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Threat of death and autobiographical memory: a study of passengers from Flight AT236

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Abstract

We investigated autobiographical memory in a group of passengers onboard a trans-Atlantic flight that nearly ditched at sea. The consistency of traumatic exposure across passengers, some of whom developed post-traumatic stress disorder (PTSD), provided a unique opportunity to assess verified memory for life-threatening trauma. Using the Autobiographical Interview, which separates episodic from non-episodic details, passengers and healthy controls (HCs) recalled three events: the airline disaster (or a highly negative event for HCs), the September 11, 2001 attacks, and a non-emotional event. All passengers showed robust mnemonic enhancement for episodic details of the airline disaster. Although neither richness nor accuracy of traumatic recollection was related to PTSD, production of non-episodic details for traumatic and non-traumatic events was elevated in PTSD passengers. These findings indicate a robust mnemonic enhancement for trauma that is not specific to PTSD. Rather, PTSD is associated with altered cognitive control operations that affect autobiographical memory in general.

Introduction

More than half of individuals experience a significant trauma during their lifetime, with consequences for mental health, particularly post-traumatic stress disorder (PTSD; Kessler, Sonnega, Bromet, Hughes, & Nelson, 1995). Memory alterations associated with trauma exposure (e.g., intrusiveness, flashbacks) are a key feature in the diagnosis of PTSD (American Psychiatric Association, 2013), yet the nature of traumatic recollection remains a topic of controversy. Here, laboratory studies demonstrate that negative emotional

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experiences enhance the expression of memory (McGaugh, 2003). This memory enhancement effect is accompanied by modulatory influences of the amygdala on brain structures involved in the encoding, storage, and retrieval of episodic memories (e.g., Dolan, Lane, Chua, & Fletcher, 2000; Dolcos, LaBar, & Cabeza, 2004; Phelps, 2006). Conversely, however, studies of real-life traumatic experiences that involve significant loss of life, serious injury, or the threat thereof show inconsistent and, at times, conflicting patterns of mnemonic responses in both patients with PTSD and in resilient, healthy individuals exposed to trauma. Although many studies have shown that trauma exposure enhances memory for the traumatic incident (Berntsen, Willert, & Rubin, 2003; Megías, Ryan, Vaquero, & Frese, 2007; Peace & Porter, 2004; Porter & Peace, 2007; Schelach & Nachson, 2001; Sharot, Martorella, Delgado, & Phelps, 2007), an attenuation or fragmentation of memory for traumatic experiences has also been observed (Briere & Conte, 1993; Koss, Figueredo, Bell, Tharan, & Tromp, 1996; Schonfeld, Ehlers, Bollinghaus, & Rief, 2007; Tromp, Koss, Figueredo, & Tharan, 1995; van der Kolk & Fisler, 1995; also see Brewin, 2001; McNally, 2006; Verfaellie & Vasterling, 2009 for review). Additional studies have focused on memory for non-traumatic events in patients with PTSD, where, on average, a pattern of overgeneral memory recollection is observed (i.e., primarily factual or repeated information as opposed to details specific in time and place definitive of episodic re-experiencing; Brown et al., 2013; Kleim & Ehlers, 2008; Moradi et al., 2008; Williams et al., 2007; also see Verfaellie & Vasterling, 2009).

In nearly all studies of PTSD, the traumatic events surveyed are heterogeneous, with varying time of occurrence, duration of exposure, proximity, repetition, and arousal characteristics — variables known to impact event processing in memory (Neisser et al., 1996; Sharot et al., 2007; van Giezen, Arensman, Spinhoven, & Wolters, 2005). Far fewer studies have assessed memory in individuals exposed to a single shared traumatic event (Fischer, Wik, & Fredrikson, 1996). In the present study, we investigated mnemonic response to trauma in a sample of survivors of a single life-threatening incident for which we had detailed information about the sequence of events. On August 24, 2001, Air Transat (AT) Flight 236 ran out of fuel mid-way over the Atlantic Ocean, with passengers and crew instructed to prepare for ditching of the aircraft at sea, including countdown to impact, loss of on-board lighting, cabin de-pressurization, and generalized panic among passengers and crew. After 25 minutes, the pilot located an island military base and glided the aircraft to a rough landing with no loss of life incurred and few injuries. This life-threatening event was associated with diagnosed PTSD in half of the passengers in our sample, allowing us to assess PTSD effects against a resilient comparison group exposed to the same traumatic event.

The diagnostic criteria for PTSD include episodic memory for the traumatic experience (spatial, sensory and mental experiences specific to incident) that is dissociable from context-independent factual knowledge surrounding it (e.g., information about the airline). These facets of memory are seldom dissociated in the literature surrounding emotion, memory, and trauma, where induced recall may involve a combination of event-specific details and factual knowledge surrounding the incident.

In the present study, we probed memory for the AT disaster with the Autobiographical Interview (AI; Levine, Svoboda, Hay, Winocur, & Moscovitch, 2002). The AI has been used widely in the neuropsychological literature to more precisely characterize episodic and non-episodic elements of autobiographical memory (AM) in epilepsy (e.g., Addis, Moscovitch, & McAndrews, 2007; Milton et al., 2010), medial temporal lobe amnesia (Rosenbaum et al., 2008; Steinvorth, Levine, & Corkin, 2005), focal brain lesions (Davidson et al., 2008; Levine, 2004), mild cognitive impairment (Murphy, Troyer, Levine, & Moscovitch, 2008), and dementia (Irish et al., 2011; McKinnon et al., 2008). This research has shown that episodic and semantic components of AM differentially relate to patterns of brain function and dysfunction, particularly in the medial temporal lobes but also in neocortical regions supporting different mnemonic processes. Specifically, patients with medial temporal lobe or temporo-prefrontal dysfunction show reduced access to episodic details, while patients with prefrontal and distributed damage show elevated non-episodic details due to impaired executive processes involved in control of mnemonic retrieval. These same methods have delineated specific patterns of episodic and non-episodic changes in AM associated with child development (Willoughby, Desrocher, Levine, & Rovet, 2012), aging (Levine et al., 2002), emotion (St Jacques & Levine, 2007), mood disorders (King et al., 2012; Söderlund et al., 2014), and non-traumatic AM in PTSD (Brown et al., 2014).

We compared episodic and non-episodic AM for the AT disaster among survivors to that of a highly negative event from the same time period among matched controls. We also assessed memory for a highly arousing negative event (terrorist attacks of September 11, 2001; hereafter referred to as 9/11), allowing for comparison of traumatic memory to memory for a negative but non-traumatic experience. Finally, we assessed AM for a neutral event from the same time period, allowing for delineation of the effects of trauma exposure and PTSD diagnosis on AM for non-traumatic events.

To our knowledge, there has been no psychological study of a group collectively threatened with imminent death in which the moment-to-moment sequence of events was known (see methods below). Owing to the documented sequence of events in the AT disaster available from official documents and from one of us (M.C.M.), who was present on the AT236 flight, we had unprecedented access to this information, giving us a benchmark against which to assess the recollections of the trauma-exposed participants. This allowed us to address the accuracy of their recall and to in turn assess the relation of recall accuracy to PTSD diagnosis and trauma-related symptoms.

Survivors of the AT incident underwent comprehensive assessment on a battery of clinical measures, which included a structured clinical interview for diagnosis of PTSD and additional co-morbidities as well as standardized scales measuring depression and anxiety symptoms. Given the importance of personality in modulating phenomenological characteristics of AM re-experiencing (Rubin & Siegler, 2004), participants also completed a personality assessment inventory.

Based on the extremity of the AT disaster and the emotion enhancement effect (McGaugh, 2003), we predicted that AT passengers would have enhanced episodic recall for the AT disaster relative to HCs' recall of a negative event. More importantly, considering research on memory alterations for traumatic and non-traumatic events in PTSD, we predicted that the presence of PTSD would modulate recall of all three events by altering the balance of episodic and non-episodic details, although the literature does not permit a strong prediction as to the nature of this imbalance. Decreased episodic details would be consistent with basic mnemonic impairment (as is the case with medial temporal lobe dysfunction). Increased non-episodic details would suggest incorporation of extraneous information in AM retrieval due to altered mnemonic control processes (Vasterling, Brailey, Constans, & Sutker, 1998; Gilbertson et al., 2006). Finally, we predicted that this mnemonic effect would relate to trait neuroticism and measures of psychopathology.

Methods

Participants

Fifteen passengers from AT Flight 236 (mean age = 38.7, *SD* = 13.1; mean years of education = 14.5, *SD* = 3.3; 7 females) were recruited through newspaper advertisements, contacts known to M.C.M., and other media presentations concerning the study. Fifteen healthy controls (HCs; mean age = 36.4, *SD* = 15.3; mean years of education = 16.6, *SD* = 3.0; 9 females) were recruited primarily from the volunteer registry at the Rotman Research Institute at Baycrest Health Sciences. Demographic and clinical characteristics of the study sample are summarized in Table 1, which depicts AT passengers stratified into PTSD (N = 7) and non-PTSD (resilient) subgroups (N = 6; diagnosis for two passengers was unknown, see below). Exclusion criteria for all participants included age below 18 or above 65, history of neurological disease or brain trauma (as defined by loss of consciousness greater than 10 min), serious and unstable medical illnesses and, in HCs, history of significant psychiatric illness requiring treatment. The study was approved by the Research Ethics Board of Baycrest Health Sciences and the University of Toronto. Information on ethnicity and socioeconomic status of participants was not obtained.

Materials

Clinical and Personality Questionnaires—Passengers completed the Beck Anxiety Inventory (BAI; Beck, Ward, Mendelson, Mock, & Erbaugh, 1961), Beck Depression Inventory (BDI; Beck, et al., 1961), Impact of Events Scale-Revised (IES-R;Weiss & Marmar, 1997), and the Spielberger State-Trait Anxiety Scale (SB-State; SB-Trait; Spielberger, 1983). The IES-R provided a current continuous measure of PTSD symptoms. With the exception of the IES-R, the HC group also received these measures. Personality functioning was assessed with the short form of the NEO-Five Factor Inventory (NEO-FFI; Costa & McRae, 1992). Four passengers did not complete these measures and were therefore excluded from analyses involving these measures.

The Structured Clinical Interview for the Diagnostic and Statistical Manual of Mental Disorders, 4th edition (SCID; First, Spitzer, Williams, & Gibbon, 1995) was administered to 12 of the passengers. Six of the passengers met DSM-IV-TR criteria for PTSD. Five had a co-morbid diagnosis of major depressive disorder; MDD, and four of these had additional co-morbidities, including delusional disorder, alcohol abuse, panic disorder, phobia, generalized anxiety, anxiety disorder not otherwise specified, and hypochondriasis. One of the three passengers who did not complete the SCID was classified as having PTSD based on an IES-R score of 68 (very severe); this score was comparable to the other participants with SCID-verified PTSD. For the remaining 2 passengers, there was insufficient information to reliably classify them. These two passengers were thus excluded from any analyses involving PTSD status comparisons.

The Autobiographical Interview (AI)

Event selection and instructions—The AI was administered as described by Levine et al. (2002), with some modifications. AT passengers were asked to provide a detailed account of three personal events: (1) an emotionally neutral event from 2001 (hereafter referred to as NEUTRAL), (2) their experience during 9/11, and (3) the AT disaster (hereafter referred to as AT). HCs recalled a highly negative event from 2001 (e.g., death of a pet, breakup, stolen wallet, wife's panic attack) in lieu of the AT disaster (hereafter referred to as NEGATIVE). For passengers, there was no significant group difference in the amount of time that had elapsed between the date of the AT event and the date of testing ($p = .34$; PTSD passengers, mean: 43.04 months; resilient passengers, mean = 53.26 months). In order to establish a complete narrative and to determine if the pattern of internal and external details differed across the duration of the narrative, each event was divided into three segments based on natural transitions. As analyses of these segments did not alter the conclusions, AI scores are presented for complete events (collapsing across the three segments). The NEGATIVE event for HCs and the NEUTRAL event for all participants were generated prior to testing with the AI.

During free recall, participants spoke extemporaneously about the event until they reached a clear ending point. The interviewer then administered general probes (nonspecific statements or repetitions of the instructions if necessary). During the specific probe phase that followed, a structured interview was administered that was designed to elicit additional contextual details. In order to prevent the contamination of subsequent memories, the specific probe was not administered until all three memories had been recounted under free recall and general probe. As a separate analysis of the free recall and general probe conditions did not add additional information over and above that obtained from specific probe, the free recall and general probe data are not presented. Participants' descriptions of the events were audio-recorded for subsequent transcription and analysis.

Text segmentation and categorization—Following transcription, each memory was segmented into informational bits or details. Each detail was then classified according to the procedure outlined in Levine et al. (2002). Briefly, details were defined as "internal" or episodic and assigned to one of five categories (event, place, time, perceptual, and emotion/thought) if they were directly related to the main event described, were specific to time and place, and conveyed a sense of episodic re-experiencing. Otherwise, details were considered "external" (non-episodic), consisting of semantic facts (factual information or extended events that did not require recollection of a specific time and place), autobiographical events tangential or unrelated to the main event, repetitions or "other" details, which included metacognitive statements ("I can't remember") or editorializing ("It was the best of times") or external event details (information from an event outside of the one that was probed).

Appendix A depicts an example of an excerpt from a single passenger's narrative, with the AI scoring method demonstrated.

Details were tallied for each category and summed to form internal and external composites, which were the main variables of interest, although targeted analyses of specific detail categories were also conducted. To avoid bias in scoring, participants' memories were placed in a common pool (along with memories from participants in other studies on depression and brain disease effects) and scored at random by experienced scorers who had achieved high inter-rater reliability (see Levine et al., 2002) and who were blind to group membership (i.e., all scorers achieved an intraclass correlation of .90 for internal and external details on a training set of 20 memories).

Participants were also asked to generate ratings for each memory using seven 10-point scales: (1) how important the event was at the time when it occurred, (2) how important the event was at the time of testing, (3) how easily the event came to mind, (4) the degree to which thoughts or feelings were re-experienced, (5) the degree to which visual or auditory imagery were re-experienced, (6) the degree to which emotional change took place over the course of the event and (7) how frequently the event has been thought about or talked about over the last year. One passenger (without PTSD) did not complete the ratings.

Accuracy

We selected 83 details from AT passengers' protocols that were verifiable (i.e., related to something that occurred in the timeline of the disaster as opposed to something unique to an individual, such as an emotional or cognitive state or a perceptual, spatial, or event detail that could not have been experienced by all passengers) and that were reported by at least two passengers. The number of these details recalled per passenger was tallied and served as a measure of accuracy of recall. In some cases, passengers were not exposed to certain details (e.g., due to fainting). Thus the accuracy score was expressed as a proportion of the total available details for each passenger (see Appendix B).

Data analyses

AM—AM-related measures (i.e., number of details on the AI, ratings) were compared across groups using a mixed-design analysis of variance (ANOVA) that treated condition (AT/NEGATIVE, 9/11, NEUTRAL) and composite detail type (internal, external) as within-subjects variables, and group as a between-subjects variable (passengers with PTSD, resilient passengers, HCs). These were followed by ANOVAs assessing the comparisons of memory conditions between groups with Bonferonni corrections applied for group comparisons. A Winsorization transformation was used to reduce the skewness of the AI data. Analyses of accuracy scores were compared across passenger groups (with and without PTSD) using an independent samples *t*-test. For all analyses involving repeated measures, a correction for violation of sphericity was made when necessary. For *t*-tests, corrections for equality of variance violation were performed when necessary. Alpha was set at 0.05 for all analyses. Estimates of effect sizes for all ANOVAs were reported with partial eta squared (η_ρ^2).

Clinical/Personality Measures—To assess the relation between clinical variables and AM performance, we employed Partial Least Squares (PLS), a flexible multivariate technique that assesses the relation between two sets of variables by modeling their covariance structure (Krishnan, Williams, McIntosh, & Abdi, 2011; McIntosh, Bookstein, Haxby, & Grady, 1996; McIntosh & Lobaugh, 2004). In the present study, PLS was used to identify how AM performance is related to clinical/personality measures in passengers only (PTSD and resilient). The strength of this analysis is that it is unbiased, as it makes no prior assumptions about the relation between these measures. Moreover, because PLS involves one single analytical step, it is not necessary to correct for multiple comparisons.

First, correlations were computed between the AI composite scores (i.e., internal and external details for each condition) and scores on the clinical measures (i.e., NEO-FFI, BDI, BAI, IES-R, and SB-trait). Singular value decomposition (SVD) was used to derive mutually orthogonal singular vectors or latent variables (LVs) representing similarities and differences in patterns of covariance between the two sets of measures, which are analogous to eigenvectors in principal components analysis.

The statistical significance of each LV was assessed by 1500 permutation tests, in which behavioral observations were shuffled within participants to calculate the probability of each LV having occurred by chance. An LV was considered statistically significant if the probability of the single value for the LV for the given permutation was less than 0.05.

Each variable has a "salience," which is a particular weight on each LV (conceptually similar to a factor loading); this value can be positive or negative depending on the nature of its relationship to the pattern described by that LV. The stability of each AI variable's contribution to the LV was assessed using a bootstrap estimation of the salience standard errors with 500 resamplings, which involves re-sampling of participants with a replacement for each measure for each subject and rerunning the PLS following each re-sampling (Sampson, Streissguth, Barr, & Bookstein, 1989). The salience of a measure was considered reliable when the salience-to-standard error ratio (hereafter referred to as a bootstrap ratio; BSR), which approximately corresponds to a z-score, was above 3.3 ($P < 0.001$).

Results

Autobiographical Interview

There was a three-way interaction between group, detail type, and condition ($F_{4, 50} = 21.10$, $p < .0001$, $\eta\rho^2 = .63$) and a main effect of group ($F_{2, 25} = 6.19$, $p = .007$, $\eta\rho^2 = .33$, condition ($F_{1.33, 33.15} = 54.64$, $p < .0001$, $\eta\rho^2 = .69$), and detail type ($F_{1, 25} = 133.44$, $p < .0001$, $\eta\rho^2 = .84$; see Figure 1). There was also a significant interaction between condition and group ($F_{2.65, 33.15} = 17.04$, $p < .0001$, $\eta\rho^2 = .58$).

Decomposing these interactions, for the AT/NEGATIVE condition, there was a significant main effect of group ($F_{2, 25} = 15.48$, $p < .0001$, $\eta\rho^2 = .55$) and a significant interaction between group and condition ($F_{2, 25} = 13.82$, $p < .0001$, $\eta\rho^2 = .53$). As seen in Figure 1, this interaction was driven by elevated internal (i.e., episodic) details in AT passengers. Considering internal details alone, there was a significant main effect of group ($F_{2, 27}$ =

17.17, $p < .0001$, $\eta\rho^2 = .56$), with both PTSD passengers and resilient passengers recalling more internal details than HCs ($p < .0001$, $p = .005$, respectively); there was no difference between PTSD passengers and resilient passengers ($p = .47$). The main effect of external (i.e., non-episodic) details was also significant ($F_{2, 27} = 8.87$, $p = .001$, $\eta\rho^2 = .42$), where passengers with PTSD generated more details than both resilient passengers ($p = .04$) and HCs ($p = .001$); the difference between resilient passengers and HCs was not significant ($p = 1.00$).

For 9/11, there was a marginally significant main effect of group ($F_{2, 25} = 2.93$, $p = .07$, $\eta\rho^2 = .19$) and a significant interaction between group and detail type ($F_{2, 25} = 5.51$, $p = .01$, $\eta\rho^2 = .31$). There were no significant group differences for internal details ($F_{2, 25} = 1.96$, $p = .16$), yet groups significantly differed for external details ($F_{2, 25} = 9.02$, $p = .001$). Passengers with PTSD produced significantly more external details relative to resilient passengers ($p = .006$) and HCs ($p = .002$), while resilient passengers and HCs did not significantly differ from each other ($p = 1.00$).

Finally, for NEUTRAL, there was no significant main effect of group ($F_{2, 25} = 1.79$, $p = .19$, $\eta\rho^2 = .13$) and no significant interaction between group and detail type ($F_{2, 25} = .86$, $p = .44$, $\eta\rho^2 = .06$). Given previous work demonstrating greater generation of external details in PTSD (Brown et al., 2014), as well as the external detail elevation observed for the AT and 9/11 events, we nonetheless probed the detail categories as above, with no significant group difference for internal details ($F_{2, 25} = 1.03$, $p = .37$, $\eta\rho^2 =.08$) but a significant effect for external details ($F_{2, 25} = 3.50$, $p = .046$, $\eta\rho^2 =.22$). Passengers with PTSD produced significantly more external details relative to resilient passengers only ($p = .04$) with no significant differences between HCs and passengers with PTSD ($p = .30$) or HCs and resilient passengers ($p = .49$).

To further probe the profile of external detail production across groups, we conducted an ancillary mixed-design ANOVA with group as a between-subjects factor and external detail category (semantic, repetitions, metacognitive statements, external events) collapsed across all three events as a within-subjects factor. There was a significant main effect of group ($F_{2, 25} = 10.82$, $p = .0001$, $\eta\rho^2 = .46$) and a significant interaction between group and detail category ($F_{4.07,50.81} = 3.71$, $p = .01$, $\eta\rho^2 = .23$). Groups significantly differed for semantic ($F_{2, 25} = 5.42$, $p = .01$, $\eta\rho^2 = .26$), repetitions ($F_{2, 25} = 9.27$, $p = .001$, $\eta\rho^2 = .43$), and metacognitive details ($F_{2, 25} = 5.95$, $p = .008$, $\eta\rho^2 = .32$), while differences for external event details did not survive Bonferroni correction ($p = .045$). *Post-hoc* analyses showed elevated semantic details, repetitions, and metacognitive details in patients with PTSD relative to resilient passengers ($p = .02$, $p = .01$, $p = .08$, respectively) and HCs ($p = .03$, $p = .001$, $p = .007$, respectively), while the latter two groups did not significantly differ (all ps > .10). These elevations could not be attributed to the AT event; the results held when the analysis was restricted to 9/11 and NEUTRAL.

Accuracy Scores—There were no significant differences in accuracy scores (represented as a proportion of total available details) between passengers with PTSD (mean = .34; *SD* = .13) and resilient passengers (mean = .36; *SD* = .10): $t_{11}= .34$, $p = .74$).

Ratings—There was a significant interaction of rating type and group ($F_{6.69, 76.88}$ = 2.41, p = .03 $\eta\rho^2$ = .17) and a significant interaction between rating and condition ($F_{5.23, 120.36}$ = 2.33, p = .04, $\eta\rho^2$ = .09; see Supplementary Table 1). Although follow-up analyses did not survive multiple comparison corrections, passengers with PTSD tended to assign higher ratings for "how frequently the event has been thought about or talked about over the last year" relative to HCs (p = .024) but not relative to resilient passengers (p = .89). Resilient passengers also did not differ from HCs (p = .57).

Relation to clinical variables—The PLS analysis allowed us to examine how AM performance related to clinical/personality scores. This analysis revealed one significant LV (p = 0.05), which accounted for 91.2% of the cross-block covariance between these measures. The pattern associated with this LV indicated that external, but not internal details, were positively correlated with psychopathology across all three conditions. As shown in Figure 2A, increased external details were related to higher scores on the NEO-FFI neuroticism subscale, BDI, IES-R, and SB inventories (95% confidence intervals plotted; those that do not cross zero reliability contribute to the observed pattern). By contrast, higher scores of extraversion on the NEO-FFI were associated with *decreased* amount of external recall. Figure 2B depicts BSRs for the internal and external composite scores for each memory condition; only external detail types were considered statistically reliable, as indicated by BSRs above 3.3 (p<0.001).

Discussion

This is the first study of detailed AM assessment in a group of individuals exposed to the same verified event involving Criterion A exposure to an imminent threat of death. There were three main findings. First, as expected, there was an overall elevation of detail generation for the traumatic event in the passengers, an effect that was enhanced for episodic (internal) details, (i.e., details that are temporally- and spatially-specific to the index event). Second, trauma-exposed passengers with a diagnosis of PTSD produced more non-episodic (external) details (i.e., details that are not specific to the index event) than traumatized passengers without PTSD for all three events probed, but there was no effect of PTSD on either richness (i.e., internal details) or accuracy (i.e., verified details) of non-traumatic AM. Finally, within the AT groups, generation of external details across all events was associated with psychopathology and personality (i.e., trait neuroticism).

Although laboratory research has shown that emotion enhances encoding and consolidation due to the effects of arousal on mnemonic systems, including feed-forward projections of the amygdala to memory structures and perceptual cortices (McGaugh, 2003), the fate of real-life traumatic memories in humans is controversial, with conflicting patterns of mnemonic responses in trauma survivors. Events included in such studies tend to vary widely, with differences in retention period, repetition, the degree of arousal, and the proximity of survivors to the traumatic incident — all factors that modulate recollection (Neisser et al., 1996; Sharot et al., 2007; van Giezen et al., 2005). The AT disaster, to the extreme misfortune of the passengers and crew, provided an unprecedented opportunity to assess memory for a life-threatening experience with a degree of control over inter-individual exposure approaching that of a laboratory experiment.

This single-blow traumatic incident produced marked enhancement of episodic recollection, with passengers recalling approximately double the number of internal details for AT relative to other events and relative to a negative (but not life threatening) event in HCs from the same time period, supporting a hypothesis of hyper-reflexive limbic activity modulating mnemonic representation of this life-threatening event (McGaugh, 2003; Patel, Spreng, Shin, & Girard, 2012). Although enhanced recall for a life-threatening event relative to other events may seem unsurprising, our results are contrasted to evidence of impoverished recall for traumatic incidents in both single blow and repeated traumatic events (Briere & Conte, 1993; Byrne, Hyman, & Scott, 2001; Rubin, Feldman, & Beckham, 2004; Tromp et al., 1995; van der Kolk & Fisler, 1995; Yovell, Bannett, & Shalev, 2003), which did not involve text-based analysis of traumatic AM protocols.

It is unknown if this effect would generalize to memories of repeated trauma, where additional variables, such as peri- and post-traumatic dissociation and age at time of exposure mediate traumatic memory. As noted above, results here are contradictory (e.g., Rubin, Feldman, & Beckham, 2004; van der Kolk & Fisler, 1995). In the present study involving single-blow trauma, trauma-related memory enhancement did not differentiate those with or without a diagnosis of PTSD, suggesting that enhanced recall alone is not sufficient to account for the presence or absence of PTSD symptoms. This observation held when analysis was restricted to details that could be verified as part of the actual AT disaster timeline.

Although an enhancement of perceptual details in association with PTSD might be predicted on the basis of enhanced trauma-related processing in re-entrant amygdalo-cortical pathways, we saw no evidence for such an effect. The profile of internal detail categories was remarkably similar across events and subject groups (see Figure S1 in the Supplemental Material available online), mirroring the typical profile observed in healthy adults that is dominated by event details, followed by perceptual and thought details (time and place details are limited by design as participants are recalling temporally and spatially-specific events; e.g., Levine et al., 2002; Irish et al., 2011). This was confirmed by an ancillary analysis of the proportion of details recalled from each internal detail category across events – there were no significant effects involving group or condition (Figure S1). This stability of the profile across internal detail categories reflects the instructions and scoring of the AI. Using laboratory-based stimuli in an overlapping sample of AT passengers, there is evidence of enhanced perceptual processing of normatively neutral words related to the AT disaster (Lee, Todd, McKinnon, Levine, & Anderson, 2013).

Studies on overgenerality for non-traumatic events in PTSD have typically used cue word methods (e.g., the Autobiographical Memory Test [AMT]; Williams & Broadbent, 1986) that entail significant executive demands to generate a memory from a non-specific retrieval cue (Dalgleish et al., 2007). Moreover, without separating episodic from semantic AM, it is unclear whether overgenerality is attributable to a reduced episodic recall or elevated non-episodic recall (Söderlund et al., 2014). Only one study has addressed this issue using the AI:Brown et al. (2014) found that combat veterans with PTSD had both reduced episodic and elevated non-episodic details in response to cue words, relative to those without PTSD. In the present study, the generative demands inherent to the cue-word method were circumvented by the provision of event titles as retrieval cues. Had we provided less specific retrieval cues, it is possible that we would have found reduced internal details for the non-traumatic events.

Passengers with PTSD produced more external (non-episodic) details across traumatic and non-traumatic events, and production of these details was associated with elevated psychopathology across the sample of AT passengers. Although elevated external details in the present study may appear consistent with the overgeneral memory effect observed in other studies of PTSD (e.g., Brown et al., 2014; Brown et al., 2013; McNally, Lasko, Macklin, & Pitman, 1995), there was no difference for internal details, even for the non-traumatic events, which would be predicted by a mechanism of episodic impoverishment in overgeneral memories. When patients with severe MDD (exclusive of PTSD) were tested on the AI for lifespan AM using pre-selected event cues, the opposite effect was observed: internal details were reduced, with no significant effect on external details (Söderlund et al., 2014), similar to findings seen in association with impaired memory access due to medial temporal lobe dysfunction (Addis et al., 2007; Davidson et al., 2008; Irish et al., 2011; Rosenbaum et al., 2008; St-Laurent, Moscovitch, Levine, & McAndrews, 2009).

The external detail composite in the AI comprises semantic details, repetitions, details about other unrelated events, and "other" details that do not fit these categories (these are frequently metacognitive; "I don't remember this very well."). We found that repetitions and semantic details were significantly elevated in individuals with PTSD. Our findings are evocative of the notion of traumatic memory fragmentation or reduced coherence (e.g., Harvey & Bryant, 1999; Jelinek, Randjbar, Seifert, Kellner, & Moritz, 2009; Jones, Harvey, & Brewin 2007) except that these were elevated for all memories, not just the traumatic memory (see e.g., Jelinek et al., 2009).

The presence of elevated external details on the AI has been observed in aging (Levine et al., 2002), frontal lobe damage (Levine, 2004), and frontotemporal dementia (McKinnon et al., 2008) due to impaired executive control affecting inhibition and monitoring in mnemonic search and retrieval. Our findings, which extend those from neuropsychological tests of learning and memory (Gilbertson et al., 2006; Vasterling et al., 1998) to AM, suggest that similar impairments in cognitive control operations affect memory retrieval in PTSD, and that this is not restricted to traumatic memories. As this was a study of direct retrieval, we did not specifically address the mnemonic alterations of flashbacks or intrusiveness that characterize PTSD. Nonetheless, such symptoms may be related to the same impairments in cognitive control operations hypothesized to contribute to elevated external detail production. Although our study focused on quantitative measures, use of various discourse analyses that focus on both quantitative and qualitative aspects of narrative recall may be informative (e.g., coherence). For example, Foa, Molnar, & Cashman (1995) and others (e.g., Jelenick et al., 2009, Jones, Harvey, Brewin, 2007) operationalize fragmentations in terms of repetitions, a measure included in the present study, which was elevated in PTSD. Yet, while our measure of repetitions includes any clause repeated in the narrative, these other studies restrict repetitions by a range of five lines of a transcribed narrative. While nuanced, these differences may reflect slightly different cognitive deficits in global versus local aspects of coherence, respectively.

Likewise, disorganization has been operationalized as disjointed or unfinished utterances (Foa et al., 1995), which is not included in our protocol, yet our other categories may map onto this construct, including metacognitive speech (measured as ‘other’ details in the AI scoring method) or semantic statements, which was also elevated in PTSD and may reflect a similar mechanism of reduced organizational thought (i.e., via the provision of clauses that break up the flow of the narrative). Future research is needed to determine the relationship between these discourse measures and how they map onto PTSD.

As is typically the case, AT passengers with PTSD carried a co-morbid diagnosis of MDD, among other diagnoses. The fact that these individuals did not show impoverished internal detail generation for non-traumatic events suggests that their mnemonic profile was more strongly influenced by their primary diagnosis of PTSD (also see Brewin, 2011). As we did not test events outside of the time period proximal to the AT disaster, our data do not speak to the quality of AM for other lifetime period events, although Brown et al. (2014) found reduced internal relative to external details in PTSD regardless of time period.

The multivariate pattern of elevated external details and psychopathology also included elevated levels of neuroticism and reduced levels of extraversion, corresponding to the association of these traits with PTSD (Breslau & Schultz, 2013; Engelhard & van den Hout, 2007; Jaksic, Brajkovic, Ivezic, Topic, & Jakovljevic, 2012). As all of our measures were taken at the same time, we cannot comment on the directionality of the relation between personality traits and PTSD, although other research has shown that personality characteristics enhance susceptibility to PTSD, particularly for neuroticism (Breslau & Schultz, 2013). Given that mnemonic factors such as vividness or accuracy of recall did not differentiate AT passengers with and without PTSD, and that event-related factors can be ruled out, we speculate that the psychopathological effects of this life-threatening experience are attributable to factors antecedent to the trauma exposure, including premorbid neurocognitive functioning involving impaired mnemonic control. Put another way, when event characteristics are controlled, it is not what happened, but to whom it happened, that determines subsequent psychopathology (Breslau & Schultz, 2013; Gilbertson et al., 2006; Gilbertson et al., 2002; Rawal & Rice, 2012; Wignall et al., 2004; also see McNally, 2006).

Much research on the effects of emotion and memory are derived from controlled laboratory studies of animals and humans (McGaugh, 2003). Generalization of these findings to naturalistic, highly traumatic events in humans is hampered by error variance attributable to inter-individual heterogeneity in event exposure. More homogenous “flashbulb” events experienced by the wider public have provided opportunities to test theories concerning emotion and memory (Brown & Kulik, 1977; Hirst et al., 2009; Sharot et al., 2007), but such events can never approximate a direct threat of death in terms of emotional arousal. Testing such a group of individuals threatened with death by the same event all but removed external variance that is normally a necessary by-product in the study of real-life trauma. Although the present design does not account for internal factors per se (e.g., individual differences in emotional reactivity at the time of trauma), by controlling for external factors, the design allowed for internal factors to be more evident. Moreover, our awareness of the chronology of the AT disaster enhanced our ability to assess the effects of memory accuracy. The participants in this study reflect only a small percentage of the 306 passengers aboard AT

Flight 236; we did not have access to the passenger manifest, and individuals with more significant psychopathology may have avoided participation for fear of re-traumatization. As such, the current study was limited to a small number of participants. Moreover, as passengers' memory was assessed several years after the traumatic incident (approximately 3.5 years later), it remains unknown how trauma might have impacted memory in the more acute stages of trauma exposure among this sample. Finally, research on mechanisms of PTSD must study individuals with more complex and repeated trauma exposure. However, interpretation of such data depends on the understanding of single-blow traumatic events.

Our findings, combined with those of others' (e.g., Vasterling et al., 1998, Gilbertson et al., 2006), suggest that altered mnemonic processing is evident in non-traumatic AM, either prior to traumatic exposure or after traumatic exposure but before the evolution of full-blown PTSD. Should future research confirm that this alteration in memory performance precedes the onset of PTSD, the pattern of elevated external details could be used to prospectively identify individuals at risk for PTSD for preventative treatment. For example, interventions designed to reduce mnemonic symptomology associated with PTSD (i.e., intrusive memories), probe traumatic memory using direct retrieval approaches similar to those employed in the present study. These involve voluntary recounting of the traumatic event in oral or written form, along with provision of strategies for reframing or integrating the experience into the patients' AM base (e.g., Exposure Therapy; Foa, Rothbaum, Riggs, & Murdock, 1991; Cognitive Processing Therapy; Resick & Schnicke, 1992). Such integration is thought to reduce the prevalence of involuntary memories by contextualizing environmental cues associated with the trauma. The presence of altered AM processing for non-traumatic events in individuals with PTSD suggests that such events (or negative or mildly traumatic events) could be targets in a preventative therapeutic approach.

We have identified elevated non-episodic detail production as associated with PTSD in our sample. Behavioral measures, however, reflect but one level in mnemonic processing. Functional neuroimaging can reveal the neural correlates of different retrieval processes, including those associated with episodic and non-episodic autobiographical memory (Svoboda, McKinnon, & Levine et al., 2006). Accordingly, additional functional neuroimaging studies of trauma-exposed individuals with and without PTSD are necessary to illuminate the brain mechanisms underlying reduced organization or coherence of traumatic experiences associated with PTSD (see e.g., Foa & Rothbaum, 1998; van der Kolk & Fisler, 1995; Ehlers & Clark, 2000). Indeed, previous studies have shown reduced activation of the brain's executive control network associated with impaired top-down control over retrieval and concomitant hyperactivity of amygdalar and posterior higher-order visual processing areas in PTSD (Lanius, Bluhm, Lanius, & Pain, 2006; also see Patel et al., 2012; Hayes, Hayes, & Mikedis., 2012). Such alterations could underlie the heightened affective and sensory nature (reliving) of traumatic memories in PTSD. Although there are a large number of functional imaging studies investigating the neural correlates of PTSD, relatively fewer studies have focused on PTSD in the context of traumatic scripts (e.g., Lanius et al., 2001), involving key comparisons to non-traumatic experiences (i.e., neutral autobiographical memories) as well as to that of healthy trauma-exposed controls (see Hayes, Hayes, & Mikedis, 2012; Hughes & Shin, 2011).

Recent studies suggest that genotype may mediate individual differences in how emotional events are encoded (de Quervain et al., 2007; Todd et al., 2013 Todd et al., 2014), rendering certain individuals more susceptible to pathological responses to trauma (de Quervain et al., 2012; also see Todd, Palombo, Levine, & Anderson, 2011 for review). These genetic markers may be expressed in neural endophenotypes (e.g., structural or functional brain imaging responses (Rasch et al., 2009; Todd et al., 2013) that are suggestive of mechanisms specific to individual differences in mnemonic processing of traumatic experiences, including increased amygdalar activity in response to negative events (Rasch et al., 2009). Future work, combining genetic, neural endophenotypic, and behavioral markers of altered processing in traumatic AM may enable the identification of neurobehavioral profiles (e.g., enhanced limbic processing, altered cognitive control operations, fragmented or incoherent event recall) that enhance the risk of negative outcomes following exposure to trauma, providing a window for prevention either through reduction of traumatic exposure risk or through a potential preventative intervention as described above.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Appendix A. Excerpt from a passenger's recollection of the Air Transat incident (Autobiographical Interview scoring technique depicted)

[internal: event detail] [external: other]
Passenger: It all started when they ask to put the masks on. No — I think before I think it was the life jackets.
[external: repetition] [internal: perceptual] [internal: event detail]
The life jackets. Right away I start to be short breath — I couldn't even get it out so my husband
[internal: event detail] [internal: perceptual] [external: repetition] [internal: perceptual]
start to get it out. People — everybody was talking in low voices, soft voices, lot of whispering. So
[internal: event detail] [internal: event detail]
my husband help me to have life jacket on and they were shouting it out for the mothers to help the
[internal: event detail] [internal: event detail]
kids — everybody had to have a life jacket on. They were experiencing some difficulties but I don't
[external: other] [internal: perceptual] [external: repetition]
remember they explaining else. A few minutes after they ask us to put the mask, and all the masks
[internal: event detail] [internal: emotion] [internal: event detail]
fell off and right away we start to feel, everybody was so scared. People putting that on, partners
[internal: event detail] [external: repetition] [external: other]
were helping partner's masks, and help into that so I was starting to feel short breath. I start to feel.
[internal: perceptual] [internal: perceptual]
After it was smoking smell inside — it was all dark…[narrative continues].

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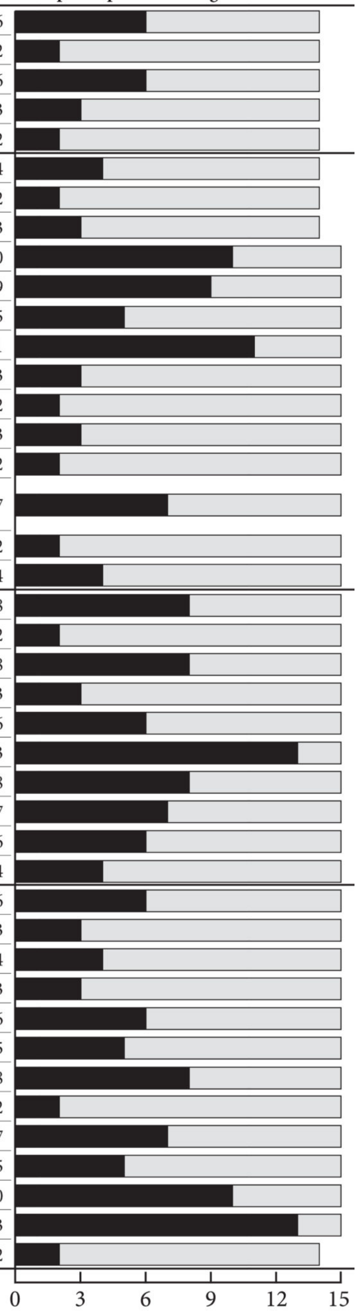
Appendix B. Sequence of events that occurred during the Air Transat incident, including the number of individuals recalling each event

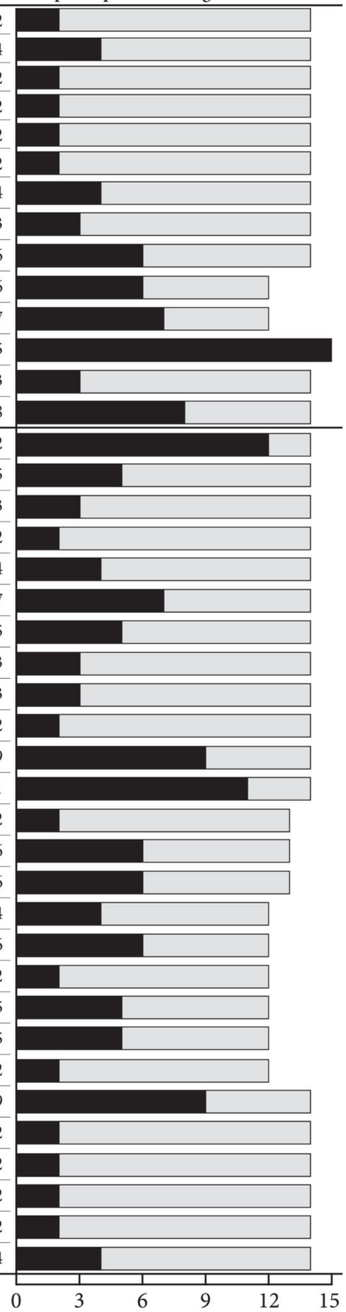
Phase	Event	# of participants recalling the event*
Pre-emergency	1. Watched movie [Chocolat]	6
Pre-emergency	2. Other TV programs followed [news; Just For Laughs]	2
Pre-emergency	3. Breakfast	6
Pre-emergency	4. Seat belt sign came on	3
Pre-emergency	5. Pilot: "ETA to Lisbon, temperature"	2
Emergency - with power	6. FA: "Emergency situation; return to seats"	4
Emergency - with power	7. TV turned off	2
Emergency - with power	8. Interior lights flickered	3
Emergency - with power	9. Pilot: "Making emergency landing; take off shoes; put on life jackets"	10
Emergency - with power	10. FA showing how to put them on (very loudly)	9
Emergency - with power	11. FA had shaky voice; cried	5
Emergency - with power	12. Put on the lifejackets	11
Emergency - with power	13. Some passengers inflated their life jackets	3
Emergency - with power	14. FA repeated instructions	2
Emergency - with power	15. Passengers became increasingly panicked	3
Emergency - with power	16. Passengers praying/low voices	2
Emergency - with power	17. Pilot: "Going in for emergency landing; when I say 'Brace! Brace!' lean forward and put hands behind your head"	7
Emergency - with power	18. Pilot making several "[x] minutes to impact" statements	2
Emergency - with power	19. Silence	4
Emergency - no power	20. Interior lights turned off	8
Emergency - no power	21. Only the emergency corridor strip lights were on	2
Emergency - no power	22. Engines stopped	8
Emergency - no power	23. Wind blowing	3
Emergency - no power	24. Everything went quiet	6
Emergency - no power	25. Oxygen masks came down	13
Emergency - no power	26. Passengers started to panic	8
Emergency - no power	27. Put on oxygen masks	7
Emergency - no power	28. Mask didn't work	6
Emergency - no power	29. Mask smelled like something burning	4
Descent	30. Airplane started making violent turns; as if going in circles	6
Descent	31. Airplane was on an angle [left to right]	3
Descent	32. Sensation of coming down too fast	4
Descent	33. Everyone started screaming	3
Descent	34. Assumed the brace position	6
Descent	35. Could hear praying	5
Descent	36. Pilot: "About to go into the water"	8
Descent	37. More panic; then quiet	2
Descent	38. Pilot: "We have a runway! We have a runway!"	7
Descent	39. Water turned to land	5
Descent	40. Pilot: "Brace! Brace! Brace!"	10
Descent	41. Violent landing	13
Descent	42. Grinding of the tires and landing gear	2



FA - flight attendant; ETA - estimated time of arrival.

*Maximum number of individuals recalling a memory fluctuated across events due to unique individual timelines (i.e., fainting, being taken to hospital).

		Event	# of participants recalling the event*
Disembarkation	43.	Passengers jumped up and cheered	2
	44.	Passengers began clapping	4
	45.	FA yelling at passengers to not take their luggage	2
	46.	FA told everyone to remain seated while the slide was being prepared	2
	47.	FA could not open the door	2
	48.	Passengers panicked and rushed towards another door	2
	49.	Opened doors	4
	50.	Inflated slide	3
	51.	FA said to evacuate	6
	52.	Smell of burnt rubber	6
	53.	Followed line up of passengers	7
	54.	Jumped down the slide	15
	55.	Firefighters helping passengers out	3
	56.	Being told to run	8
	57.	Passengers running from the plane	12
	58.	Running through field of high grass	5
	59.	Wet field	3
	60.	Foggy & cold	2
	61.	Could see landing gear on fire	4
	62.	American soldiers beside cargo plane	7
	63.	Soldiers told to not cross line	5
	64.	Soldiers thought the plane was going to explode	3
	65.	Soldiers told us to move as far away as possible	3
	66.	Received shoes	2
	67.	Buses came	9
	68.	Took us to airport	11
	69.	Passengers crying and shouting	2
	70.	Had sandwiches/food/water	6
	71.	Long queue to use the phone	6
	72.	Lined up outside to retrieve carry-ons	4
	73.	Bus took passengers back to American side of the island	6
	74.	Long line-up	2
	75.	Placed us into rooms	5
	76.	Took a bus to a ferry	5
	77.	Air Transat representative came	2
	78.	Boarded a ferry	9
	79.	Not best conditions on the water	2
	80.	Eventually ran out of food on ferry	2
	81.	Long wait at the airport	2
	82.	Lots of media/journalists at the airport	2
	83.	Boarded the plane	4



FA - flight attendant.

*Maximum number of individuals recalling a memory fluctuated across events due to unique individual timelines (i.e., fainting, being taken to hospital).

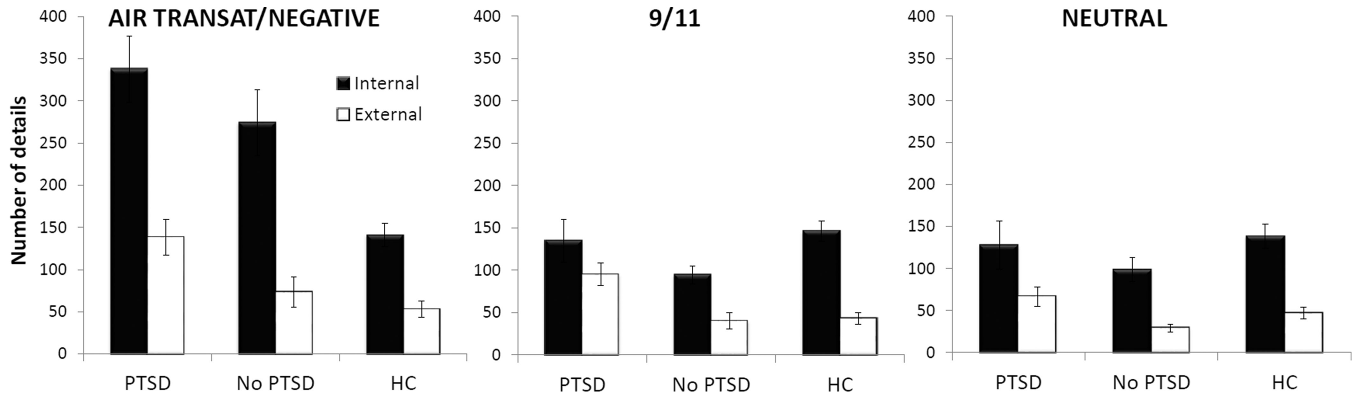
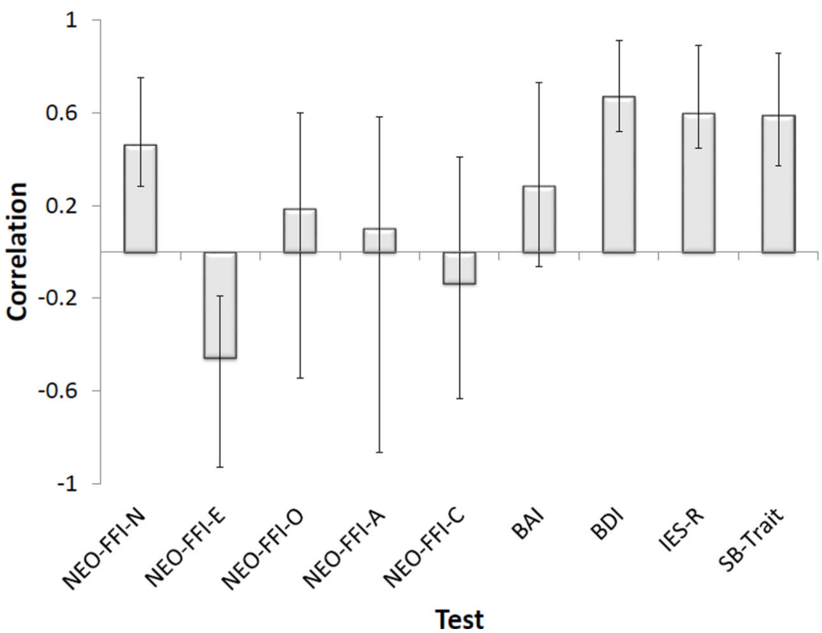


Figure 1.

Mean number of details recalled across all events for passengers (with and without post-traumatic stress disorder; PTSD) and healthy controls (HCs) for the specific probe section of the Autobiographical Interview. In lieu of the Air Transat disaster, HCs recalled a highly negative event. Error bars indicate standard error of the mean.

A



B

Condition	Detail Type	BSR
AIR TRANSAT	Internal	1.66
	External	**4.54**
9/11	Internal	1.17
	External	**4.26**
NEUTRAL	Internal	0.93
	External	**5.41**

Figure 2.

A. Significant latent variable from the partial least squares analysis indicating a relationship between external details on the Autobiographical Interview and scores on clinical/ personality measures, expressed as correlations. Error bars represent 95% confidence intervals. This figure shows that external, but not internal details were positively related to scores on the NEO-Five Factor Inventory (NEO-FFI) neuroticism (N) subscale, Beck Depression Inventory (BDI), Impact of Events Scale-Revised (IES-R), and the trait subscale of the Speilberger State-Trait Anxiety Scale (SB-Trait) and negatively related to the NEO-FFI extroversion (E) subscale. **B.** Bootstrap ratios (BSR; analogous to a z-score) for composite scores; a BSR threshold of 3.3 corresponds to a p value of p <0.001, significant BSR indicated in bold font. BAI, Beck Anxiety Inventory; O, openness; C, conscientiousness; A, agreeableness.

Table 1

Clinical and demographic characteristics of study sample.

	AT Passengers		HCs
	PTSD	*No PTSD*	
Demographic			
Age	39.9 (10.9)	38.2 (18.1)	36.4 (15.3)
Education	13.7 (2.5)	16.3 (3.8)	16.6 (3.0)
NEO-FFI			
Neuroticism	44.3 (7.1)*	28.0 (5.4)	29.0 (11.9)
Extroversion	33.4 (6.8)+	48.8 (1.7)	38.6 (9.1)
Openness	33.5 (5.5)	36.8 (3.4)	36.0 (6.1)
Agreeableness	41.3 (3.2)	47.5 (1.9)	44.2 (6.4)
Conscientiousness	38.4 (5.1)	44.5 (9.3)	46.1 (6.9)
BAI	29.8 (8.7)***,+++	5.8 (5.1)	7.1 (6.4)
BDI	27.3 (7.9)***,+++	3.8 (1.5)	7.5 (8.0)
IES-R	71.5 (5.5)+++	28.5 (21.5)	N/A
SB-State	51.5 (15.9)**,++	29.3 (5.9)	32.2 (8.5)
SB-Trait	56.7 (8.6)*, ++	35.8 (4.3)	38.3 (12.6)

Note: Values are mean (standard deviations). Group differences were assessed with ANOVA and *post-hoc* tests.

* $p < .05$,

** $p < .01$,

*** $p < .001$; comparison between passengers with PTSD and HCs.

+ $p < 0.5$,

++ $p <0.01$,

+++ $p <0.001$; comparison between passengers with PTSD and resilient passengers.

Abbreviations: AT, Air Transat; PTSD, post-traumatic stress disorder; HCs, Healthy controls; NEO-FFI, NEO-Five Factor Inventory; BAI, Beck Anxiety Inventory; BDI, Beck Depression Inventory; IES-R, Impact of Events Scale-Revised; SB, Speilberger State-Trait Anxiety Scale.