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Research paper

Linguistic predictors of response to internet-based written CBT for PTSD symptoms of 9/11 world trade center recovery workers and survivors

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ABSTRACT

Trauma-focused cognitive-behavioral therapies (CBT) are the mainstay of posttraumatic stress disorder (PTSD) treatment, but treatment response is heterogeneous. We used automated linguistic analysis to identify markers of PTSD symptom improvement in response to integrative testimonial therapy (ITT), an internet-based, therapist-assisted written CBT for PTSD, for 9/11 World Trade Center rescue and recovery workers and survivors with PTSD symptoms. Therapy comprised 11 written narratives, separated into biographical reconstruction, exposure, and cognitive reappraisal narrative modules. Narrative data of 35 ITT completers in a larger clinical trial were analyzed using the Linguistic Inquiry and Word Count (LIWC) software and the Valence Aware Dictionary and sEntiment Reasoner (VADER) toolkit. Separate regression analyses were conducted to predict treatment response, assessed with the PTSD Checklist for DSM-5 (PCL-5) at baseline and post-treatment. Four LIWC word categories collectively explained 59 % of the variance in PCL-5 score improvement: higher use of death, causation, and motion words in biographical narratives, and lower use of social behavior words in exposure narratives, were associated with greater improvement. Higher VADER negative sentiment score in biographical narratives was also associated with greater improvement. Findings provide insight into potential factors driving therapeutic response to written CBT for PTSD and may help advance personalized treatment for individuals with this disorder.

1. Introduction

Posttraumatic stress disorder (PTSD) is characterized by recurring disturbing thoughts and feelings following exposure to a traumatic event, persistent avoidance of reminders of the event, negative alterations in cognition and mood, and increased arousal and reactivity such as being easily startled or feeling "super alert" (Association, 2022). The estimated lifetime prevalence of PTSD ranges from 3.9 to 6.1 % in the United States and cross-nationally in the general adult population (Goldstein et al., 2016; Koenen et al., 2017). High-risk populations with exposure to severe mass violence face even higher PTSD rates and often endure persistent negative effects. Specifically, among the hundreds of thousands of individuals exposed to the September 11, 2001 (9/11) World Trade Center (WTC) attacks, PTSD prevalence ranged from 14.3 to 21.9 % in the second decade following the attacks, nearly four times the general population rate (Bromet et al., 2016; Feder et al., 2016; Jordan et al., 2019).

Current consensus points to trauma-focused cognitive-behavioral

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therapies (CBT) as the first-line therapeutic intervention for PTSD (Watkins et al., 2018). Numerous meta-analyses and systematic reviews have confirmed the efficacy of trauma-focused CBT modalities in reducing symptom severity and maintaining improvement after treatment completion (Bisson and Andrew, 2007; Lely et al., 2019; Mavranezouli et al., 2020; Watts et al., 2013). Further, written forms of trauma-focused psychotherapies such as narrative exposure therapy (NET) and written exposure therapy (WET) have shown similar efficacy and lower rates of dropout compared to other trauma-focused psychotherapies (Jericho et al., 2022; Robjant and Fazel, 2010; Sloan et al., 2023; Sloan et al., 2018). While many individuals with PTSD respond to trauma-focused CBT, response is heterogeneous (Herzog and Kaiser, 2022). Therapeutic response can vary by demographic and clinical factors including age, social support, symptom presentation, and comorbidities, yet these factors often inconsistently predict treatment outcomes and have limited utility in informing treatment approaches (Dewar et al., 2020; Kelly et al., 2009). It is thus important to identify factors associated with better psychotherapeutic response. In particular, the ability to predict in early sessions which patients will improve in a specific treatment could optimize time and resources and reduce suffering by informing a personalized approach (Kleim et al., 2018).

Automated linguistic analysis is a scalable, low-cost approach that can provide objective data to predict response early in therapy. This method conceptualizes language as a window into psychological states beyond an individual's conscious awareness (Gottschalk and Gleser, 1969; Tausczik and Pennebaker, 2009; Weintraub and Aronson, 1969). Pennebaker and colleagues develop the Linguistic Inquiry and Word Count (LIWC) software, one of the most commonly used methods for studying PTSD through linguistic analysis of narratives (Boyd et al., 2022). By classifying words into psychologically meaningful categories and examining their frequency, LIWC seeks insight into an individual's psychological experience based on objective word usage data. Applying LIWC to the written narratives of undergraduate students disclosing traumatic experiences, they found that students who used a higher proportion of negative words (e.g., "sad", "hate," "hurt") and lower proportion of positive words (e.g., "happy," "joy," "peaceful") showed improvements on a composite outcome index including decreased health center visits, improved school grades and immune function (Pennebaker, 1993).

Research on linguistic analysis and PTSD symptoms has largely focused on cross-sectional associations in non-treatment studies using written narratives or recorded and transcribed interviews, which have yielded mixed findings (Quillivic et al., 2024). Previous studies in a range of trauma survivors have shown that greater use of emotional words (both positive and negative), cognition words (e.g., "because," "why"), and pronouns indicating lower self-focus ("we") are associated with lower PTSD symptomatology (Jaeger et al., 2014; Kleim et al., 2018; Papini et al., 2015; Wardecker et al., 2017). An AI-based linguistic analysis of transcribed interviews with 9/11 World Trade Center first responders, a non-treatment study, found greater use of "depressive language" and first-person singular words associated with greater PTSD symptom severity cross-sectionally, while "anxious language" predicted worsening of PTSD symptom levels over a follow-up period of up to seven years (Son et al., 2021).

A few additional studies have examined linguistic predictors of PTSD symptom levels longitudinally, varying greatly in context and methods (Guzick et al., 2024; Quillivic et al., 2024). Analysis of transcribed naturalistic genocide testimony interviews conducted in 2002 with survivors of the 1994 Rwandan Genocide found that expressions of sadness ("crying," "grief," "sad") predicted lower hyperarousal symptoms six years later. This suggested that the ability to express sadness may indicate adaptive emotional processing and promote mental health (Ng et al., 2015). In another study, assault survivors were asked to describe their assault within 18 days of its occurrence, "as vividly and in as much detail as possible." (Kleim et al., 2018). Higher use of death-related words (interpreted in this context to indicate "perceived threat to life") and lower use of cognition words predicted greater PTSD symptom severity six months later (Kleim et al., 2018). In contrast, for undergraduate students not directly affected by the 9/11 attacks who were asked, the week after 9/11/2001, to write about how they had first heard about the attacks in vivid detail, greater use of cognition words predicted greater self-reported PTSD symptom severity five months later (D'Andrea et al., 2012).

Few studies have used automatic linguistic analysis to examine predictors of psychotherapy response for PTSD (Alvarez-Conrad et al., 2001; Jennings et al., 2021). One study asked 45 female assault survivors with chronic PTSD to "recount their assault as if it was happening now" during exposure therapy (sessions 3 and 4) (Alvarez-Conrad et al., 2001). Automated analysis of transcribed narratives from these exposure sessions revealed that use of death-related words was associated with worse functioning post-treatment, measured as a composite measure of PTSD symptom severity, social functioning, and physical symptom levels. A randomized controlled trial (RCT) of patients with substance use disorder (SUD) comorbid with subthreshold or full PTSD assigned them to standard CBT for SUD vs. combined CBT for SUD and PTSD (Jennings et al., 2021). Linguistic analysis of transcribed audio recordings of the seventh ("critical") session in both treatment arms, for 37 patients – the first "cognitive restructuring" session in CBT for SUD, and a trauma-processing session for the combined CBT for SUD and PTSD – found that greater use of cognition words predicted lower PTSD symptom levels post-treatment in the full sample, after adjusting for treatment condition.

To date, only one study has examined linguistic predictors of response to written psychotherapy for PTSD. This RCT randomized 126 treatment-seeking adults with chronic PTSD to written exposure therapy (WET) or cognitive processing therapy (CPT), the latter including written trauma accounts as homework. The authors examined predictors of treatment-related sudden gains in PTSD symptoms using qualitative analysis rather than automated linguistic analysis, applied only to the first written narrative of all patients (Sloan et al., 2022). Greater expression of negative emotion in this first narrative predicted sudden gains in PTSD symptoms in both treatment conditions assessed by PCL-5.

Overall, despite variability in methods, samples, and findings across studies, word categories including emotional words and cognition words repeatedly emerged as significant linguistic markers associated with PTSD symptomatology. Since both cognition- and emotion-related language are of interest when evaluating change resulting from psychotherapy, applying LIWC to written therapy sessions may objectively measure such contributions by quantifying patients' use of word categories in therapy (McCarthy et al., 2017).

This study used automated linguistic analysis to explore linguistic markers of PTSD symptom improvement in integrative testimonial therapy (ITT), an internet-based, therapist-assisted written CBT for PTSD. The study was designed as an exploratory investigation without a-priori hypotheses, with the goal of generating empirical observations to inform future hypothesis-driven research on linguistic predictors of therapeutic response. The study sample drew from a larger RCT comparing ITT to internet-based modified present-centered therapy (I-MPCT) for 9/11 WTC rescue and recovery workers and WTC survivors with WTC-related PTSD symptoms (Brinkman et al., 2021; Feder et al., 2024). To our knowledge, this is the first study to employ automated linguistic analysis to identify predictors of response to written psychotherapy for PTSD.

2. Methods

2.1. Participant recruitment and screening

Study data were collected from participants as part of a larger, institutional review board-approved RCT conducted at the Icahn School of Medicine at Mount Sinai (ISMMS). The trial compared two internet-based, therapist-assisted, written psychotherapies for WTC-related

PTSD symptoms in WTC workers and survivors: ITT focused on WTC-related trauma and I-MPCT focused on current life stressors (Brinkman et al., 2021; Feder et al., 2024). Funded by the Centers for Disease Control and Prevention/National Institute of Occupational Safety and Health, the study was registered at clinicaltrials.gov (NCT03154151).

Patients were either WTC workers or survivors with WTC-related PTSD symptoms, enrolled between 2017 and 2021. WTC workers included rescue, recovery, and clean-up workers participating in the post-9/11 WTC recovery effort. WTC survivors included individuals living, working, or passing through the WTC area during the attacks. Patients were recruited through collaboration with the Data Center from the WTC Health Program General Responder Cohort, advertising by the WTC Health Registry and at community groups with large cohorts of WTC workers or survivors, and through referrals from mental health clinicians treating WTC-affected patients (Brinkman et al., 2021).

After completing a brief online pre-screening questionnaire and the study electronic consent form on the Research Electronic Data Capture (REDCap) platform (Harris et al., 2009), eligible participants completed a screening questionnaire eliciting a brief description of their WTC-related experience and the PTSD Checklist for *DSM-5* (PCL-5) (Blevins et al., 2015) about WTC-related trauma exposure. Trained staff administered by telephone the Mini International Neuropsychiatric Interview (MINI) and medical history and current medication questions (Sheehan et al., 1998). The Trauma History Screen was administered at baseline to assess lifetime exposure to varied traumas (Carlson et al., 2011).

2.2. Inclusion criteria

Inclusion criteria included current full WTC-related PTSD (meeting DSM-5 diagnostic criteria) or subthreshold PTSD, the latter operationalized with two commonly used definitions in the literature (Brinkman et al., 2021), confirmed by MINI. In the RCT, 73.6 % of 44 total patients randomized to ITT met full PTSD criteria at screening. Participants were excluded if they were currently receiving psychotherapy or counseling; endorsed active suicidal or homicidal ideation; had current psychotic or significant dissociative symptoms; met criteria for lifetime psychotic/bipolar disorder or alcohol/substance use disorder within the past three months; had a history of brain injury, central nervous system disorder, any uncontrolled medical condition; or were currently taking antipsychotic medications, lithium, valproic acid, or daily benzodiazepine or opioid medication.

Data for the current linguistic analysis study derived from patients randomized to trauma-focused therapy, ITT, further described below. Thirty-five (80 %) of 44 patients who completed ITT comprised the present study sample. Of the remaining nine, one was excluded due to head trauma history overlooked at screening, and another did not complete the post-treatment PCL-5. The remaining seven had had a total past-week PCL-5 score of ≤12 at pretreatment baseline, falling below the reliable change index (RCI) of 12.55 (meaningful change beyond chance or measurement error) computed from the full RCT sample ($N = 105$); SD for baseline PCL-5 scores = 13.8, Cronbach's α for baseline PCL-5 items = 0.892. Therefore, these patients were excluded, as their baseline PCL-5 scores did not leave room for the minimum amount of change needed to be considered clinically meaningful. Reliable change was determined by the Jacobsen-Truax method using standard deviation and internal consistency of baseline PCL-5 scores (Jacobson and Truax, 1991). Table 1 presents demographic and clinical characteristics. At baseline, the mean PCL-5 score was 28.7 (SD = 13.7), which decreased significantly to 17.8 (SD = 13.4) at post-treatment ($t_{[df=34]} = 4.66$, $p < 0.001$).

2.3. Treatment: integrative testimonial therapy (ITT)

Knaevelsrud et al. developed ITT to address mental health treatment barriers for older adults with posttraumatic symptoms, including fear of stigmatization and geographical barriers, by delivering a trauma-focused CBT through an internet-based written intervention (Knaevelsrud et al., 2014). Developed from Interapy (which includes trauma exposure and cognitive reframing phases), ITT incorporates from narrative exposure therapy the construction of biographical narratives from childhood to the time of the index trauma and thereafter, with the aim of integrating the trauma experience into the individual's life story (Lange et al., 2003a; Lange et al., 2003b). Originally studied in German World War II survivors with posttraumatic stress symptoms, ITT was found to significantly reduce PTSD symptom severity compared to waitlist controls, with patients reporting high levels of therapeutic alliance (Knaevelsrud et al., 2017; Knaevelsrud et al., 2014). All interactions between patient and therapist occur in writing, asynchronously, on different days. ITT was administered by one of two licensed clinical social workers (one masters-level, one doctoral-level), supervised by an expert consultant (M.B.). Patients and therapists corresponded through a secure, HIPAA-compliant REDCap platform (or used a password-protected secure email system prior to platform finalization).

This study adapted therapist instructions to treat WTC workers and survivors (Brinkman et al., 2021). Treatment comprised 11 writing assignment "narratives" organized into four treatment modules (see Table 2). Patients were asked to complete 45-minute written narratives twice weekly but were allowed to take longer, generally completing the therapy within 6 to 12 weeks. *Module 1, Pre-9/11 Resource-Oriented Biographical narratives*, comprised three narratives, autobiographical reconstructions of phases of the individual's life from early childhood until 9/10/2001, focusing on key events or issues, sources of pride, and problems encountered. *Module 2, Exposure narratives*, included four first-person narratives describing the patient's traumatic WTC-related

Table 1
Demographic and clinical characteristics.

Demographic and clinical characteristics		
n = 35	n or mean	% or SD
Age	57.7	8.9
Sex		
Male	18	51.4 %
Female	17	48.6 %
Race-Ethnicity		
Hispanic	8	22.9 %
Non-Hispanic White	23	65.7 %
Non-Hispanic Black	4	11.4 %
Education		
≤ Associate's Degree	19	54.3 %
≥ Bachelor's Degree	16	45.6 %
Work Status		
Employed	24	68.6 %
Disabled from a WTC-related Health Problem	5	14.3 %
Disabled from a non-WTC. Related Health Problem, Unemployed, or Student	1	2.9 %
Retired	5	14.3 %
Relationship Status		
Single	3	8.6 %
Married or Partnered	28	80.0 %
Widowed, Separated, or Divorced	4	11.4 %
Participant Type		
Traditional Worker (e.g., police, firefighter)	15	42.9 %
Non-Traditional Worker (e.g., construction worker)	8	22.9 %
Survivor	12	34.3 %
PTSD Severity at Screening		
Subthreshold PTSD	11	31.4 %
Full Threshold PTSD	24	68.6 %
Treatment Duration (days)	62.9	25.2
PCL-5 Score at Screening (past month)	36.6	10.7
PCL-5 Score at Pre-Treatment Baseline (past week)	28.7	13.7
PCL-5 Score at Post-Treatment (past week)	17.8	13.4

PTSD = Posttraumatic stress disorder.
PCL-5 = PTSD Checklist for DSM-5.
SD = standard deviation.

Table 2
Integrative Testimonial Therapy (ITT) Sample Written Therapist Instructions.

Treatment Phase	Integrative Testimonial Therapy (ITT) Sample Written Therapist Instructions
Module 1: Pre-9/11 Resource-Oriented Biographical Narratives Three narratives dedicated to autobiographical reconstructions of various phases of the participant's life up to 9/11	**Narrative 1: pre-9/11 Biographical Narrative #1** (birth to age 12) *In your first narrative, you will focus on your life from birth to age 12. It's important to note down exactly what you experienced during that time period. (You can answer questions like: How did you feel? Which events do you like remembering?)* *Here are some events or things that may be important: kindergarten, friends, character traits, role models…* *As you write about these, please also focus on what you were proud of during this phase of your life, as well as problems you encountered during childhood and how you solved them.* **Narrative 2: Biographical Narrative #2** (ages 13 to 18) *In your 2nd narrative, concentrate for 45* min *about your life between ages 13 and 18. Here are some cues: high school graduation, job, family, intimate relationships…* *You are encouraged to write everything you remember about your life back then, including seemingly unimportant memories* **Narrative 3: Biographical Narrative #3** (ages 19 to 9/11/2001) *Please write about your life from age 19 to 09/10/2001. Here are other possible suggestions for your biography at this time: residences, marriages, job, hobbies, lifestyle…*
Module 2: Exposure Narratives Four narratives dedicated to descriptions of a participant's traumatic WTC-related experience from the first-person perspective	**Narrative 4: Exposure Narrative #1** *The aim of this writing session is to describe the event in as much detail as possible, including all of the sensations you had. What did you experience then? What did you see at the time? What did you hear? What did you smell? What did you feel (fear, grief, desperation, panic)? How did your body react (cold hands, palpitations, nausea, trembling)?"* *During the writing, please try to concentrate on the most stressful memories of the traumatic experience. Try to focus on the scenes which come into your mind again and again, and which may continue to appear in your nightmares* **Narrative 5: Exposure Narrative #2** *Focus again on the most stressful moment in your WTC experience. Try to explain the moment that preoccupied/frightened you the most back then, and that involuntarily keeps coming into your mind today* **Narrative 6: Exposure Narrative #3** *Continue to focus on the most traumatic moment in your WTC experience. Please try and elaborate on the most stressful parts you mentioned in your fifth narrative.* **Narrative 7: Exposure Narrative #4** *I want you to concentrate even more intently on the feelings you had at the time of the most traumatic moment in your WTC experience*
Module 3: Post-9/11 Resource-Oriented Biographical Narrative One narrative dedicated to an autobiographical reconstruction of the participants life from 9/11 to the present	**Narrative 8: Biographical Narrative #4** (9/11/2001 to the present) *The traumatic events of 9/11 have stayed with you through the years, though they may not have always been on a conscious up to level. While writing your biography up to the present, you might focus on situations in which these traumatic events were present for you and how they influenced your ability to act, respond, and behave*
Module 4: Cognitive Reappraisal/ Integration Three supportive letters written by participants to their former self from their current perspective, aimed at generating a new perspective and regaining a feeling of control by integrating the traumatic event into their life narrative	**Narrative 9: Letter to Self Narrative #1** *The focus of this phase is to find a proper conclusion to your writing experience during these last few weeks. In the following writing sessions, you will draft 2 supportive letters and a kind of farewell letter in which you will try to view your biography from a different perspective.* **Narrative 10: Letter to Self Narrative #2** *Elaborate on the first letter in greater detail* **Narrative 11: Letter to Self Narrative #3** *For your last writing session, I would like you to write a final letter to the person you are now, in which you describe the place that this event has in your life now. How would you describe your feelings and thoughts about this event now? How do you want to deal with it in the future?*

experience. Patients were asked to write about their most painful 9/11 memories or their work for the WTC recovery effort in as much detail and sensory description as possible. *Module 3* was a single *Post-9/11 Resource-Oriented Biographical narrative,* an autobiographical reconstruction of the patient's life from 9/11 to the present. The final phase, *Module 4, Cognitive Reappraisal/Integration* narratives, included three successive versions of a supportive letter the patient wrote to their former self from their current perspective, aimed at generating a new perspective and gaining a feeling of control by integrating the traumatic event into their life narrative. Excerpted therapist instructions for each narrative appear in Table 2**.** Therapists' written feedback to patient narratives, provided per protocol for every 1–2 patient narratives, followed a standardized response template tailored by the therapist to address the individual patient's narrative content.

2.4. Measures

2.4.1. Posttraumatic stress symptoms

The PCL-5 is a 20-item self-report measure assessing the 20 DSM-5 PTSD symptoms over the past month, here in relation to 9/11/2001, on a 5-point scale of 0 (not at all) to 4 (extremely). The PCL-5 has demonstrated strong internal consistency, test-retest reliability, and validity, and has specifically shown psychometric validity in first responders (Blevins et al., 2015; Morrison et al., 2021). The 120 MINI questions assess 17 common psychiatric disorders, including lifetime PTSD, using DSM-5 criteria. Previous research has demonstrated MINI reliability and validity (Sheehan et al., 1998).

2.4.2. Linguistic analysis

2.4.2.1. LIWC. Linguistic Analysis was conducted using the 2022 version of the *Linguistic Inquiry and Word Count (LIWC-22)* software, which maps words of a chosen text onto psychologically relevant word categories within the LIWC dictionary of over 12,000 words. The LIWC-22 Development describes development of the dictionary (Boyd et al., 2022). LIWC's dictionary captures two main language categories:

content words and function words. Content words provide meaning and convey information, whereas function words such as pronouns, prepositions, and conjunctions help shape language. Previous work has indicated that function words reflect an individual's psychological state, allowing language evaluation beyond consciously chosen content (Chung and Pennebaker, 2007). When analyzing text, LIWC determines whether each word appears in the LIWC dictionary, and if so, to which category or categories it belongs. For example, the word "sad" is assigned to the category "Affect." As LIWC dictionary categories contain a hierarchy of subcategories, "sad" would be further categorized into "Emotion" and "Negative Emotion" subcategories. We employed the LIWC software to analyze patients' narratives separately by each of the four therapy modules so that the computed value for each word category represented the percentage of words in that category the patient used in written narratives from a particular therapy module.

2.4.2.2. VADER. While accumulating literature suggests LIWC usefully assesses language content, its word-by-word analysis is a potential weakness, as it ignores context and word combinations. For this reason, we complemented LIWC-generated data on affect with a sentiment analysis approach using the *Valence Aware Dictionary and sEntiment Reasoner (VADER)*. VADER is a lexicon-based natural language toolkit algorithm that considers both the polarity and intensity, known as valence, of sentiment-related lexical features (Hutto and Gilbert, 2014). VADER rates words in the lexicon on a valence scale of −4 (most negative) to +4 (most positive). Based on these valences, VADER produces three scores per sentence: positive, neutral, and negative scores. Each score represents the proportion of the sentence falling into each category. For example, a negativity score of 0.45 indicates that 45 % of the sentence contained negative sentiment. Finally, the fourth, compound score sums the valence score of each sentiment-bearing word, adjusts for syntactic considerations, and normalizes the score to a decimal between −1 (most negative) and +1 (most positive) to represent the overall sentiment of a sentence.

VADER takes into account syntactical considerations of punctuation, capitalization, degree modifiers (adverbs or degree adverbs), conjunctions, and polarity negation to accurately capture shifts in sentiment polarity and where negation flips polarity. For example, the statement "This is an excellent restaurant with great food!" has negative score = 0.0, neutral score = 0.435, positive score = 0.565, and compound score = 0.832. The sentence, "This is an excellent restaurant with GREAT food!!" has scores of 0.0, 0.397, 0.603, and compound score 0.878. VADER was created to analyze brief text on social media. The present study tokenized the narrative text in R, assigning each sentence within narratives a positive, neutral, negative, and compound score. Sentence scores in a patient's narratives were averaged to produce four overarching scores for each of the four therapy modules.

2.5. Data analysis plan

Descriptive statistics were computed to summarize demographic and clinical variables. The primary treatment response outcome used baseline and post-treatment PCL-5 scores. Bivariate Spearman correlations within each treatment phase or "module" were computed to examine associations between PCL-5 score improvement from baseline to post-treatment, and LIWC scores and VADER scores. Scores associated with symptom improvement at the $p < 0.10$ level were included in subsequent multivariable regression analyses; this less conservative p value threshold intentionally allowed entry of more word categories into a multivariable model. LIWC word categories associated at this level were entered into a hierarchical stepwise linear regression with word categories from each treatment module entered in separate steps to predict PTSD symptom improvement. A binary logistic regression analysis then explored word categories associated with a reliable change in PCL-5 scores of ≥12.55, computed from the full RCT sample (see *Inclusion criteria*) (Jacobson and Truax, 1991). A parallel set of regression models was conducted to examine how VADER sentiment scores related to PTSD symptom improvement and reliable change. Statistical analyses were conducted using SPSS Statistics for Macintosh, Version 29.0.

3. Results

Language Use and PTSD Symptom Improvement.

3.1. LIWC results

Results of linear and logistic regression analyses are shown in Table 3. Collectively, four word categories explained 59 % of the total PCL-5 score improvement variance from baseline to post-treatment ($R^2_{adjusted} = 0.59$, $F(1,30) = 13.33$, $p = 0.01$). Higher use of words relating to *(1)* death (e.g., "kill," "passed away," "die"), *(2)* causation (e.g., "how," "because," "why") and *(3)* motion (e.g., "come," "go," "went") in Module 1 (Pre-9/11 Resource-Oriented Biographical narratives) were associated with greater PTSD symptom improvement from pre- to post-treatment. In contrast, greater use of words relating to social behavior (e.g., "said," "called," "care," "fight") in Module 2 (WTC-related trauma exposure narratives) was associated with less improvement.

Use of death words emerged as the strongest predictor of PCL-5 score improvement, explaining 23.3 % of the overall variance ($R^2_{adjusted} = 0.23$, $F(1,33) = 11.33$, $p = 0.002$). Similarly, results from the binary logistic regression examining linguistic predictors of reliable change indicated that, in Module 1, each standard deviation increase in the proportion of death words (OR: 3.95, 95 % CI 1.31–11.93) and causation words (OR: 2.92, 95 % CI 1.15–7.43) was associated with increased odds of having a reliable change in total PCL-5 scores. Neither total number of self-reported lifetime trauma types nor endorsement of lifetime "sudden death of close family member or friend" on the baseline-administered Trauma History Screen (Carlson et al., 2011) were associated with the proportion of death words used in Module 1 biographical narratives ($r = 0.25$, $p = 0.14$ and $r = -0.15$, $p = 0.40$, respectively). Further, use of death words remained a significant predictor of score improvement ($\beta = 0.52$, $p < 0.001$) and reliable change in total PCL-5 scores (OR: 3.54, 95 % CI 1.13–11.04) after adjustment for total number of self-reported lifetime trauma types and endorsement of lifetime "sudden death of close family member or friend."

3.2. VADER results

Table 4 presents results of linear and logistic regression analyses. Regarding narrative sentiments, higher negative score in Module 1 and lower overall (compound) sentiment score in Module 2 were associated with greater PCL-5 score improvement ($R^2_{adjusted} = 0.29$, $F(2,32) = 6.26$, $p = 0.001$). Additionally, each standard deviation increase in negative score was associated with >4-fold greater odds of a reliable change in total PCL-5 scores over the treatment period (OR: 4.20, 95 % CI 1.53–11.50).

3.2.1. Sensitivity analyses adjusting for baseline PCL-5 scores

Because higher baseline PCL-5 scores were associated with greater PCL-5 post treatment improvement ($r = 0.62$, $p < 0.001$), we conducted sensitivity analyses to determine whether LIWC and VADER word categories remained associated with treatment response after adjusting for baseline PCL-5 scores. For LIWC analyses, all word categories—death ($\beta = 0.43$, $p < 0.001$), causation ($\beta = 0.25$, $p = 0.023$), motion ($\beta = 0.25$, $p = 0.015$), and social behavior ($\beta = -0.38$, $p < 0.001$)—remained significantly associated with greater continuous PCL-5 score improvement; baseline PCL-5 scores were also significant in this model ($\beta = 0.37$, $p = 0.001$). Both word categories—death (Wald = 5.03, $p = 0.025$; OR = 4.73, 95%CI = 1.22–18.38) and causation (Wald = 4.66, $p = 0.031$; OR = 4.47, 95%CI = 1.15–17.42)— remained significantly associated

Table 3
Stepwise linear and binary logistic regression analyses of LIWC linguistic predictors of PCL-5 score improvement from baseline to post-treatment.

	Predictors of *Continuous* PCL-5 Score Improvement				Predictors of *Reliable Change* in PCL-5 Score Improvement			
	$R^2_{adjusted}$	β	F	p	Wald	p	OR	95 % CI
Step 1	0.23		11.33	0.002				
Death words (M1)		0.51		0.002	4.46	0.035	2.60	1.07–6.32
Step 2	0.39		9.67	0.004				
Death words (M1)		0.60		<0.001	5.96	0.015	3.95	1.31–11.93
Causation words (M1)		0.43		0.004	5.03	0.025	2.92	1.14–7.43
Step 3	0.50		8.26	0.007				
Death words (M1)		0.53		<0.001				
Causation words (M1)		0.41		0.003				
Motion words (M1)		0.35		0.007				
Step 4	0.59		7.61	0.010				
Death words (M1)		0.52		<0.001				
Causation words (M1)		0.28		0.027				
Motion words (M1)		0.36		0.003				
Social Behavior words (M2)		−0.33		0.010				

LIWC = Linguistic Inquiry and Word Count.
PCL-5 = PTSD Checklist for DSM-5.
M1 = Module 1, Resource-Oriented Biographical Narratives.
M2 = Module 2, Exposure Narratives.
OR = odds ratio; 95 % CI = 95 % confidence interval.
Proportion range and mean (SD) for each of the four word categories across all 35 participants: Death words (M1) 0.0–0.69, 0.19 (0.18); Causation words (M1) 0.50–2.31, 1.07 (0.39); Motion words (M1) 1.31–2.63, 2.03 (0.33); Social Behavior words (M2) 0.91–4.49, 2.79 (0.80).

Table 4
Hierarchical linear and binary logistic regression analysis of VADER score predictors of therapy-related PCL-5 score improvement from baseline to post-treatment.

	Predictors of *Continuous* PCL-5 Score Improvement				Predictors of *Reliable Change* in PCL-5 Score Improvement			
	$R^2_{adjusted}$	β	F	p	Wald	p	OR	95 % CI
Step 1	0.13		6.26	0.018				
Negative Score (M1)		0.40		0.018	7.77	0.005	4.20	1.53–11.50
Step 2	0.29		8.09	0.001				
Negative Score (M1)		0.38		0.013	7.26	0.007	4.74	1.53–14.70
Compound Score (M2)		−0.42		0.006	3.66	0.056	0.39	0.15–1.02

VADER = Valence Aware Dictionary for Sentiment Reasoning.
PCL-5 = PTSD Checklist for DSM-5.
Compound Score = overall sentiment.
M1 = Module 1, Resource-Oriented Biographical Narratives.
M2 = Module 2, Exposure Narratives.
OR = odds ratio; 95 % CI = 95 % confidence interval.

with greater odds of reliable change in PCL-5 scores; baseline PCL-5 scores remained significant in this model (Wald = 5.03, p = 0.025; OR = 3.49, 95%CI = 1.17–10.41).

For VADER analyses, negative score ($\beta = 0.40$, $p = 0.004$) but not compound score ($\beta = -0.23$, $p = 0.11$) was associated with greater continuous PCL-5 score improvement; baseline PCL-5 scores were also significant in this model ($\beta = 0.44$, p = 0.004). Similarly, negative score (Wald = 7.57, $p = 0.006$; OR = 12.48, 95%CI = 2.07–75.35), but not compound score (Wald = 0.33, $p = 0.56$; OR = 0.69, 95%CI = 0.19–2.45), was associated with greater odds of reliable change in PCL-5 scores; baseline PCL-5 scores remained significant in this model (Wald = 6.11, $p = 0.013$; OR = 5.20, 95%CI = 1.41–19.19).

Additionally, bivariate Spearman correlation analyses were conducted to examine associations between baseline PTSD symptom severity (PCL-5 scores) and key linguistic features (LIWC and VADER) described above. No significant correlations were observed between

Table 5
Correlation matrix between baseline PCL-5 score and language categories.

	1	2	3	4	5	6	7
1. PCL-5 Baseline	1						
2. Cognition (M1)	0.06	1					
3. Death (M1)	0.213	−0.235	1				
4. Motion (M1)	0.305	−0.064	0.138	1			
5. Social Behavior (M2)	0.11	−0.377	0.083	−0.144	1		
6. Compound Sentiment (M2)	−0.315	0.066	−0.272	−0.366	0.267	1	
7. Negative Sentiment (M1)	0.027	0.191	0.386	0.395	−0.143	−0.17	1

PCL-5 = PTSD Checklist for DSM-5.
Compound Score = overall sentiment.
M1 = Module 1, Resource-Oriented Biographical Narratives.
M2 = Module 2, Exposure Narratives.

baseline PCL-5 scores and any of the linguistic variables. However, several significant associations emerged among the linguistic features themselves. Specifically, there was a negative correlation between social behavior word use in trauma narratives (Module 2) and cognitive processing word use in early narratives (Module 1; $\rho = -0.38$, $p = 0.026$). In Module 1, death word ($\rho = 0.39$, $p = 0.022$), and motion word ($\rho = 0.40$, $p = 0.019$; see Table 5) use were positively corelated with negative sentiment. These results suggest that linguistic markers of emotional tone and cognitive elaboration in early narratives are interrelated and may reflect underlying patterns of engagement with therapy.

4. Discussion

To our knowledge, this is the first study to use automated linguistic analysis to predict response to written psychotherapy among individuals with WTC-related PTSD symptoms. The modularized structure of ITT enabled us to examine how language use across distinct therapeutic phases—biographic, exposure-based, and cognitive reappraisal/integration written narratives—relates to treatment outcomes. Results revealed the utility of this analysis in predicting treatment response based on linguistic markers alone, independent of baseline PTSD symptom severity. Specifically, greater use of death, causation, and motion words in early, resource-oriented biographical narratives (Module 1), as well as lower use of social behavior words in trauma exposure narratives (Module 2), were significantly associated with greater reductions in PTSD symptoms. Negative sentiment, particularly in pre-9/11 biographical narratives, also predicted greater improvement. Collectively, linguistic features from Module 1 explained nearly 60 % of the variance in treatment response, highlighting the potential utility of patients' early language patterns as predictors of therapeutic outcome.

The predictive value of death words in Module 1 is notable, potentially reflecting decreased avoidance and ability to process existential themes, thus greater readiness for engagement in exposure-based WTC trauma narratives later in therapy. This interpretation aligns with previous work linking death-related language within expressive narrative interventions to lower avoidance symptoms (Papini et al., 2015) and PTSD symptom improvement (Margola et al., 2010). Similarly, greater use of causation words in Module 1 may suggest attempts to find meaning in previous life events, aligning with previous literature indicating the benefits of cognitive processing on overall mental health (Pennebaker, 1993; Pennebaker et al., 1997).

Motion-related words, a subcategory of "perception" in LIWC, have received limited attention in prior research but may serve as indicators of narrative coherence or engagement in storytelling. Their use may reflect an individual's capacity to organize life events into a linear and integrated autobiographical narrative. The emergence of these markers in pre-9/11 narratives suggests that early autobiographical processing may help prepare individuals for more effective engagement in trauma-focused work later in therapy.

Use of negatively valenced words measured by VADER in Module 1 (biographical narratives from birth to 9/11) predicted greater symptom improvement, while overall (compound) sentiment did not. Thus, although a higher proportion of sentences from these narratives contained negatively rated words, how they were combined and conveyed in the sentence reflected neutral sentiment. This finding, despite the association between higher use of death words and greater PTSD symptom improvement in biographical narratives, might suggest more neutral or accepting perceptions of death and negative events held by patients who showed greater improvement by post-treatment (Miller-Lewis et al., 2021). Additionally, a higher proportion of negatively valenced words early in ITT, associated with greater PTSD symptom improvement, might indicate greater affective release, an important aspect of PTSD treatment (Markowitz and Milrod, 2024; Markowitz et al., 2015).

Within Module 2, WTC trauma exposure narratives, social behavior words were associated with less improvement in PTSD symptoms, which is counterintuitive given prior studies suggest social support is generally protective in PTSD (Charuvastra and Cloitre, 2008). Although a causal explanation is not feasible, this finding could relate to the death of others experienced on 9/11 and possible survivor's guilt as an obstacle to therapeutic improvement with ITT. Alternatively, excessive focus on others during trauma narratives may reflect emotional distancing or externalization, potentially hindering internal processing. Further research is needed to evaluate factors that may mediate this association.

Taken together, the results of this exploratory study in individuals with PTSD symptoms exposed to a shared trauma contribute to an emerging literature on the potential utility of automated linguistic analysis to predict outcomes in trauma-focused psychotherapy. In our automated linguistic analyses, we considered all LIWC word categories, as our approach was exploratory, without a priori hypotheses. We also employed VADER to examine the role of sentiment in predicting treatment response. Linguistic patterns may help identify patients who would benefit from additional support during the early stages of therapy or those likely to respond to written therapy modalities such as ITT. As digital and written therapies become more common, integrating linguistic feedback into clinical decision-making could enhance the personalization of care.

This study has several limitations. First, the sample size was modest ($n = 35$), restricted to treatment completers, and included participants with either subthreshold or full PTSD at baseline (mean baseline PCL-5 score: 28.7). Second, we did not assess participants' prior therapy engagement, limiting the generalizability of findings to broader PTSD populations. Third, the absence of a control group further restricts causal inference, as we cannot determine whether the observed effects are specific to ITT or generalizable to other trauma-focused therapies. Fourth, linguistic analysis may also be detecting broad therapeutic processes—such as emotional awareness or readiness to change—rather than mechanisms unique to written exposure therapy. Fifth, reliance on the PCL-5, a self-report measure, may reduce the accuracy of outcome assessments compared to clinician-administered tools like the CAPS-5. Sixth, we used stepwise regression due to the large number of linguistic predictors, which increases the risk of type I error. Finally, the lack of pre-specified hypotheses also raises the possibility of chance findings, although several results align with previous research.

Despite these limitations, results of this study have meaningful implications. The finding that linguistic features from early therapy narratives predicted PTSD symptom improvement beyond baseline severity supports growing evidence that automated language analysis—a scalable and accessible tool for assessing psychological expression—can help forecast treatment response. Further, early linguistic indicators such as cognitive elaboration, emotional disclosure, and death-related language may serve as clinically meaningful targets for optimizing written trauma-focused interventions. Future research should employ more advanced natural language processing (NLP) techniques, recruit larger and more diverse samples, include control groups, and evaluate whether providing linguistic feedback to therapists can improve outcomes. Language use may offer a valuable complement to traditional self-report measures in tracking psychological adaptation and guiding personalized intervention strategies.

CRediT authorship contribution statement

Tomasina Leska: Writing – original draft, Visualization, Resources, Methodology, Formal analysis, Data curation. **Zoe Schreiber:** Writing – review & editing, Resources. **Eden Astorino:** Data curation. **Maya Verghese:** Data curation. **John C. Markowitz:** Writing – review & editing, Supervision. **Saren Seeley:** Writing – review & editing, Software, Data curation. **Hannah Brinkman:** Writing – review & editing, Methodology, Conceptualization. **Mary Kowalchyk:** Writing – review & editing, Data curation. **Leah Cahn:** Resources, Investigation. **Cindy J. Aaronson:** Resources, Investigation. **Maria Boettche:** Methodology,

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Declaration of competing interest

Dr. Feder is named co-inventor on issued patents in the US and outside the US filed by the Icahn School of Medicine at Mount Sinai related to the use of ketamine for the treatment of PTSD. This intellectual property has not been licensed. The other authors have no potential competing interests to report.

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