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ORIGINAL ARTICLE

Dimensional structure and course of post-traumatic stress symptomatology in World Trade Center responders

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Background. Post-traumatic stress disorder (PTSD) in response to the World Trade Center (WTC) disaster of 11 September 2001 (9/11) is one of the most prevalent and persistent health conditions among both professional (e.g. police) and non-traditional (e.g. construction worker) WTC responders, even several years after 9/11. However, little is known about the dimensionality and natural course of WTC-related PTSD symptomatology in these populations.

Method. Data were analysed from 10 835 WTC responders, including 4035 police and 6800 non-traditional responders who were evaluated as part of the WTC Health Program, a clinic network in the New York area established by the National Institute for Occupational Safety and Health. Confirmatory factor analyses (CFAs) were used to evaluate structural models of PTSD symptom dimensionality; and autoregressive cross-lagged (ARCL) panel regressions were used to examine the prospective interrelationships among PTSD symptom clusters at 3, 6 and 8 years after 9/11.

Results. CFAs suggested that five stable symptom clusters best represent PTSD symptom dimensionality in both police and non-traditional WTC responders. This five-factor model was also invariant over time with respect to factor loadings and structural parameters, thereby demonstrating its longitudinal stability. ARCL panel regression analyses revealed that hyperarousal symptoms had a prominent role in predicting other symptom clusters of PTSD, with anxious arousal symptoms primarily driving re-experiencing symptoms, and dysphoric arousal symptoms primarily driving emotional numbing symptoms over time.

Conclusions. Results of this study suggest that disaster-related PTSD symptomatology in WTC responders is best represented by five symptom dimensions. Anxious arousal symptoms, which are characterized by hypervigilance and exaggerated startle, may primarily drive re-experiencing symptoms, while dysphoric arousal symptoms, which are characterized by sleep disturbance, irritability/anger and concentration difficulties, may primarily drive emotional numbing symptoms over time. These results underscore the importance of assessment, monitoring and early intervention of hyperarousal symptoms in WTC and other disaster responders.

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Key words: Confirmatory factor analysis, disaster, post-traumatic stress disorder.

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Introduction

Tens of thousands of people were involved in rescue, recovery and clean-up work following the 11 September 2001 attacks (9/11) on the World Trade Center (WTC) (Centers for Disease Control and Prevention, 2004). Individuals who responded to this disaster included traditional first responders such as police officers, firefighters and emergency medical personnel, as well as non-traditional responders such as construction workers, telecommunications workers, sanitation workers and other volunteers, most of whom had no prior training in disaster response (Herbert *et al.* 2006). In 2002, the Centers for Disease Control and Prevention (CDC) established the WTC Medical Monitoring and Treatment Program (MMTP; now the WTC Health Program, WTC-HP), a regional clinical consortium that provides monitoring and treatment of WTC-related health conditions in WTC responders. The Department of Community and Preventive Medicine of the Icahn School of Medicine at Mount Sinai was designated as the coordinating entity of five consortium institutions. Data obtained in the first monitoring visit 10–61 months after 11 September 2001 from this cohort revealed that 14.4% of responders screened positive for WTC-related posttraumatic stress disorder (PTSD), with higher rates among non-traditional disaster responders such as construction workers (23.0%) than more traditional disaster responders such as police officers (5.9%; Stellman *et al.* 2008).

PTSD is one of the most prevalent and persistent health conditions in WTC responders, even several years after 9/11 (Perrin *et al.* 2007; Stellman *et al.* 2008; Berninger *et al.* 2010; Bowler *et al.* 2010; Cukor *et al.* 2011; Soo *et al.* 2011; Wisnivesky *et al.* 2011; Lucchini *et al.* 2012; Luft *et al.* 2012, Pietrzak *et al.* 2012*a*, 2013*a*; Webber *et al.* 2013). To date, however, no study has evaluated the structure/clustering or natural course of WTC-related PTSD symptoms in this population. This information is essential to elucidating the dimensionality of WTC-related PTSD symptoms, understanding the developmental progression of heterogeneous PTSD symptom clusters, and informing prevention and treatment strategies for WTC and other disaster responders.

PTSD is a heterogeneous disorder characterized by clusters of relatively disparate re-experiencing, avoidance, numbing and hyperarousal symptoms. A large body of confirmatory factor analytic (CFA) studies conducted over the past 15 years (Yufik & Simms, 2010; Elhai & Palmieri, 2011) has demonstrated the superiority of two four-factor models of PTSD symptoms relative to the three-factor model described in the Diagnostic and Statistical Manual of Mental Disorders, 4th edition (DSM-IV; APA, 2000). These models include the dysphoria model, which is comprised of separate clusters of re-experiencing, avoidance, dysphoria and hyperarousal symptoms (Simms *et al.* 2002), and the emotional numbing model, which is comprised of separate clusters of re-experiencing, avoidance, emotional numbing and hyperarousal symptoms (King *et al.* 1998). The only difference between these models is that three symptoms – D1 (i.e. difficulty falling or staying asleep), D2 (i.e. irritability or anger outbursts) and D3 (i.e. difficulty concentrating) – are assigned to the dysphoria cluster in the dysphoria model, while they are assigned to the hyperarousal cluster in the emotional numbing model (see Table 1).

Recently, Elhai *et al.* (2011) suggested that one way to reconcile differences between the two four-factor models of PTSD symptom structure is to separate symptoms that comprise the hyperarousal symptom cluster into 'dysphoric arousal' (i.e. sleep disturbance, irritability, and concentration difficulties) and 'anxious arousal' (i.e. hypervigilance, exaggerated startle) clusters. This separation is based on a theoretical model proposed by Watson (2005), which separates symptoms characterized by restlessness and agitation, such as irritability and sleep difficulties, from more physiological/fear-based panic-like symptoms, such as hypervigilance and exaggerated startle response. A growing number of CFA studies, which have been conducted in nationally representative samples of adults in the USA and Australia (Armour *et al.* 2013*a*), a national clinic-referred youth sample (Elhai *et al.* 2013), general adult samples of medical patients (Armour *et al.* 2012), survivors of domestic violence (Elhai *et al.* 2011), natural disaster (Wang *et al.* 2011*a*, *b*, 2013*a*, *b*; Armour *et al.* 2013*b*, Pietrzak *et al.* 2012*b*, *c*, 2013*b*) and a violent riot (Wang *et al.* 2011*b*), military veterans (Armour *et al.* 2012; Pietrzak *et al.* 2012*b*) and drug-dependent individuals (Reddy *et al.* 2013), have found that this five-factor model provides a significantly better representation of PTSD symptom structure than the three-factor DSM-IV, and four-factor dysphoria and emotional numbing models.

To date, only two studies of utility workers (Palmieri *et al.* 2007) and a mixed sample of law enforcement and non-traditional responders (Ruggero *et al.* 2013) who responded to the WTC attack examined the dimensional structure of WTC-related PTSD symptoms. Results of both studies revealed that the dysphoria model provided a better representation of PTSD symptoms compared with alternative models such as the DSM-IV model. The five-factor dysphoric arousal model was not evaluated in either of these studies.

Characterization of the dimensionality of PTSD symptoms has important implications for understanding

Table 1. *Item mappings of DSM-IV, dysphoria, numbing and dysphoric arousal structural models of PTSD symptom dimensionality*

	Item mappings			
DSM-IV PTSD symptom	Model 1: DSM-IV	Model 2: dysphoria	Model 3: numbing	Model 4: dysphoric arousal
B1. Intrusive thoughts of trauma	R	R	R	R
B2. Recurrent dreams of trauma	R	R	R	R
B3. Flashbacks	R	R	R	R
B4. Emotional reactivity to trauma cues	R	R	R	R
B5. Physiological reactivity to trauma cues	R	R	R	R
C1. Avoiding thoughts of trauma	A	A	A	A
C2. Avoiding reminders of trauma	A	A	A	A
C3. Inability to recall aspects of trauma	A	D	N	N
C4. Loss of interest	A	D	N	N
C5. Detachment	A	D	N	N
C6. Restricted affect	A	D	N	N
C7. Sense of foreshortened future	A	D	N	N
D1. Sleep disturbance	H	D	H	DA
D2. Irritability	H	D	H	DA
D3. Difficulty concentrating	H	D	H	DA
D4. Hypervigilance	H	H	H	AA
D5. Exaggerated startle response	H	H	H	AA

PTSD, Post-traumatic stress disorder; R, re-experiencing; A, avoidance; D, dysphoria; N, numbing; H, hyperarousal; DA, dysphoric arousal; AA, anxious arousal.

the structure and clinical presentation of PTSD symptoms in disaster responders, and may help inform etiological models of PTSD. For example, emerging work from our research group suggests that the five-factor model of PTSD symptomatology is differentially associated with neurobiological markers of PTSD (Pietrzak *et al.* 2013*b*, *c*, *d*), suggesting that distinct neurobiological abnormalities may underlie the phenotypic expression of component aspects of this multi-faceted disorder. Understanding of the dimensional structure of PTSD may also inform approaches to the assessment and treatment of this disorder in disaster responders. For example, in some disaster responders, PTSD symptoms may be characterized predominantly by anxious arousal symptoms such as hypervigilance and exaggerated startle, while in others they may be characterized predominantly by emotional numbing symptoms such as detachment and restricted affect. Accordingly, treatments that primarily address particular hyperarousal symptoms (i.e. anxious arousal) may differ from treatments that primarily address emotional numbing symptoms (Leskin *et al.* 1998; Pitman & Delahanty, 2005; Strawn & Geracioti, 2008; Macdonald *et al.* 2011). Knowledge of the dimensional structure of PTSD symptoms in disaster responders may thus lead to the development of more personalized and targeted approaches to assessment, monitoring and treatment of PTSD that address specific clusters of PTSD symptoms that are most disabling and contribute to the chronicity of this disorder.

In addition to a lack of research on the dimensional structure of PTSD symptoms in disaster responders, little is known about the prospective course of PTSD symptom clusters and their complex functional interrelationships in this population. Studies of the natural course of PTSD in other trauma survivor populations have found that symptoms that characterize this disorder are heterogeneous in nature, and characterized by dynamic and functionally meaningful interrelationships among symptom clusters over time (Creamer *et al.* 1992; Schell *et al.* 2004; Marshall *et al.* 2006; Solomon *et al.* 2009). For example, some researchers have posited that avoidance of trauma-related thoughts and reminders may precede re-experiencing symptoms (Horowitz, 2001), that re-experiencing symptoms may precede avoidance symptoms (Creamer *et al.* 1992), and that emotional numbing symptoms may arise from avoidance symptoms (Keane *et al.* 1985) or from both hyperarousal and avoidance symptoms (Foa *et al.* 1995). Empirical studies of young adult survivors of community violence (Schell *et al.* 2004), injury (Marshall *et al.* 2006), and war veterans (Solomon *et al.* 2009) have directly evaluated these hypotheses by employing autoregressive cross-lagged (ARCL) panel regression analyses of longitudinal data on PTSD symptom clusters. These studies found that hyperarousal is the strongest predictor of subsequent re-experiencing, avoidance and numbing symptoms, thereby underscoring the critical role of this symptom cluster in maintaining the chronicity of PTSD.

We had three aims in the current study: (1) to employ a theory-driven approach to evaluating the dimensional structure of WTC-related PTSD symptoms in police and non-traditional responders; (2) to examine the longitudinal factorial invariance of the best-fitting dimensional model of WTC-related PTSD symptoms; and (3) to assess how PTSD symptom clusters from the best-fitting model interrelated over an average 3, 6 and 8 years since 9/11.

Method

Sample

A total of 10 835 WTC responders, including 4035 police and 6800 non-traditional (e.g. construction and utility worker) responders, completed three visits as part of the WTC-HP. These visits were conducted an average of 3.3 (S.D. = 1.9, range = 0.8–8.0), 5.7 (S.D. = 1.7, range = 3.1–9.0) and 7.9 (S.D. = 1.3, range = 5.3–10.1) years after 11 September 2011. The WTC-HP is a CDC/National Institute for Occupational Safety and Health-funded regional clinical consortium that provides medical and mental health monitoring of WTC responders. This umbrella consortium of clinics that comprise the WTC-HP recruited subjects for participation through outreach efforts that included union meetings, mailings, media articles, and some 50 000 phone calls in multiple languages. Eligibility for the monitoring program required either having worked or volunteered as part of the rescue, recovery, restoration or clean-up in Manhattan south of Canal Street, or the barge-loading piers in Manhattan, or the Staten Island landfill, for at least 24 h between 11 and 30 September 2001, or for more than 80 h between 11 September and 31 December 2001. At 18 months after their first visit, participants were eligible to return for a second visit, with subsequent visits scheduled every 18 months thereafter. Institutional review boards of each affiliated site approved and monitored compliance of study procedures and all participants provided written informed consent.

WTC-related PTSD symptoms

The Posttraumatic Stress Disorder Checklist-Specific Version (PCL-S; Weathers *et al.* 1993) is a 17-item self-report instrument based on DSM-IV criteria for PTSD that was used to assess WTC-related PTSD symptoms. An example of a checklist item is: 'In the past month, how much have you been bothered by repeated, disturbing memories, thoughts or images of the World Trade Center disaster?' The PCL-S is administered routinely to all WTC responders at each scheduled visit to the WTC-HP.

Data analysis

Preliminary inspection of PCL-S data distributions in police and non-traditional WTC responders revealed the presence of multivariate non-normality at each assessment time point, as evidenced by Mardia coefficients >1.96. Complete data were available for over 90% of participants at each visit, and 98.6% of all surveys included responses to at least 15 of the 17 PCL-S items. CFAs were conducted using Mplus (Muthén & Muthén, 2002), which employs robust maximum likelihood estimation with the Satorra and Bentler (S-B) χ^2 scaling correction (Satorra & Bentler, 2001). This correction estimates standard errors under conditions of multivariate non-normality and computes other χ^2-dependent fit statistics based on the S-B χ^2 statistic. Full-information methodology has not been developed for analyses using robust χ^2 statistics, so analyses were based on complete cases. In all CFAs, PCL items were specified to load on a single factor, all factors were allowed to correlate, all error covariances were fixed to zero, and all tests were two-tailed. Model fit was evaluated using several fit statistics, including the S-B χ^2, comparative fit index (CFI), Tucker–Lewis index (TLI), root mean square error of approximation (RMSEA), Akaike's Information Criterion (AIC) and the Bayesian Information Criterion (BIC). By convention, higher CFI and TLI values, and lower χ^2 values, RMSEA, AIC and BIC values will be used as indicators of better fit. In CFA studies, fit is determined by empirically defined benchmarks, with CFI and TLI $\geqslant 0.90$ indicative of adequate fit and $\geqslant 0.95$ indicative of excellent fit, and with RMSEA $\leqslant 0.08$ indicative of adequate fit and $\leqslant 0.06$ indicative of excellent fit (Hu & Bentler, 1998, 1999). To compare the relative fit of nested models, χ^2 difference tests for nested models with a correction factor (given the use of the S-B χ^2 statistic) were computed (i.e. five-factor *versus* DSM-IV, dysphoria and numbing models; DSM-IV *versus* numbing models) (Fan & Sivo, 2009). To compare non-nested models (i.e. DSM-IV *versus* dysphoria model; numbing *versus* dysphoria model), we used the BIC (Schwarz, 1978). Following convention, models with a lower BIC value are indicative of better fit, with a difference of 6–10 indicative of strong support and a difference >10 indicative of very strong support in favor of this model (Raftery, 1995).

Four models of PTSD symptom structure were evaluated. Model 1 was the DSM-IV three-factor model of intercorrelated re-experiencing, avoidance and hyperarousal symptoms. Model 2 was the four-factor dysphoria model of intercorrelated re-experiencing, avoidance, dysphoria and hyperarousal factors (Simms *et al.* 2002). Model 3 was the four-factor emotional numbing model of intercorrelated re-experiencing, avoidance, emotional numbing and hyperarousal factors (King *et al.* 1998). Model 4 was the recently proposed five-factor dysphoric arousal model, which separates D1–D3 and D4–D5 symptoms into distinct dysphoric and anxious arousal factors (Elhai *et al.* 2011). Table 1 shows item mappings for each of these models.

We also evaluated the invariance of the best-fitting structural model of PTSD symptoms across the three assessment time points in both police and non-traditional responders. In evaluating longitudinal invariance (unlike evaluating invariance across population subgroups), we freely estimated the covariance between corresponding items' error terms and factors at different times (time 1 with 2, 2 with 3, and 1 with 3). The minimum level of invariance tested was configural invariance, wherein the same factor model was used at all three visits, but no constraints of equality were imposed. The next level of invariance tested was weak metric invariance, wherein corresponding factor loadings were constrained to be equal over time. A further level of invariance tested was strong metric invariance, wherein the constraint of equality intercepts over time was added to the requirements of weak metric invariance. Finally, strict metric invariance imposes yet an additional constraint that corresponding item error variances be equal across time. Because even robust χ^2 statistics can lead to rejection of null hypotheses due to substantively unimportant deviations from model assumptions in large samples, testing of the successive levels of invariance relied on the criterion ΔCFI $\leqslant 0.01$.

To evaluate the natural course and functional interrelationships of PTSD symptom clusters of the best-fitting CFA-derived dimensional representation of WTC-related PTSD symptoms, we conducted ARCL panel regression modeling using full information maximum likelihood estimation in Mplus (http://www.statmodel.com). This approach allows one to examine the longitudinal stability of individual PTSD symptom clusters, as well as how severity of PTSD symptom clusters at one time point predicts severity of other PTSD symptom clusters at later time points (Jöreskog, 1979; Mayer & Carrol, 1987). PTSD symptom clusters were modeled as latent factors in these analyses. As was done for CFAs, model fit was assessed using conventional fit statistics; non-significant paths were removed from the model until the best-fitting model was ascertained (Solomon *et al.* 2009).

Results

Demographic and WTC exposure characteristics

Table 2 shows demographic characteristics of police and non-traditional WTC responder samples. Compared with non-traditional responders, police responders were younger, more likely to be white/non-Hispanic, college or higher educated, married/partnered, and to have income $\geqslant$\$70 000/year. They also reported more total WTC-related exposures and greater severity of WTC-related PTSD symptoms at each visit. Sex and proportions of responders who reported having been treated for an injury or illness while working at the WTC site did not differ.

CFAs

Table 3 shows fit statistics for each of the models evaluated in police and non-traditional responders.

In the police responder sample, corrected scaled χ^2 difference tests revealed that the five-factor model fit the baseline PCL-S data significantly better than the DSM-IV [χ^2(df=7)=740.05, $p<0.0005$], numbing [χ^2(df=4)=237.25, $p<0.0005$] and dysphoria [χ^2(df=4)=319.62, $p<0.0005$] models. There was also greater evidence of 'excellent fit' for this model according to empirically defined benchmarks (Hu & Bentler, 1998, 1999). Comparison of non-nested models revealed very strong support for the dysphoria model fitting better than the DSM-IV (ΔBIC=1013.06) and numbing (ΔBIC=265.31) models. Internal consistency analyses suggested excellent reliability for total scores on the PCL-S (Cronbach's α=0.95), and good reliability for each of the five PTSD symptom clusters that comprise the five-factor model, with Cronbach's α=0.89 for the re-experiencing cluster, 0.80 for the avoidance cluster, 0.87 for the numbing cluster, 0.85 for the dysphoric arousal cluster, and 0.82 for the anxious arousal cluster.

In the non-traditional responder sample, corrected scaled χ^2 difference tests revealed that the five-factor model fit the baseline PCL-S data significantly better than the DSM-IV [χ^2(df=7)=1936.09, $p\leqslant 0.0005$], numbing [χ^2(df=4)=606.97, $p<0.0005$] and dysphoria [χ^2(df=4)=843.32, p=<0.0005] models. There was also greater evidence of 'excellent fit' for this model according to empirically defined benchmarks (Hu & Bentler, 1998, 1999). Comparison of non-nested models revealed very strong support for the dysphoria model fitting better than the DSM-IV (ΔBIC1=903.81) and

Table 2. *Demographic, exposure and clinical characteristics of police and non-traditional WTC responders*

	Police responders (n=4035)	Non-traditional responders (n=6800)	Statistics	p
Demographics				
Mean age at visit 1, years (S.D.)	41.2 (6.6)	45.3 (9.6)	t=24.23	<0.005
Sex, n (%)				
Female	592 (14.67)	913 (13.43)	χ^2=3.27	0.07
Male	3443 (85.33)	5886 (86.57)		
Race/ethnicity, n (%)				
White, non-Hispanic	2732 (67.74)	4145 (60.97)	χ^2=50.03	<0.005
Hispanic	817 (20.26)	1663 (24.46)		
Black, non-Hispanic	396 (9.82)	808 (11.89)		
Other	88 (2.18)	182 (2.68)		
Education, n (%)				
High school or less	615 (16.01)	2599 (42.03)	χ^2=736.07	<0.005
More than high school	3226 (83.99)	3584 (57.97)		
Marital status, n (%)				
Married or partnered	2902 (73.71)	4373 (67.12)	χ^2=54.11	<0.005
Never married	563 (14.30)	1084 (16.64)		
Widowed, separated or divorced	472 (11.99)	1058 (16.24)		
Income ⩽$70000, n (%)	1988 (57.18)	3983 (74.30)	χ^2=282.06	<0.005
WTC-related exposures				
Mean total number of exposures (S.D.)	5.19 (1.95)	3.47 (1.91)	t=45.23	<0.005
Arrived 11–13 September 2001, n (%)	3552 (88.03)	4427 (65.10)	χ^2=685.74	<0.005
Caught in dust cloud, n (%)	1239 (30.71)	941 (13.84)	χ^2=448.32	<0.005
Exposed to human remains, n (%)	2666 (66.07)	2506 (36.85)	χ^2=866.57	<0.005
Know somebody who was injured on 9/11, n (%)	2058 (56.90)	1774 (30.61)	χ^2=637.46	<0.005
Search, rescue and recovery September–October 2001, n (%)	1239 (30.71)	681 (10.01)	χ^2=743.61	<0.005
Slept on-site during September–October 2001, n (%)	724 (20.34)	859 (17.04)	χ^2=15.15	<0.005
Somatic injury/illness while at worksite, n (%)	1074 (27.19)	1850 (28.00)	χ^2=0.80	0.370
Traumatic death of colleague, family member or friend, n (%)	2578 (71.14)	2193 (37.82)	χ^2=990.58	<0.005
Worked adjacent to pit/pile, n (%)	3320 (82.28)	5435 (79.93)	χ^2=9.04	0.003
Worked more than median hours, n (%)	2510 (62.21)	2903 (42.69)	χ^2=385.74	<0.005
Mean WTC-related PTSD symptoms (PCL-S score) (S.D.)				
3 years post-9/11	26.0 (11.2)	35.2 (16.0)	t=31.99	<0.0005
6 years post-9/11	26.5 (12.2)	36.5 (17.0)	t=32.32	<0.0005
8 years post-9/11	26.3 (12.5)	36.5 (17.6)	t=32.38	<0.0005

WTC, World Trade Center; S.D., standard deviation; 9/11, WTC disaster of 11 September 2001; PTSD, post-traumatic stress disorder; PCL-S, Posttraumatic Stress Disorder Checklist – Specific Version.

numbing (ΔBIC4=33.09) models. Internal consistency analyses suggested excellent reliability for total scores on the PCL-S (Cronbach's α=0.96), and good reliability for each of the five PTSD symptom clusters that comprise the five-factor model, with Cronbach's α=0.92 for the re-experiencing cluster, 0.85 for the avoidance cluster, 0.90 for the numbing cluster, 0.87 for the dysphoric arousal cluster, and 0.74 for the anxious arousal cluster.

Invariance testing of the five-factor model of PTSD symptoms

Table 4 shows results of longitudinal factorial invariance testing. Inspection of fit statistics suggested that models with constraints at all four levels of invariance had excellent fit, with CFI values ranging from 0.965 to 0.968 for police, and 0.969 to 0.974 for non-traditional responders. RMSEA values also suggested

Table 3. *Fit statistics for confirmatory factor analyses of post-traumatic stress disorder symptom structure at baseline visit*

Model	S-B χ^2	df	CFI	TLI	AIC	BIC	RMSEA
Police responders							
Model 1 – DSM-IV	1879.337	116	0.91	0.90	129 284.88	129 450.98	0.063
Model 2 – dysphoria	1393.722	113	0.94	0.92	128 262.59	128 437.92	0.054
Model 3 – numbing	1271.685	113	0.94	0.93	127 997.28	128 172.61	0.052
Model 4 – dysphoric arousal	1018.662	109	0.95	0.94	127 475.25	127 662.88	0.047
Non-traditional responders							
Model 1 – DSM-IV	4083.382	116	0.92	0.91	257 942.64	258 133.19	0.075
Model 2 – dysphoria	2858.932	113	0.95	0.94	256 028.27	256 229.38	0.063
Model 3 – numbing	2582.970	113	0.95	0.94	255 595.16	255 796.28	0.060
Model 4 – dysphoric arousal	1947.681	109	0.96	0.96	254 614.28	254 829.52	0.053

S-B, Satorra–Bentler; df, degrees of freedom; CFI, comparative fit index; TLI, Tucker–Lewis index; AIC, Akaike's Information Criterion; BIC, Bayesian Information Criterion; RMSEA, root mean square error of approximation.

Table 4. *Results of longitudinal factorial invariance testing*

Group	Type of invariance	S-B χ^2	df	CFI	TLI	AIC	Corrected BIC	RMSEA	Change χ^2	df	p
Police	Configural	3603.859	1068	0.968	0.961	319 813.375	320 731.313	0.026	N.A.	N.A.	N.A.
	Weak metric	3668.665	1092	0.967	0.962	319 900.281	320 746.938	0.026	66.541	24	0.00 001
	Strong metric	3891.157	1126	0.965	0.960	320 144.094	320 889.750	0.027	313.727	34	0.00 000
	Strict metric	3936.224	1160	0.965	0.961	320 247.156	320 891.813	0.026	65.548	34	0.00 092
Non-traditional	Configural[a]	5537.228	1068	0.974	0.969	572 406.500	573 435.188	0.029	N.A.	N.A.	N.A.
	Weak metric[b]	5627.495	1092	0.973	0.969	572 451.500	573 400.313	0.029	82.383	24	0.00 000
	Strong metric[c]	6219.204	1126	0.970	0.966	573 146.250	573 981.813	0.030	766.751	34	0.00 000
	Strict metric[d]	6453.304	1160	0.969	0.966	573 467.500	574 189.938	0.030	226.066	34	0.00 000

S-B, Satorra–Bentler; df, degrees of freedom; CFI, comparative fit index; TLI, Tucker–Lewis index; AIC, Akaike's Information Criterion; BIC, Bayesian Information Criterion; RMSEA, root mean square error of approximation; N.A., not applicable.

[a] Configural variance is based on the fit of a model incorporating all three visits with the same factor structure, but no constraints on loadings, intercepts or error variances. In all longitudinal models, covariances between item error variances at different times are estimated freely, as are covariances among corresponding factors.

[b] Weak metric variance is configural variance plus a constraint that corresponding loadings be equal across times.

[c] Strong metric variance is weak metric variance plus a constraint that corresponding intercepts be equal across times.

[d] Strict metric variance is strong metric variance plus a constraint that corresponding error variances be equal across times.

excellent fit, ranging from 0.026 to 0.027 for police, and 0.029 to 0.030 for non-traditional responders. Testing each step of invariance, each additional level of constraints led to no appreciable change in model fit, with ΔCFI <0.01 in every instance. Online Supplementary Table S1 shows factor loadings of PTSD symptoms that comprise the five-factor model at each of the visits.

ARCL panel regression analyses

Table 5 and Fig. 1 show results of ARCL panel regression analyses in police and non-traditional responders. The models fit the data well in both police [$\chi^2(25) = 939.77$, $p < 0.001$, CFI = 0.979, TLI = 0.919, SRMR = 0.035] and non-traditional [$\chi^2(25) = 1727.93$, $p < 0.001$, CFI = 0.979, TLI = 0.919, SRMR = 0.040] responders. All five PTSD symptom clusters were stable over time, as evidenced by high coefficients across the three assessment time points. With regard to crossed paths among police responders, anxious and dysphoric arousal symptoms at the initial visit were the strongest predictor of re-experiencing symptoms at visit 2, while re-experiencing symptoms were the strongest prospective predictor of numbing symptoms at visits 2 and 3; dysphoric arousal symptoms strongly predicted numbing symptoms at visits 2 and 3, and numbing symptoms at visit 2 predicted dysphoric arousal

Table 5. *Regression coefficients from autoregressive cross-lagged panel analyses of WTC-related PTSD symptoms at 3, 6 and 8 years post-9/11*

	Police responders			Non-traditional responders		
Path	β	(S.E.)	p	β	(S.E.)	p
Re-exp 1 → Re-exp 2	0.53	(0.02)	<0.001	0.47	(0.02)	<0.001
Avoidance 1 → Re-exp 2	0.05	(0.04)	0.16	0.13	(0.03)	<0.001
Numbing 1 → Re-exp 2	0.04	(0.02)	0.085	0.03	(0.02)	0.057
Dysphoric arousal 1 → Re-exp 2	0.12	(0.03)	<0.001	0.16	(0.02)	<0.001
Anxious arousal 1 → Re-exp 2	0.14	(0.04)	<0.001	0.17	(0.03)	<0.001
Re-exp 2 → Re-exp 3	0.58	(0.02)	<0.001	0.54	(0.02)	<0.001
Avoidance 2 → Re-exp 3	0.15	(0.03)	<0.001	0.15	(0.03)	<0.001
Numbing 2 → Re-exp 3	0.06	(0.02)	0.002	0.09	(0.02)	<0.001
Dysphoric arousal 2 → Re-exp 3	0.06	(0.02)	0.006	0.06	(0.02)	0.004
Anxious arousal 2 → Re-exp 3	0.08	(0.03)	0.014	0.18	(0.03)	<0.001
Re-exp 1 → Avoidance 2	0.08	(0.01)	<0.001	0.08	(0.01)	<0.001
Avoidance 1 → Avoidance 2	0.43	(0.02)	<0.001	0.35	(0.02)	<0.001
Numbing 1 → Avoidance 2	0.01	(0.01)	0.26	0.02	(0.01)	0.017
Dysphoric arousal 1 → Avoidance 2	0.08	(0.01)	<0.001	0.08	(0.01)	<0.001
Anxious arousal 1 → Avoidance 2	0.03	(0.02)	0.11	0.05	(0.01)	0.001
Re-exp 2 → Avoidance 3	0.08	(0.01)	<0.001	0.06	(0.01)	<0.001
Avoidance 2 → Avoidance 3	0.47	(0.02)	<0.001	0.40	(0.02)	<0.001
Numbing 2 → Avoidance 3	0.05	(0.01)	<0.001	0.06	(0.01)	<0.001
Dysphoric arousal 2 → Avoidance 3	0.03	(0.01)	0.007	0.04	(0.02)	0.001
Anxious arousal 2 → Avoidance 3	0.02	(0.02)	0.39	0.04	(0.01)	0.006
Re-exp 1 → Numbing 2	0.12	(0.02)	<0.001	0.08	(0.02)	<0.001
Avoidance 1 → Numbing 2	0.00	(0.04)	0.99	0.12	(0.03)	<0.001
Numbing 1 → Numbing 2	0.46	(0.03)	<0.001	0.43	(0.02)	<0.001
Dysphoric arousal 1 → Numbing 2	0.26	(0.03)	<0.001	0.27	(0.02)	<0.001
Anxious arousal 1 → Numbing 2	0.04	(0.04)	0.31	0.09	(0.03)	0.005
Re-exp 2 → Numbing 3	0.14	(0.02)	<0.001	0.07	(0.02)	<0.001
Avoidance 2 → Numbing 3	0.06	(0.03)	0.063	0.08	(0.03)	0.008
Numbing 2 → Numbing 3	0.53	(0.02)	<0.001	0.56	(0.02)	<0.001
Dysphoric arousal 2 → Numbing 3	0.11	(0.02)	<0.001	0.19	(0.02)	<0.001
Anxious arousal 2 → Numbing 3	0.05	(0.03)	0.097	0.10	(0.03)	0.001
Re-exp 1 → Dysphoric arousal 2	0.07	(0.02)	<0.001	0.05	(0.01)	<0.001
Avoidance 1 → Dysphoric arousal 2	−0.02	(0.03)	0.47	0.07	(0.02)	0.004
Numbing 1 → Dysphoric arousal 2	0.05	(0.02)	0.008	0.03	(0.01)	0.006
Dysphoric arousal 1 → Dysphoric arousal 2	0.60	(0.02)	<0.001	0.55	(0.02)	<0.001
Anxious arousal 1 → Dysphoric arousal 2	0.02	(0.03)	0.45	0.06	(0.02)	0.008
Re-exp 2 → Dysphoric arousal 3	0.09	(0.02)	<0.001	0.05	(0.01)	<0.001
Avoidance 2 → Dysphoric arousal 3	0.04	(0.02)	0.11	0.02	(0.02)	0.32
Numbing 2 → Dysphoric arousal 3	0.11	(0.02)	<0.001	0.10	(0.01)	<0.001
Dysphoric arousal 2 → Dysphoric arousal 3	0.50	(0.02)	<0.001	0.52	(0.02)	<0.001
Anxious arousal 2 → Dysphoric arousal 3	0.03	(0.03)	0.32	0.08	(0.02)	<0.001
Re-exp 1 → Anxious arousal 2	0.09	(0.01)	<0.001	0.06	(0.01)	<0.001
Avoidance 1 → Anxious arousal 2	0.03	(0.02)	0.17	0.03	(0.02)	0.049
Numbing 1 → Anxious arousal 2	0.00	(0.01)	0.97	0.02	(0.01)	0.037
Dysphoric arousal 1 → Anxious arousal 2	0.09	(0.01)	<0.001	0.11	(0.01)	<0.001
Anxious arousal 1 → Anxious arousal 2	0.39	(0.02)	<0.001	0.38	(0.02)	<0.001
Re-exp 2 → Anxious arousal 3	0.09	(0.01)	<0.001	0.07	(0.01)	<0.001
Avoidance 2 → Anxious arousal 3	0.04	(0.02)	0.013	0.02	(0.01)	0.26
Numbing 2 → Anxious arousal 3	0.03	(0.01)	0.004	0.04	(0.01)	<0.001
Dysphoric arousal 2 → Anxious arousal 3	0.02	(0.01)	0.044	0.07	(0.01)	<0.001
Anxious arousal 2 → Anxious arousal 3	0.45	(0.02)	<0.001	0.43	(0.01)	<0.001

WTC, World Trade Center; PTSD, post-traumatic stress disorder; 9/11, WTC disaster of 11 September 2001; β, standardized regression coefficient; S.E., standard error; Re-exp, re-experiencing symptoms; 1, visit 1 (3 years post-9/11); 2, visit 2 (6 years post-9/11); 3, visit 3 (8 years post-9/11).

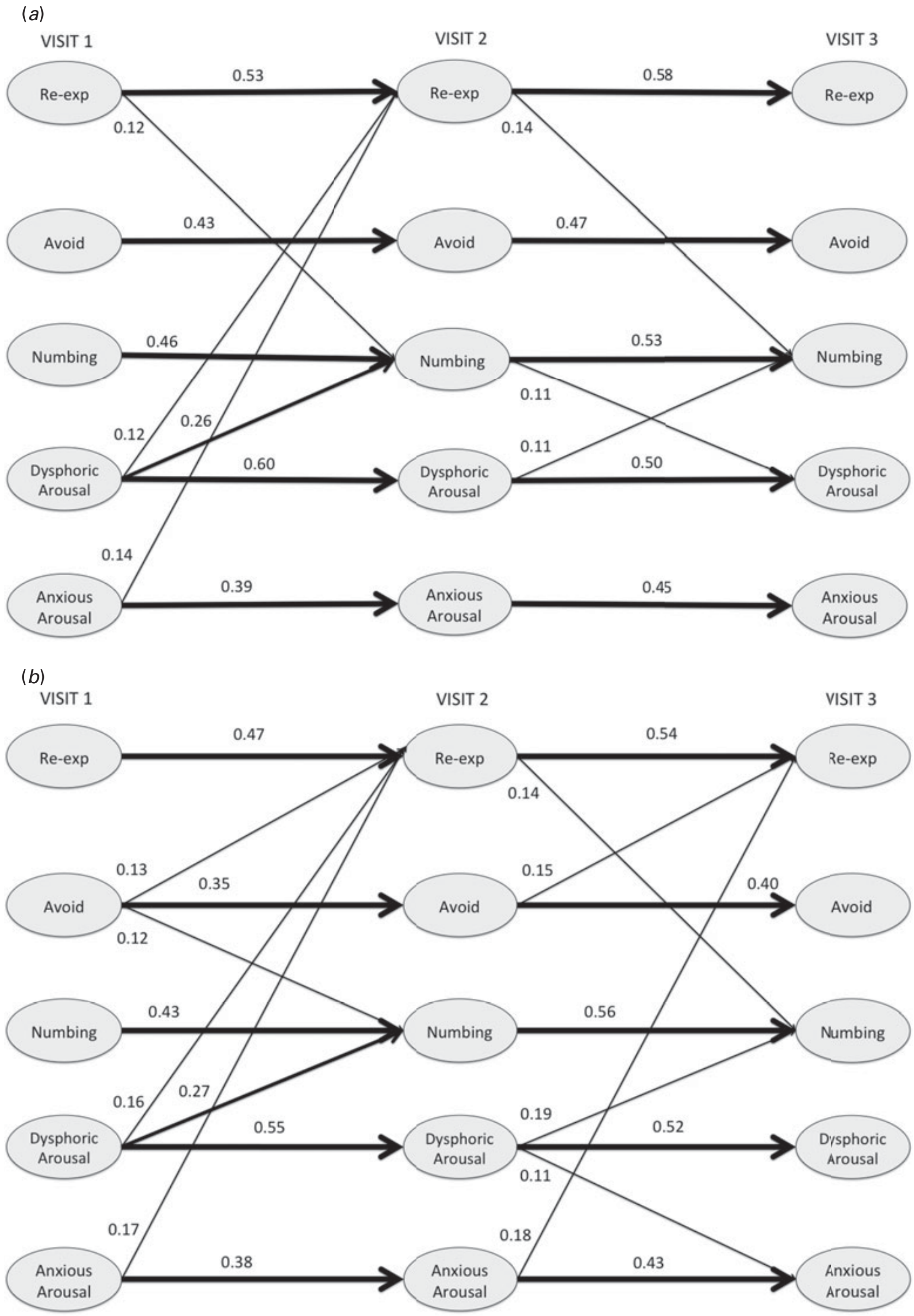

Fig. 1. Results of autoregressive cross-lagged panel analyses of World Trade Center (WTC)-related post-traumatic stress disorder symptoms at 3, 6 and 8 years after the WTC disaster of 11 September 2001 (9/11). (*a*) Police responders. (*b*) Non-traditional responders. Re-exp, Re-experiencing symptoms; Avoid, avoidance symptoms. Values represent standardized regression coefficients (β); only coefficients $\geqslant$75th percentile for crossed paths are shown.

symptoms at visit 3. A similar pattern of crossed paths was observed among non-traditional responders, with anxious arousal additionally predicting re-experiencing symptoms; avoidance symptoms predicting re-experiencing symptoms at visits 2 and 3, and numbing symptoms at visit 2. While other crossed associations among symptom clusters were significant (see Table 5), they were relatively reduced in magnitude.

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Discussion and conclusions

In this study, we evaluated the nature and prospective evolution of WTC-related PTSD symptoms over an average of 8 years in a large cohort of police and non-traditional WTC responders. Results revealed that: (1) the five-factor dysphoric arousal model provided the optimal representation of PTSD symptom dimensionality in both groups of WTC responders; (2) this five-factor dimensional structure was invariant over two follow-up assessments conducted over an 8-year period of time; and (3) in both police and non-traditional WTC responders, anxious arousal and avoidance symptoms most strongly predicted re-experiencing symptoms, and dysphoric arousal most strongly predicted emotional numbing symptoms over time.

Results of this study build on a large and growing body of CFA literature supporting a five-factor dysphoric arousal model of the dimensional structure of PTSD that is comprised of re-experiencing, avoidance, numbing, dysphoric arousal and anxious arousal symptom clusters (Wang *et al.* 2005, 2011*a*, *b*, 2013*a*; Elhai *et al.* 2011; Armour *et al.* 2012, 2013*a*; Pietrzak *et al.* 2012*b*, *c*, 2013*b*). We extend this work to suggest that this five-factor model optimally characterizes the dimensional structure of PTSD in large prospective cohorts of professional (i.e. police), as well as non-traditional disaster responders (e.g. utility workers). Collectively, these CFA studies provide empirical substantiation of Watson's (Watson, 2005) theoretical model in which dysphoric arousal symptoms, which are characterized by restlessness and agitation (e.g. irritability), are seen as conceptually distinct from symptoms that comprise the emotional numbing cluster, which is characterized by a generalized numbing of responsiveness (e.g. anhedonia) (Watson, 2005; Elhai *et al.* 2011). Further, symptoms that comprise the dysphoric arousal cluster are also conceptually distinct from the two other symptoms that comprise the DSM-IV hyperarousal cluster – hypervigilance and exaggerated startle – which reflect anxious arousal symptoms of physiological fear-based hyperreactivity. Importantly, the substantial body of CFA literature supporting the five-factor 'dysphoric arousal' model of PTSD symptom dimensionality in a diverse range of trauma survivors suggests that a theoretically based modification to the four-factor numbing and dysphoria models (Watson, 2005; Elhai *et al.* 2011) may help reconcile mixed findings that characterize the CFA literature on the dimensional structure of PTSD (Yufik & Simms, 2010).

Results of ARCL panel regression analyses suggested that the five symptom clusters were stable in severity over time. Anxious arousal and avoidance symptoms were the strongest crossed-path predictors of subsequent re-experiencing symptoms, and dysphoric arousal symptoms were the strongest crossed-path predictors of subsequent emotional numbing symptoms in both groups of WTC responders. These results are consistent with prior work in young adult survivors of community violence (Schell *et al.* 2004), injury (Marshall *et al.* 2006), and war veterans (Solomon *et al.* 2009), which similarly found that hyperarousal symptoms –encompassing both dysphoric and anxious arousal symptoms – were primary determinants of subsequent re-experiencing and avoidance/numbing symptoms, as well as with results of a study that linked avoidance symptoms to chronicity of re-experiencing symptoms in burn survivors (Lawrence *et al.* 1996). Results of the current study provide greater specificity regarding the component aspects of hyperarousal symptoms that contribute to the temporal progression of re-experiencing and numbing symptoms. Notably, the finding that anxious arousal symptoms most strongly predicted re-experiencing symptoms in both groups of responders suggests that fear-based panic symptoms – hypervigilance and exaggerated startle – may primarily drive the development of intrusive trauma-related thoughts and memories in disaster responders. Further, that dysphoric arousal symptoms most strongly predicted emotional numbing symptoms suggests that hyperarousal symptoms characterized by restlessness and agitation (e.g. irritability/anger, sleep difficulties) may primarily drive the development of emotional numbing symptoms in disaster responders. Notably, this finding may also, at least in part, reflect the progressive development of depressive symptoms in this cohort. This particular pattern of interrelationships among PTSD symptom clusters accords with results of a prior longitudinal study of adult trauma survivors, which found support for synchronous change (i.e. mutually reinforcing effects of PTSD and depressive symptoms) and depressogenic (i.e. depressive symptoms driving PTSD symptoms) models of symptom interplay (Schindel-Allon *et al.* 2010). The prominence of hyperarousal in maintaining the chronicity of PTSD symptomatology is also in line with prior work, which found that physiological markers of hyperarousal (i.e. heart rate) predict the development of PTSD (Bryant *et al.* 2003), that hyperarousal is the first symptom cluster to develop following exposure to trauma (Bremner *et al.* 1996), and that hyperarousal predicts negative intrusive memories in laboratory paradigms (Nixon *et al.* 2007). Given that subsets of this WTC responder cohort manifested heterogeneous trajectories of PTSD symptoms (Pietrzak *et al.* 2013*a*), additional studies are needed to evaluate how PTSD symptom clusters progress and interrelate over time in these subgroups (e.g. chronic, recovering and delayed-onset trajectories).

These findings have several clinical implications. First, although we used a DSM-IV-based instrument in this study, these results suggest that future revisions to the recently published DSM-5 (APA, 2013) criteria for PTSD, which reorganize symptoms into four clusters, should consider that dysphoric arousal and anxious arousal symptoms may constitute distinct symptom clusters that may be differentially linked to the development of PTSD. Second, given that clinical profiles of trauma-affected individuals may differ based on the five symptom dimensions of PTSD, assessment and monitoring of the nature, severity and temporal progression of symptom clusters that characterize the complex phenotype of PTSD may be helpful in informing the selection and modification of pharmacotherapeutic and/or psychotherapeutic treatments to target symptoms that precipitate and maintain this disorder. Third, these findings underscore the importance of assessing, monitoring and treating dysphoric and anxious arousal symptoms after exposure to trauma, as they may have prognostic utility in predicting the chronicity of PTSD (Schell *et al.* 2004; Marshall *et al.* 2006; Solomon *et al.* 2009), as well as concomitant functional difficulties (Thompson *et al.* 2004; Malta *et al.* 2009). For example, treatments that target heightened arousal, such as beta-adrenergic blockers (Vaiva *et al.* 2003; Hoge *et al.* 2012) and cognitive–behavioral therapies (Rabe *et al.* 2006; Hinton *et al.* 2009) may be particularly helpful in treating individuals with highly elevated dysphoric or anxious arousal symptoms after exposure to trauma.

This study has some methodological limitations. First, CFAs were based on a self-report measure of DSM-IV PTSD symptoms. Whether results of CFAs would differ if a DSM-5-based instrument or a clinician interview-based measure of PTSD such as the Clinician-Administered PTSD Scale were to be employed is not clear. Second, because assessment of WTC-related PTSD symptoms occurred an average of 3, 6 and 8 years after 9/11, it is not clear whether a different pattern of results would be observed at earlier time points after trauma exposure (e.g. months). Third, the construct validity of the five-factor model was not examined, as external measures of the unique constructs assessed by the dysphoric arousal and anxious arousal clusters (e.g. mixed anxiety and depressive symptoms; panic symptoms) were not assessed. Further research is needed to examine the natural history and construct validity of re-experiencing, avoidance, numbing, and dysphoric and anxious arousal symptoms, and to evaluate the utility of the five-factor model of PTSD in predicting long-term distress, functioning and treatment outcomes in trauma-exposed individuals. Fourth, it is unclear whether the DSM-IV-based separation of hyperarousal into dysphoric and anxious arousal symptom clusters will apply to the revised DSM-5 criteria for PTSD, which describe a four-factor model that is based largely on the CFA literature on the four-factor numbing and dysphoria models. Although additional CFA studies are needed to determine a five-factor model that will better characterize these revised symptoms, criterion E does contain similar hyperarousal symptoms as in DSM-IV, with the addition of self-destructive or reckless behavior. Thus, it is reasonable to suspect that the separation of dysphoric and anxious arousal symptoms using DSM-5 criteria will provide a better representation of this symptom cluster than a single hyperarousal factor. Importantly, however, given evidence of possible order effects on commonly used PTSD assessment instruments in CFA studies (Marshall *et al.* 2013), additional research is needed to evaluate how such effects might influence structural models of PTSD using DSM-5 criteria.

Despite these limitations, results of this study suggest that a five-factor model of PTSD symptoms that is comprised of separate clusters of re-experiencing, avoidance, numbing, dysphoric arousal and anxious arousal symptoms provides the optimal structural representation of PTSD symptom dimensionality in WTC responders. The results further suggest that hyperarousal symptoms have a prominent role in predicting other symptom clusters of PTSD, with anxious arousal symptoms primarily driving re-experiencing symptoms, and dysphoric arousal symptoms primarily driving emotional numbing symptoms over time. Additional research is needed to evaluate the optimal structural representation of DSM-5 diagnostic criteria for PTSD, assess interrelationships among symptom clusters from the best-fitting DSM-5-based model of PTSD symptom dimensionality over time, and examine the relationship between PTSD symptom clusters and other measures relevant to disaster responders and other trauma-exposed populations, such as health-related quality of life, and family and occupational functioning.

Supplementary material

For supplementary material accompanying this paper visit http://dx.doi.org/10.1017/S0033291713002924.

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Declaration of Interest

R.H.P. is a scientific consultant to Cogstate, Ltd for work unrelated to this project. B.J.L. has served as a consultant for and has received royalties from Baxter Pharmaceuticals for work unrelated to this project.

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