**0.944 ns**
5. c_{nasalt}, e_{nasalt}, $h_{hypervigilance}$, $e_{hypervigilance}$	2935.619	622	5 vs. 4	7.384*

Note: N_{MZ} = 86 pairs; NDZ = 71 pairs; *p < .05; T = moderation of genes common to the assaultive trauma exposure and PTSS; βr_E = moderation of environmental influences common to the assaultive trauma exposure and PTSS; βh_y = moderation of the genetic influences unique to PTSS; βe_y = moderation of the environmental influences unique to PTSS; h_{asalt}, = genetic influences on assaultive trauma exposure; h_y = genetic influences on PTSS; e_x = nonshared environmental influence on assaultive trauma exposure; e_y = nonshared environmental influence on PTSS; r_G = genetic correlation between assaultive trauma exposure and PTSS; r_E = nonshared environmental correlation between assaultive trauma exposure and PTSS; best-fitting models are in bold.

family members along paths e_x and e_y, respectively (Hetherington et al., 1994), in addition to random error variance.

Parameter estimates for h_x, h_y, c_x, c_y, e_x, and e_y are squared and divided by the total variance to compute the familiar standardized proportions of the variance, h^2_x, h^2_y, c^2_x, c^2_y, e^2_x and e^2_y attributable to each source of genetic and environmental influence. The paths labeled r_G, r_C, and r_E index the degree to which PTSS are influenced by the same genetic environmental factors (Gx, Cx, and Ex) that determine frequency of trauma exposure. G_y, C_y, and E_y obviously represent genetic and environmental effects unique to PTSS.

In order to allow testing for the moderation of genetic and environmental influences in common, Purcell (2002) developed and tested a model fitting device in which the number of traumatic exposures, X, is specified in the model for a second time (β) that permits the definition of moderated genetic, shared, and nonshared environmental effects unique to PTSS. βh_y, βc_y, βe_y, βr_G, βr_c, and βr_e index the moderation of

genetic and environmental effects in common to the moderator and PTSS.

Nonassaultive Trauma

The first set of analyses examined the relationship between exposure to nonassaultive trauma and each of the four PTSS clusters (re-experiencing, avoidance, numbing, and hyperarousal). Previously published univariate analyses (Stein et al., 2002) indicated that nonassaultive trauma was not heritable and its observed variability was entirely attributable to shared (C_x) and nonshared environmental (E_x) effects, whereas the observed variability of PTSS was directly attributable to genetic (G_y) and nonshared environmental (E_y) influences. Previous research with these measures (Jang et al., 2003; Stein et al., 2002) provided a clear justification that reduces the total number of parameters to be estimated and tested that enhances power and further reduces the probability of Type I error. Model 1 estimated the following effects: c_x, c_y, h_y, e_y, r_E, moderation of genes unique to each symptom (βh_y), moderation of nonshared environment unique to each symptom (βe_y), and

Table 2

Model Fitting Statistics for Assaultive Trauma

Model (Parameters in each model)	χ^2	df	Models Tested	$\Delta\chi^2$
Re-experiencing				
1. h_{asalt}, $h_{rexperiencing}$, e_{asalt}, $e_{rexperiencing}$, r_G, r_E, βr_G, βr_E, βh_y, βe_y	3494.349	652	—	—
2. h_{asalt}, $h_{rexperiencing}$, e_{asalt}, $e_{rexperiencing}$, r_G, r_E, βr_G, βr_E, βe_y,	3492.196	653	2 vs. 1	2.349 ns
3. h_{asalt}, $h_{rexperiencing}$, e_{asalt}, $e_{rexperiencing}$, r_G, r_E, βr_E, βe_y	3498.311	654	3 vs. 2	5.658*
4. h_{asalt}, $h_{rexperiencing}$, e_{asalt}, $e_{rexperiencing}$, r_G, r_E, βr_G, βr_E	3495.802	654	4 vs. 2	3.606 ns
5. h_{asalt}, $h_{rexperiencing}$, e_{asalt}, $e_{rexperiencing}$, r_G, r_E, βr_G	**3496.301**	**655**	**5 vs. 4**	**0.499 ns**
Avoidance				
1. h_{asalt}, $h_{avoidance}$, e_{asalt}, $e_{avoidance}$, r_G, r_E, βr_G, βr_E, βh_y, βe_y	2991.120	652	—	—
2. h_{asalt}, $h_{avoidance}$, e_{asalt}, $e_{avoidance}$, r_G, r_E, βr_G, βr_E, βe_y	2991.246	653	2 vs. 1	0.126 ns
3. h_{asalt}, $h_{avoidance}$, e_{asalt}, $e_{avoidance}$, r_G, r_E, βr_E, βe_y	2993.056	654	3 vs. 2	1.810 ns
4. h_{asalt}, $h_{avoidance}$, e_{asalt}, $e_{avoidance}$, r_G, r_E, βr_E	**2994.604**	**655**	**4 vs. 3**	**1.548 ns**
5. h_{asalt}, $h_{avoidance}$, e_{asalt}, $e_{avoidance}$, r_G, r_E	3005.563	656	5 vs. 4	10.959*
Numbings				
1. h_{asalt}, $h_{numbing}$, e_{asalt}, $e_{numbing}$, r_G, r_E, βr_G, βr_E, βh_y, βe_y	3417.147	652	—	—
2. h_{asalt}, $h_{numbing}$, e_{asalt}, $e_{numbing}$, r_G, r_E, βr_G, βr_E, βe_y	3417.175	653	2 vs. 1	0.028 ns
3. h_{asalt}, $h_{numbing}$, e_{asalt}, $e_{numbing}$, r_G, r_E, βr_E, βe_y	3421.662	654	3 vs. 2	4.487*
4. h_{asalt}, $h_{numbing}$, e_{asalt}, $e_{numbing}$, r_G, r_E, βr_G, βr_E	3420.570	654	4 vs. 2	3.395 ns
5. h_{asalt}, $h_{numbing}$, e_{asalt}, $e_{numbing}$, r_G, r_E, βr_G	**3420.972**	**655**	**5 vs. 4**	**0.402 ns**
Hypervigilance				
1. h_{asalt}, $h_{hypervigilance}$, e_{asalt}, $e_{hypervigilance}$, r_G, r_E, βr_G, βr_E, βh_y, βe_y	3493.665	652	—	—
2. h_{asalt}, $h_{hypervigilance}$, e_{asalt}, $e_{hypervigilance}$, r_G, r_E, βr_G, βr_E, βe_y	3493.681	653	2 vs. 1	0.026 ns
3. h_{asalt}, $h_{hypervigilance}$, e_{asalt}, $e_{hypervigilance}$, r_G, r_E, βr_E, βe_y	3503.402	654	3 vs. 2	9.721*
4. h_{asalt}, $h_{hypervigilance}$, e_{asalt}, $e_{hypervigilance}$, r_G, r_E, βr_G, βr_E	3496.761	654	4 vs. 2	3.080 ns
5. h_{asalt}, $h_{hypervigilance}$, e_{asalt}, $e_{hypervigilance}$, r_G, r_E, βr_G	**3497.457**	**655**	**5 vs. 4**	**0.696 ns**

Note: NMZ = 81 pairs; NDZ = 85 pairs; *$p < .05$ tested at 1 df; βr_G = moderation of genes common to the assaultive trauma exposure and PTSS; βr_E = moderation of environmental influences common to the assaultive trauma exposure and PTSS; βh_y = moderation of the genetic influences unique to PTSS; βe_y = moderation of the environmental influences unique to PTSS; h_{asalt}, = genetic influences on assaltive trauma exposure; $h$symptom = genetic influences on PTSS; e_x = nonshared environmental influence on assaultive trauma exposure; e_y = nonshared environmental influence on PTSS; r_G = genetic correlation between assaultive trauma exposure and PTSS; r_E = nonshared environmental correlation between assaultive trauma exposure and PTSS. Best-fitting models in bold.

moderation of nonshared environmental effects in common to nonassaultive trauma and stress response factor (βr_E), were specified.

The second model (Model 2) dropped βh_y and evaluated against Model 1 to test for moderation of genes unique to a symptom. Differences in the log-likelihood of nested models were compared with the χ^2 distribution. When there was a significant χ^2 ($p < .05$) for a difference in degrees of freedom between the models, the model with the fewest degrees of freedom was adopted. Model 3 dropped βe_y from the model as a test for moderation of nonshared environment unique to each stress response factor. Finally, Model 4 dropped βr_E as a test of moderation of nonshared environmental effects in common to nonassaultive trauma and symptom.

Assaultive Trauma

Previously published univariate heritability analyses indicated the variability of both assaultive trauma and each symptom could be accounted for by genetic (G_x, G_y) and nonshared environmental (E_x, E_y) effects. As such, Model 1 only estimated h_x, e_x, h_y, e_y, r_G, r_E, and

the moderation of common genetic and nonshared environmental influences (βr_G) and (βr_E), and moderation genetic and nonshared environmental influences and unique to each stress response factor (βh_y and βe_y). Four additional models were tested by systematically dropping βh_y, βe_y, βr_G and βr_E.

Results

Nonassaultive Trauma

Participants reported experiencing between 1 to 8 nonassaultive traumas. The average number was 2.63 ± 2.32. Table 1 presents the model fitting results for nonassaultive trauma for each of the PTSS clusters. Systematically dropping each of the moderation effects yielded nonsignificant changes in log-likelihood χ^2 tested at $p < .05$. For each type of symptom, Model 4, in which all moderation effects had been dropped from the model, provided the most satisfactory fit in all cases. In this model, the observed relationship between nonassaultive trauma and each symptom is solely due to the fact they are influenced by the same nonshared environmental effects (r_E). The general form of Model 4 is illustrated in Figure

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Table 3

Heritability of Posttraumatic Stress Symptoms as a Function of Number of Assaultive Traumas Experienced

Number of traumas	Reexperiencing				Avoidance				Numbing				Hypervigilance			
	h^2_c	e^2_c	h^2_u	e^2_u	h^2_c	e^2_c	h^2_u	e^2_u	h^2_c	e^2_c	h^2_u	e^2_u	h^2_c	e^2_c	h^2_u	e^2_u
1	.33	.09	.12	.46	.07	.22	.15	.57	.36	.09	.11	.44	.31	.10	.02	.57
2	.28	.09	.13	.50	.07	.18	.16	.59	.31	.10	.12	.48	.27	.11	.02	.61
3	.23	.10	.14	.53	.07	.15	.16	.62	.25	.11	.13	.50	.22	.11	.02	.64
4	.19	.10	.15	.56	.07	.11	.17	.64	.20	.12	.14	.55	.18	.12	.02	.68
5	.14	.11	.16	.59	.08	.09	.18	.66	.15	.12	.15	.58	.14	.13	.02	.71
6	.10	.12	.17	.62	.08	.06	.18	.68	.10	.13	.16	.61	.11	.13	.02	.74
7	.06	.12	.17	.65	.08	.04	.19	.69	.06	.14	.16	.64	.07	.14	.02	.77
8	.03	.12	.18	.67	.08	.01	.19	.71	.03	.14	.17	.66	.04	.14	.03	.79
9	.01	.13	.18	.68	.08	.00	.19	.72	.01	.14	.17	.68	.02	.14	.03	.81
10	.00	.13	.18	.69	.08	.00	.19	.73	.00	.14	.17	.68	.01	.15	.03	.82
11	.00	.13	.18	.69	.08	.00	.19	.73	.01	.14	.17	.68	.00	.15	.03	.83
12	.00	.13	.18	.68	.08	.00	.19	.72	.02	.14	.17	.67	.00	.15	.03	.83
13	.00	.12	.18	.67	.08	.00	.19	.71	.05	.14	.16	.65	.01	.15	.03	.82
14	.00	.12	.17	.65	.08	.00	.19	.70	.09	.13	.16	.62	.02	.14	.03	.80
15	.10	.12	.16	.62	.08	.00	.19	.68	.14	.12	.15	.59	.05	.13	.03	.78
$p\Delta$	.05	ns	ns	.05	ns	.05	ns	.05	.05	ns	ns	.05	.05	ns	ns	.05

Note: h^2_c = proportion of the observed variance on a PTSD symptom attributable to genetic factors in common with assaultive trauma; e^2_c = proportion of the observed variance on PTSS attributable to nonshared environmental factors in common with assaultive trauma; h^2_e = proportion of the variability observed on PTSS attributable to genetic factors unique to PTSS; e^2_u = proportion of the variability observed on PTSS attributable to nonshared environmental factors unique to PTSS; $p\Delta$ = tested level of statistical significance of total change in estimate of h^2_c, e^2_c, h^2_e, or e^2_u, respectively over all levels of assaultive traumas reported; ns = not statistically significant ($p > .05$).

2. Model 5, which dropped r_E, yielded a significant ($p < .05$) increase in log-likelihood χ^2.

Assaultive Trauma

The range of assaultive trauma reported by participants ranged between 1 and 15 (mean number 5.84 ± 3.87). The results of the model-fitting for assaultive trauma are presented in Table 2. For reexperiencing, numbing, and hypervigilance, the frequency of assaultive trauma moderated the genetic effects on each type of symptom (βr_G) and provided the most satisfactory explanation to the data (Model 5 is illustrated in Figure 3). In contrast, assaultive trauma moderated the nonshared environmental influences it shares with PTSS.

Table 3 presents the estimates of genetic and nonshared environmental influences for each symptom that is in common with assaultive trauma (h^2_{common} and e^2_{common}) and unique to each symptom (h^2_u & e^2_u) for each level of experienced trauma. For reexperiencing, numbing, and hypervigilance, h^2_c dramatically declined as a function of the number of reported assaultive experiences. To illustrate, for reexperiencing symptoms, the heritability ranged from .33 to near zero as more traumas were experienced, with nonsignificant fluctuations observed for values of e^2_{common}, h^2_u, and, e^2_u. For avoidance, significant decreases were observed in e^2_{common} (.22 to .00) whereas nonsignificant fluctuations were observed in the remaining parameters.

Discussion

The present results suggest that the observed relationship, of the covariance between the experience of traumatic events and subsequent symptoms, is the result of the interplay of genetic and environmental influences. The specific mechanism varies with type of traumatic event. In the case of nonassaultive trauma, variance in PTSS is affected by environmental factors that also influence exposure to nonassaultive traumas experienced as indexed r_E. For example, differences in the total number of motor vehicle accidents experienced by one twin compared to his/her co-twin sibling explains a significant proportion of the variability in reexperiencing, avoidance, numbing, and hypervigilance. As the number of nonassaultive traumas experiences increases, the severity of these PTSS increases in a linear fashion.

With assaultive trauma, the results indicated that both genetic and nonshared environmental influences jointly affect PTSS as indexed by r_G and r_E. However, unlike nonassaultive trauma, the number of traumatic events (e.g., sexual abuses, fights) appears to moderate the severity of PTSS. For example, in the cases of reexperiencing, numbing, and hypervigilance, when the number of traumas experienced exceeds three or four events in total, a significant reduction of genetic covariance is observed. The question that these findings raise is what is the role of common genetic factors? One interpretation is that they confer some resilience to traumatic events; resilient people are

unlikely to report experience of traumatic events because they have suffered less PTSS. However, resilience may not make a difference for those who experienced too many traumatic events.

Just as plausible is that these genetic factors are a liability to PTSS by facilitating the selection of environments (as discussed in Stein et al., 2002; Jang et al., 2003) that increase risk for experiencing traumatic events; the more one is likely to experience traumatic events, the more one is likely to have PTSS by in fact experiencing the larger number of traumatic events. However, the severity of PTSS becomes unrelated to the number of traumatic events experienced for those who experienced too many traumatic events; perhaps what matters for those people is the recency of the traumatic events or other environmental factors, such as social support. The present data are unable to address this question because it is limited to examining aggregate trauma frequency over the lifespan as an index of the trauma dose–response relationship. What is required are specific data on the timing of each trauma and the details of PTSS that followed each traumatic experience.

It is important that the present results are taken as an exploratory study of the relationship between traumatic events and PTSS that sets the stage for future research. An important factor that remains to be tested is trauma severity; in the present study, we were only able to discern presence or absence of exposure to particular trauma types, without any index of severity of each exposure. Despite this limitation, the present results provide insight into the etiology of PTSS. The results indicate that genetic factors may be relatively unimportant for nonassaultive trauma, whereas the number of traumatic events is very important. With regards to assaultive trauma, genetic factors appear to define a threshold beyond which environmental stressors supervene. Conventional wisdom is that genetic factors are seen as important factors that would put someone at risk for adverse psychiatric outcomes following severe stress (e.g., combat stress), but these data also raise the possibility that genes may be most influential in relatively less extreme situations. Clearly, these data require replication in other samples. This latter point is quite important given that our conclusions are based on a relatively modest sample size. However, recognizing this limitation, the conservative approach used here was to maximize validity and precision of measurements as described earlier, instead of relying on the sheer force of numbers to aggregate out error. The approach must have been successful given that interaction effects were nonetheless detected. If replicated with a larger sample, there is little doubt that similar effects will be detected with greater strength and clarity. Ultimately, beyond issues of sample size alone, other designs and instruments that measure trauma exposure and subsequent symptomology are required to answer questions about specifically

which genes confer susceptibility, and how they transmute experiential trauma into psychological symptoms. For example, instruments or designs that can better index the severity and impact of individual traumatic events, as well as the time in which they were experienced, as opposed to aggregating the number of events over the lifespan, are a crucial next step to addressing these questions.

Endnotes

1 The questionnaire also surveyed combat exposure but due to low endorsement rates in this Canadian sample this event was not included in any analyses.

2 Analyses described in this paper were repeated excluding these twin pairs and are available upon request. The results were highly similar to the findings from the total sample of 167 MZ and 156 DZ reported.

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