Virtual Reality Exposure Therapy for the Treatment of Posttraumatic Stress Disorder Following September 11, 2001

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Objective: This preliminary study endeavored to evaluate the use of virtual reality (VR) enhanced exposure therapy for the treatment of posttraumatic stress disorder (PTSD) consequent to the World Trade Center attacks of September 11, 2001.

Method: Participants were assigned to a VR treatment (N = 13) or a waitlist control (N = 8) group and were mostly middle-aged, male disaster workers. All participants were diagnosed with PTSD according to DSM-IV-TR criteria using the Clinician-Administered PTSD Scale (CAPS). The study was conducted between February 2002 and August 2005 in offices located in outpatient buildings of a hospital campus.

Results: Analysis of variance showed a significant interaction of time by group ($p < .01$) on CAPS scores, with a between-groups posttreatment effect size of 1.54. The VR group showed a significant decline in CAPS scores compared with the waitlist group ($p < .01$).

Conclusions: Our preliminary data suggest that VR is an effective treatment tool for enhancing exposure therapy for both civilians and disaster workers with PTSD and may be especially useful for those patients who cannot engage in imaginal exposure therapy.

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At the time the World Trade Center (WTC) attacks occurred, expert treatment guidelines for posttraumatic stress disorder (PTSD), which were published for the first time in 1999, recommended that cognitive-behavioral therapy (CBT) with imaginal exposure should be the first-line therapy for PTSD.[1] The efficacy of CBT with imaginal exposure had been demonstrated in an array of studies with diverse trauma populations including female victims of sexual assault,[2–4] motor vehicle accident victims,[5–8] Vietnam combat veterans,[9–14] and mixed trauma populations.[15]

Despite its documented efficacy,[16] imaginal exposure presents an impossible dilemma for some patients. Effective imaginal exposure, according to standard protocols used in PTSD treatment outcome research,[3] requires that patients tell their trauma in the present tense to their therapist, over and over again; yet avoidance of reminders of the trauma (e.g., thoughts, emotions, places) is inherent in PTSD. Hence, most people with PTSD never seek treatment.[17] Some patients who seek treatment refuse to engage in the treatment, and others, though they express willingness, are unable to engage their emotions or senses, retelling a flat, emotionless tale reflecting their numbness. Such patients typically fail to improve.

Theory suggests that emotional engagement or fear activation plays a critical role in exposure therapy. Foa and Kozak[18] propose that in order for a reduction in fear to occur, fear-relevant information associated with the patient's memory of the traumatic event (i.e., the fear structure) must be accessed and activated through emotional engagement. After the fear structure is aroused through emotional engagement, new or corrective information is incorporated into the patient's memory structure. These authors suggest that repeated engagement with the feared stimulus in a safe environment is necessary for the fear structures to change, thereby allowing long-term habituation to take place.[18]

The few studies that have addressed the question of treatment failures have concluded that failure to engage emotionally predicts a poor treatment outcome. One of the few studies to examine treatment variables that mediate outcome investigated the impact of the variables of

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emotional engagement and habituation on successful outcome of exposure therapy for chronic PTSD in female assault victims.[19] Results showed that although all participants made treatment gains, those with therapeutic emotional engagement in the treatment and habituation to emotion-eliciting stimuli were 8 times more likely to meet stringent criteria for good end-state functioning (i.e., a 50% reduction in PTSD symptom scores and normal scores on measures of depression and anxiety).

Virtual reality (VR) technology may provide a tool to facilitate high emotional engagement. Virtual reality environments afford opportunities not only to capitalize on the patient's imaginative and memorial capacities, but also to augment them with visual, auditory, and even tactile computer-generated experiences.[20–23] For patients who are reluctant to engage in recollections of feared memories, VR provides a sensory-rich environment, which may facilitate emotional engagement.[22] Moreover, VR environments can be manipulated above and beyond the constraints of the everyday world.[20,21,24] The VR world does not include the same risks as returning to the feared environment in the real world, and patients have been found to be more willing to consider VR therapy than other forms of exposure therapy.[20,21,24]

Numerous studies have documented that VR exposure therapy is an effective treatment for anxiety disorders. The efficacy of VR exposure has been demonstrated for fear of heights,[25–27] fear of flying,[28–30] claustrophobia,[31,32] and spider phobia.[33,34] As with PTSD, patients with specific phobias avoid the feared stimulus, but must confront it to get well. Rothbaum, Hodges, and colleagues[35,36] demonstrated the potential efficacy of VR enhanced exposure therapy for the treatment of chronic PTSD in an open trial of Vietnam War veterans who had failed to improve with other treatment modalities. Recognizing that not all of those individuals who would need treatment for PTSD following the WTC attacks[37–40] would respond to the first-line empirically validated treatment of prolonged exposure therapy,[36,41,42] we sought to conduct preliminary research on the application of VR technology to the treatment of PTSD in survivors of the WTC attacks of September 11, 2001, the first case of which was published in 2002.[43]

The principal aim of our study was to evaluate the efficacy of VR exposure therapy in the treatment of PTSD. The study was specifically designed for individuals with PTSD resulting from terrorism who directly witnessed the WTC attacks on September 11, 2001. To our knowledge, this is the only controlled study of treatment of PTSD following the WTC attacks.

METHOD

Design

In this preliminary study of a novel treatment technique, participants in the VR treatment group were compared with a matched waitlist control group. We hypothesized that those in the VR group would show a statistically and clinically significant reduction in PTSD symptom severity compared with the waitlist group both at the outcome assessment and the 6-month follow-up. We further hypothesized that significantly fewer participants in the VR group would have a diagnosis of PTSD compared with the waitlist control group both at the outcome assessment and the 6-month follow-up. Subjects in the treatment group received treatment based on a protocol that integrated VR exposure with other therapeutic techniques commonly used in PTSD outcome studies involving CBT including psychoeducation, relaxation training, and cognitive restructuring.

Participants

Participants were referred to our clinical research program from multiple referral sources including physicians and psychologists within the hospital network, the New York City Fire Department, and other entities that employed civilians and disaster workers directly exposed to the WTC attacks. The study was institutional review board approved, and prior to conducting all evaluations, the clinical treatment options and research studies available through our program were described to all evaluees. The evaluations and treatment occurred in the offices of the investigators located in outpatient buildings at the hospital campus (Weill Medical College, New York, N.Y.). Informed consent was obtained prior to beginning the interview. The study was conducted between February 2002 and August 2005.

Twenty-five participants were evaluated. Four people did not meet the eligibility criteria for this study. One patient was psychotic, another was excluded due to language barriers (i.e., the patient did not speak English well enough to complete the assessment instruments and communicate with the therapist), and the remaining 2 people did not meet full criteria for PTSD. Thirteen people were enrolled in the VR protocol and 8 people in the waitlist control group. The waitlist control group was matched to the VR group on Clinician-Administered PTSD Scale[44] (CAPS) severity scores, WTC exposure, and sociodemographic characteristics. There were no significant differences between the VR treatment group and the waitlist control group on any demographic variables (Table 1).

Of the 13 people who were enrolled in the VR protocol, 5 participants were firefighters, 4 were nonrescue disaster relief workers, and 4 were civilians. Three VR participants were taking a stable dose of a selective serotonin reuptake inhibitor for at least 2 months prior to participating in this project. Prior to enrolling in this study, 5 participants in the VR group had been in other treatments for PTSD related to the WTC attacks, which did not result in meaningful improvement. Four were treated with prolonged therapy exposure in our research program, but

Table 1. Sociodemographic Characteristics and Psychiatric and Trauma Histories of the Virtual Reality and Waitlist Groups

Variable	Virtual Reality	Waitlist	Test Result	p Value
Age, mean (SD), y	40.92 (9.90)	45.13 (7.14)	t = –1.03	.32
Gender, N			χ^2 = 0.03	.85
Male	11	7		
Female	2	1		
Education, N			χ^2 = 3.51	.32
Some or no high school	1	0		
High school	3	5		
Some college	3	1		
College	6	2		
Marital status, N			χ^2 = 2.30	.51
Cohabitating	2	0		
Separated/divorced	2	1		
Married	8	5		
Single	1	2		
Ethnicity, N			χ^2 = 0.86	.65
White	10	6		
Black	2	2		
Hispanic	1	0		
Psychiatric history, N	2	4	χ^2 = 2.91	.09
Trauma history, N	8	5	χ^2 = 0.00	.97

were unable to engage emotionally, as evidenced by Subjective Units of Distress Scale[45] (SUDS) scores of zero across several treatment sessions. The remaining participant was treated elsewhere, and his pre-VR treatment SUDS data were unavailable.

Inclusion of the patients who had failed prior treatments necessitated deviating from the standard randomization procedure. While we could have simply treated these subjects without including their data in the analyses, we decided instead to accommodate them by converting our design to a quasi-experimental approach. We felt that the inclusion of subjects who had in fact failed prior treatments had the potential to strengthen our conclusions. A successful outcome for this particular subsample of patients would go a long way toward showing how effective VR treatment could be. The design thus converted from randomized blocks to intact units.[46] The 5 treatment failures were entered into the VR condition, and a block of subjects matched on the key characteristics were entered into the waitlist control condition.

Of the 13 patients who began the VR protocol, 3 patients did not complete the process. One patient could not continue in the protocol because of his immediate geographic relocation outside of the New York metropolitan area and another had been diagnosed with a malignant cancer and had to begin treatment for debilitating symptoms, which precluded weekly visits for his PTSD treatment. Only 1 patient dropped out of treatment after beginning the VR exposure sessions. The baseline characteristics of these noncompleters did not differ significantly from those who did complete the study.

All participants were diagnosed with PTSD, using the CAPS, according to DSM-IV-TR criteria. The mean baseline CAPS score was 69.31 (SD = 21.91) for the VR group and 71.75 (SD = 12.02) for the waitlist control group; both fell within the severe range. There were no significant differences between the baseline CAPS scores in the VR and waitlist conditions (t = –.29, p = .78).

Procedure

After informed consent was obtained, persons who had at least partial direct exposure[1] to the attacks on the WTC were assessed by a doctoral-level psychologist with the CAPS,[44] the Trauma History Questionnaire,[47] and the Structured Clinical Interview for DSM-IV.[48] The self-report questionnaires include the PTSD Checklist (PCL),[49] Beck Depression Inventory (BDI),[50] and Brief Symptom Inventory (BSI), which also yields the subscale score of the Global Severity Index (GSI).[51] Inclusion criteria were (1) at least partial direct exposure to the WTC attacks of September 11, 2001; (2) between the ages of 18 and 70 years; and (3) met full criteria for DSM-IV-TR PTSD based on the CAPS interview. Exclusion criteria were presence of current organic mental disorder, schizophrenia, bipolar disorder, depression with psychotic features, current substance dependence, delusional disorder, and active suicidal or homicidal ideation, intent, or plan; history of chronic childhood sexual abuse; use of a pacemaker; and history of motion sickness. An independent assessor conducted assessments pretreatment, posttreatment, and at 6 months posttreatment. To calculate interrater reliability, a psychologist with 10 years' experience using the CAPS made independent ratings while observing interviews. Intraclass correlations[52] ranged from 0.98 to 0.99 for the 3 symptom cluster severity scores and CAPS total severity score.

In addition, VR participants completed self-report measures prior to every treatment session. All VR ses-

sions were videotaped and reviewed in weekly supervision with the senior psychologist (J.D.) associated with the project, who had 15 years' experience assessing and treating PTSD in diverse trauma populations. All psychologists conducting treatment had been trained in behavioral exposure treatment protocols for the treatment of PTSD in a diverse trauma sample, including civilian and disaster worker survivors of the WTC attacks, prior to learning the VR treatment protocol.

Equipment

A Dell (http://www.dell.com) 530 workstation with dual 2-gigabyte central processing units, 2 gigabytes of RAM, a Wildcat 5110 video card, Windows 2000 operating system, and MultiGen-Paradigm, Inc., Vega VR software, (http://www.multigen.com) was coupled with a 10242 × 768 resolution Kaiser XL-50 VR helmet with 40-degree horizontal field of view (http://www.keo.com/proviewxl3550.htm). A Polhemus Fastrak position tracking system was used to measure the position of the user's head (http://www.polhemus.com).

The essence of immersive VR is the illusion it gives patients that they have gone inside the 3-D computer-generated environment/virtual world, as if they are "there" in the virtual world. In the present study, the place the patients visited was lower Manhattan and the event reexperienced was a computer simulation of the September 11th attacks on the WTC.

During VR exposure therapy, the patient wore a head-mounted VR helmet that positioned 2 goggle-sized miniature liquid crystal display computer screens close to the patient's eyes. Position tracking devices kept the computer informed of changes in the patient's head location. An electromagnetic head orientation device fed the x, y, and z coordinates of the patient's head to the computer, which could quickly change what the patient saw in VR accordingly (e.g., the patients saw the streets and buildings if they looked straight ahead; they saw the WTC towers and sky if they looked up). The scenery in VR changed as the patient moved his or her head orientation (e.g., virtual objects in front of the patient in VR got closer as the patient, wearing the VR helmet, leaned forward in the real world). The WTC virtual environment was developed to permit a graded hierarchical exposure to the sensory stimuli in the world. The program was carefully constructed in this fashion to prevent overwhelming or flooding the patient and to allow the treatment to follow the principles of behavioral exposure in vivo and imaginal graded exposure therapy. Over the course of the exposure sessions, the patient progressed through a series of 11 computer-generated 3-D sequences that gradually increased in intensity and detail at a pace the patient could tolerate. The virtual world was programmed so that the therapist was able to control what the patient experienced while immersed in the virtual world by touching preprogrammed keys on the keyboard. During the exposure segments, the therapist simultaneously viewed the virtual environments on a video monitor.

The following is a list of the graded hierarchical elements of the WTC virtual world:

a. A jet flies over the WTC towers, but doesn't crash; normal New York City street sounds
b. A jet flies over, hits building, but no explosion
c. A jet flies over, crashes with explosion, but no sound effects
d. A jet flies over, crashes with explosion, with explosion sound effects
e. Burning and smoking building (with hole where jet crashed), no screaming
f. Burning and smoking building (with hole where jet crashed), screaming
g. Burning and smoking building (with hole where jet crashed), screaming, and people jumping
h. Second jet crashes into second tower with explosion and sound effects
i. Second tower collapses with dust cloud
j. First tower collapses with dust cloud
k. The full sequence

Treatment

The number of treatment sessions was flexible with a maximum of 14 sessions. The mean (SD) number of VR exposure sessions was 7.5 (3.6) with a range from 6 to 13 sessions. All patients received at least 6 weeks of exposure therapy. The 75-minute treatment sessions were held weekly. The target time in the virtual world was 45 minutes per session. The first 2 treatment sessions were used to provide psychoeducation about PTSD, to introduce relaxation training, and to introduce and provide the rationale for exposure therapy. The information obtained in the introductory imaginal exposure exercise was used to orient the therapist to the patient's trauma experience so that he or she could carefully plan the VR graded exposure.

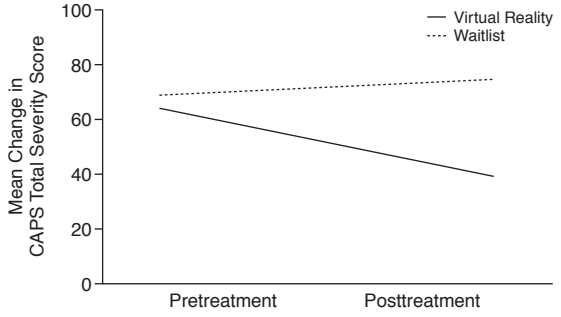
Sessions 3 through 12 were focused on the VR exposure therapy. The VR exposure exercises followed the principles of graded behavioral exposure. The pace was individualized and patient driven. Prior to putting on the head-mounted display, patients were instructed that they would be asked to recount their trauma in the first person, as if it were happening again, with as much attention to sensory detail as they could provide. Once the patient was immersed in the virtual world, the therapist prompted the patient to recount his or her story by asking the patient, "What comes to mind about your experience?" Using clinical judgment, the therapist might prompt the patient with questions about his or her experience or encouraging remarks if it was deemed necessary to help facilitate the exposure session.

Table 2. Mean (SD) Outcome Measures at Pretreatment (Baseline) and Posttreatment in the Virtual Reality and Waitlist Groups

	Virtual Reality Group (N = 10)		Waitlist Group (N = 8)	
Measure	Baseline	Posttreatment	Baseline	Posttreatment
CAPS				
Total score	62.50 (19.46)	39.90 (25.79)	71.75 (12.02)	75.50 (13.14)
Percent change from baseline	…	–39.69 (–90 to 6)	…	8 (–28 to 52)
Cluster B score	16.20 (9.19)	9.65 (9.36)	16.62 (8.79)	19.50 (7.76)
Cluster C score	27.10 (9.71)	16.10 (12.28)	28.50 (4.50)	29.50 (6.34)
Cluster D score	19.20 (4.18)	14.15 (8.56)	26.62 (3.88)	26.50 (5.42)
BDI score	16.80 (11.59)	11.10 (8.37)	19.12 (8.67)	21.50 (9.53)
GSI score	1.25 (0.76)	0.69 (0.55)	1.68 (0.68)	1.11 (1.02)

Abbreviations: BDI = Beck Depression Inventory, CAPS = Clinician-Administered Posttraumatic Stress Disorder Scale, GSI = Global Severity Inventory.

Figure 1. Mean Change in CAPS Total Severity Score in the Virtual Reality and Waitlist Groups (pretreatment to posttreatment)[a,b]



[a]Time by group interaction: F = 10.82; df = 1,16; p < .01.
[b]Between-groups posttreatment effect size: 1.54.
Abbreviation: CAPS = Clinician-Administered Posttraumatic Stress Disorder Scale.

The therapist monitored the patient's self-reported SUDS score on a scale of 0 to 100 every 5 minutes during the exposure work. For the sequences in the WTC world that were relevant to the patient's experience, each sequence in the VR menu was repeated until the SUDS level decreased by at least 50%. Each sequence was repeated a number of times before habituation occurred. The next sequence was not approached without the patient's verbal consent. This procedure was designed to evoke a level of response that created discomfort but that was tolerable. Gradually, as the patient habituated to his or her experience, he or she was able to approach sequences that more nearly approximated the traumatic event. After the patient completed the graded hierarchical exposure, which usually took several sessions, the patient was asked to recount memories that were spontaneously recalled during earlier parts of the treatment while the therapist showed the patient the sequence that had triggered the memory. The final 2 sessions were used for planning for pleasure, reviewing progress in treatment, and relapse prevention.

Statistical Analysis

Means and standard deviations (for all continuous measures) and frequencies (for categorical measures) were calculated across the sample and separately for each group. T tests and χ^2 tests were used to compare the groups, so as to ensure that the samples were comparable prior to treatment. Separate repeated-measures analyses of variance (ANOVAs) were performed on the CAPS, BDI, and BSI scores, with appropriate contrasts to compare the groups. Effect sizes for the overall ANOVA (partial η^2) and the posttreatment between-groups effect (Cohen's d)[53] are also reported.

RESULTS

All participants were diagnosed with PTSD using the CAPS according to DSM-IV-TR criteria. The mean (SD) baseline CAPS score was 62.50 (19.46) for the 10 VR completers and 71.75 (12.02) for the waitlist control group (Table 2). There were no statistically significant differences between the baseline CAPS scores in the VR and waitlist conditions (t = –1.17, df = 16, not significant). The groups did not differ significantly on any other characteristics at baseline (Table 1).

The VR group showed both statistically and clinically significant improvement in CAPS total severity scores compared with the waitlist comparison group. Repeated-measures ANOVA revealed a significant time by group interaction (F = 10.82; df = 1,16; p < .01) (Figure 1). There was a large interaction effect size (partial $\eta^2 = 0.40$) as well as a large posttreatment between-groups effect size (Cohen's d = 1.54). The initial CAPS severity scores for both groups fell within the severe range. At the end of the treatment period, the mean (SD) CAPS score for the VR group fell just within the upper border of the mild range (39.90 [25.79]), while the mean (SD) CAPS score for the waitlist control group remained within the severe range (75.50 [13.14]).

Post hoc comparisons showed significant group differences in final CAPS scores between the VR and waitlist groups (Tukey least significant difference = 29.20,

$p < .01$). Focused within-group contrasts revealed that CAPS scores showed a significant pretreatment to posttreatment decrease in the VR group ($p < .001$) but no significant decrease in the waitlist control group. Chi-square analysis showed that 7 of 10 people in the VR group no longer carried a diagnosis of PTSD, while all of the waitlist control group retained the diagnosis at the end of the waiting period ($\chi^2 = 9.6$, df = 1, N = 18, $p < .01$).

Among the 10 VR treatment completers, the mean percent decrease in CAPS score from pretreatment to posttreatment was 39.69% (Table 2). Of the 5 patients who previously failed to improve with imaginal exposure therapy, 3 showed at least a 25% decrease in symptoms, and the remaining 2 showed more than a 50% reduction in CAPS severity scores after VR exposure therapy. Similarly, 4 of the patients who had not received prior treatment for PTSD showed at least a 50% reduction in CAPS severity scores after VR exposure therapy, and 1 patient showed no improvement at the outcome assessment. As Schnurr and colleagues[54] report that a change of 10 points on the CAPS is clinically significant, the VR group had a clinically as well as statistically significant decrease in CAPS scores. Nine of 10 VR patients indicated a clinically significant reduction in CAPS scores of at least 10 points. The VR group showed a mean decrease in CAPS scores of 22.60 points compared with a mean 3.75-point increase in the waitlist control group.

Repeated-measures ANOVA showed a time by group interaction for both the reexperiencing cluster (B: $F = 7.70$; df = 1,16; $p < .05$) and avoidant symptom cluster (C: $F = 11.33$; df = 1,16; $p < .01$) but not the hyperarousal cluster (D: $F = 1.74$; df = 1,16; not significant). Focused within-group contrasts confirmed that the reexperiencing and avoidant symptom clusters showed a significant within-group decrease from baseline to the posttreatment assessment for the VR group ($p < .05$ and $p < .01$, respectively), but there was not a significant change in the hyperarousal symptom cluster. Post hoc Tukey honestly significant difference (HSD) tests showed significant differences between the groups on CAPS B and C clusters (Tukey HSD = 3.82, $p < .05$ and Tukey HSD = 6.47, $p < .01$, respectively) and no improvement on the D cluster (Tukey HSD = 2.76, not significant). Tukey HSD tests also showed that no symptom clusters had a significant decrease in the waitlist group (Tukey HSD, B = –1.78, C = –0.54, and D = 0.06, all not significant).

Repeated-measures ANOVAs indicated that there was no significant time by group interaction on the BDI ($F = 2.34$; df = 1,16; not significant) or the GSI ($F = 0.48$; df = 1,10; not significant), but these scores were low at baseline. There was a significant main effect for time on the GSI across both groups ($F = 7.43$; df = 1,10; $p < .05$) illustrating a slight decrease in general distress symptom levels over time.

Subjective Units of Distress Scale and immersion scores suggested that participants were able to emotionally engage in the virtual WTC attack simulation and to habituate to the sensory input offered in the VR world. The mean (SD) SUDS score across all participants in the first VR session was 46.35 (25.23), which is notable considering that patients begin by seeing only the towers or a plane flying past them, which usually elicit low if any distress. By the sixth session, which was the minimum number available to participants, the mean (SD) SUDS score had decreased, as would be expected with habituation, to 25.57 (19.92). The mean (SD) peak SUDS score in session 1 was 67.50 (34.82) and 45.87 (34.41) in session 6. Immersion scores were elicited by the Immersion Questionnaire,[55] a measure that assesses how absorbed subjects become during exposure sessions (the minimum total score is 7 and a maximum total score is 49). The mean (SD) immersion score across all VR sessions was 32.75 (7.43) with a range of 24.71 to 42.33.

Six-Month Follow-Up

Nine of the 10 VR participants were available for follow-up, and paired t tests show that the treatment gains were maintained at the long-term follow-up assessment (mean [SD] CAPS initial score = 62.7 [19.46] vs. CAPS follow-up score = 27.3 [16.3]; $t = 5.03$, df = 8, $p < .01$). Consistent with the initial outcome data, there were no baseline to follow-up changes on the BDI or GSI.

DISCUSSION

The results of our study provide preliminary evidence for the efficacy of a novel tool, VR simulations of trauma, to enhance treatment for PTSD. Nine of 10 patients with severe PTSD and extensive exposure to the WTC attacks showed both clinically meaningful as well as statistically significant improvement compared with a waitlist control group. The large effect size is particularly impressive because 5 of the 10 patients had participated in other treatments for PTSD, most notably imaginal exposure therapy, without any improvement prior to undertaking the VR treatment. The results are also notable because the treatment was effective for patients who had vastly different exposure to the WTC attacks and their aftermath, including emergency services personnel, disaster workers, and civilians.

Though our sample size was small, it was not smaller than several of the seminal studies documenting the efficacy of other PTSD treatments,[36,56] and our effect size was large compared with other psychotherapy outcome studies for PTSD,[57] suggesting that VR simulations of trauma may offer a promising new treatment tool for PTSD. To date, only one other study, an open trial of 9 Vietnam veterans with no control group, has examined the efficacy of VR for the treatment of PTSD.[36] That study,

too, reported a significant decline in PTSD symptoms in a group of veterans who had previously received multiple unsuccessful treatments for their PTSD prior to trying VR therapy.

As VR is a relatively new treatment tool for PTSD, we were particularly interested to learn if patients would tolerate the treatment well. Our results suggest that the treatment was well tolerated; only 1 patient who began the VR exposure sessions did not complete treatment. None of our patients reported feeling overwhelmed by the exposure nor did anyone get worse. Consistent with studies showing that patients prefer VR to imaginal exposure treatment for other anxiety disorders, our dropout rate of only 1 person was low.[20,21,24,34]

With regard to the clinical significance of this study, all treatment completers showed a clinically meaningful improvement in their PTSD symptom severity; however, 1 patient who completed treatment did not maintain these gains and evidenced no improvement at the outcome assessment, as described above. The range of symptom reduction was between 25% to 90%. Most notably, all 5 of those who had received prior treatment showed at least a 25% reduction in symptoms after VR therapy. It was our clinical impression that if we had included additional VR exposure sessions, these patients would have shown a further decrease in symptoms.

It may be important to note the context in which the treatment occurred. All participants lived in the New York City metropolitan area, and all the firefighters and disaster workers had continuing ongoing exposure to the effects of the WTC attacks at the disaster. During the period of study, the New York City metropolitan area was consistently rated as code orange, one of the highest levels of threat as delineated by the U.S. government (http://www.dhs.gov/dhspublic/display?theme=29); the only higher level is code red, indicating that the United States is currently under severe threat of terrorist attack. Thus, all participants received treatment in an environment of perceived ongoing threat. Previous studies of PTSD treatment have not occurred in the context of perceived ongoing threat to all study participants. It is difficult to determine the precise effect the ongoing threat had on treatment outcome. However, it was our clinical impression that many of our patients, in this as well as our other studies of WTC-related PTSD,[58] who had residual symptoms when they were interviewed, were reacting to the ongoing anticipated terrorist threats to the New York City metropolitan region. We speculate that the perception of ongoing threat may have been a factor in the maintenance of residual hyperarousal symptoms in our patients. This observation may have important implications for research conducted in similarly life-threatening environments, such as in Israel, where terrorist threats are ongoing, or within the combat theater, where soldiers are treated for PTSD.

One skepticism of VR treatment for PTSD has been that standardized virtual simulations would be of limited therapeutic value because each patient's trauma experience is idiosyncratic. The arguments suggest that one standardized virtual trauma simulation could not encompass the vast array of stimuli experienced by large numbers of people exposed to the same type of trauma sufficiently (e.g., the attacks on the WTC) to engage patients with their diverse experiences. Our results contradict this assertion. Our patients had substantially different experiences of the WTC attacks. Five participants were New York City firefighters, 3 were disaster workers, and 3 were civilians. One civilian witnessed the attacks across the street from the towers, and the virtual WTC world encompassed her entire experience. Another patient was a fire chief who played an integral role in directing the fire department's operations inside the lobby of the North Tower and who had to escape as the tower collapsed. Yet another patient, a nonrescue disaster worker, was summoned to the site from a nearby location and did not see the plane crashes but arrived in time to witness people jumping from the buildings. All of these patients had high engagement scores in VR, but low engagement scores in imaginal exposure therapy, and illustrate the point that one carefully crafted virtual trauma simulation can encompass a broad enough array of sensory stimuli to provide emotional resonance to diverse trauma experiences.

We can only speculate why VR-enhanced treatment may be effective. Several studies regarding the phenomenology of trauma memories have suggested that these memories are usually more fragmented and characterized by sensory perceptual qualities than nontrauma memories.[59,60] Because of the multisensory capacity of the VR simulations, VR may prove to be a uniquely effective environment in which to process and integrate these memory fragments together into a coherent story that patients are comfortable accessing. The sensory cues in the virtual trauma simulation may match or parallel the sensory quality and phenomenology of the memory fragments. The sensory cues in the VR world may serve as triggers for the patient's memory fragments, helping him or her to access his/her fear structures, thereby facilitating both the patient's emotional engagement and the sensory and emotional processing of the memory fragment. Although an anecdotal observation, we were impressed that several VR patients who did not respond to prolonged exposure therapy noted that the sound of the VR simulation was particularly powerful and helped "bring them into" the VR WTC simulation and to their personal memories.

One obvious limitation to the current study results from the comparison of the VR treatment group with a waitlist control group rather than comparing the VR treatment with the standard of care treatment, prolonged exposure therapy. Additionally, our relatively small sample

size and quasi-experimental design suggest caution when interpreting our results. Nonetheless, these promising results suggest that further studies are warranted. To address the efficacy of VR exposure therapy and to determine its clinical benefits, studies should be developed to use VR trauma simulations with a variety of traumas and include randomized controlled clinical trials comparing VR to prolonged exposure therapy. We conclude that VR may be an effective treatment tool for those with PTSD and may be particularly valuable for those who do not respond to prolonged exposure therapy.

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