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A pilot randomized trial of a dual n-back emotional working memory training program for veterans with elevated PTSD symptoms

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ABSTRACT

Anxiety is characterized by excessive attention to threatening information, leading to impaired working memory (WM) performance and elevated anxious thoughts. Preliminary research indicates that individuals with PTSD show particular difficulty with WM in emotional contexts (Schweizer et al., 2011). Although several studies show that computerized training can improve WM capacity for anxious individuals (Owens et al., 2013; Schweizer et al., 2011; 2013), there has been very little research on WM training for PTSD or with Veterans (Saunders et al., 2015). In a pilot randomized trial, we assigned Veterans with elevated PTSD symptoms to an online emotional WM training, either adaptive (*n*-back; $n = 11$) or a less potent training (1-back; $n = 10$). Overall, both groups showed significant decreases in PTSD symptoms. The *n*-back group showed a trend of outperforming the 1-back group in improving reexperiencing symptoms (which are likely to be associated with impaired WM functioning). This population anecdotally found the intervention quite challenging, which may be why even the less potent 1-back was still helpful. These preliminary findings justify the effort for developing new WM-focused PTSD intervention for complex, vulnerable populations, particularly as online training can improve accessibility.

1. Introduction

Posttraumatic stress disorder (PTSD) affects approximately 8% of the US population and causes significant impairment (Kessler et al., 1995; Galatzer-Levy et al., 2013). PTSD is especially common among combat Veterans (Kulka et al., 1990). Behavioral treatments are considered the front-line intervention for PTSD (APA, 2017), but they are not universally effective, with some evidence indicating that Veterans in particular may not benefit as much as civilians from existing PTSD treatments (Steenkamp et al., 2015). Thus, there is a need for treatment innovation, including interventions provided out of the traditional mental health context in order to appeal to Veterans who (1) face stigma around mental health treatments (Seal et al., 2011), (2) have logistical difficulties attending in-person treatment (Hoge et al., 2004), or (3) would find more appeal in technology-based interventions (Gerardi et al., 2008). Thus, we proposed to test the feasibility of a computerized working memory (WM) training for Veterans with PTSD.

Some previous theoretical and empirical work suggests that WM plays an important role in anxiety and common comorbidities, including the anxiety and intrusive symptoms characteristic of PTSD. Elevated anxiety has been associated with inefficient filtering of threatening material from WM (Stout et al., 2015) and increased storage of task-irrelevant threat distractors in WM (Stout et al., 2013). Thus, people with high levels of anxiety may disproportionately allocate cognitive resources toward threatening stimuli, yet continue to have difficulties keeping threatening thoughts from entering into—and staying in—WM. This increase in threatening information and difficulty gating could in turn bias attention and action in the future, leading to increased intrusive anxious cognitions and to interference with ongoing behavior or task performance (Bishop, 2007). The hallmark intrusive symptoms of PTSD indicate a diminished ability to filter threatening material from WM, even when unrelated to the task at hand. Additionally, impaired WM performance has been empirically associated with dysphoria (Owens et al., 2013), emotion dysregulation (Thiruchselvam et al., 2012) and intrusive symptoms (Bomyea and Amir, 2011), all of which are part of the syndrome of PTSD. In particular, the presence of reexperiencing/intrusion symptoms is thought to reflect inadequate WM functioning in filtering out or inhibiting salient but contextually-irrelevant materials associated with traumas (Bomyea et al., 2012; Gillie and Thayer, 2014; Swick et al., 2012). Research also

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shows that individuals with PTSD have difficulty utilizing WM in emotional contexts (Schweizer et al., 2011), thus leading to difficulties in occupational and interpersonal functioning especially during times of stress.

As evidence has increased of the connection between WM impairment and poor mental health, researchers have increasingly been studying the potential for intervening to enhance WM and inhibitory control. Indeed, a recent meta-analysis of WM training interventions found 33 randomized controlled trials of WM training in healthy adults (Soveri et al., 2017). This meta-analysis found an overall effect of WM training on WM, although fewer distal improvements in outcomes were observed (and most studies were of healthy rather than clinical populations). There has been significant variability in the effectiveness of WM training in the literature. Some researchers have suggested that WM training that incorporates affective stimuli may have more potential to increase ability to utilize WM *within emotional contexts* and to improve emotion regulation (Schweizer et al., 2013), a finding that has particular relevance in a PTSD population.

Despite the possibility that computerized emotional WM training could be helpful for a Veteran PTSD population, there are very few WM studies that have specifically examined this population. In a pilot study ($n = 4$), a (non-emotional) WM training along with a transcranial direct current stimulation device led to significant improvements on a range of cognitive and emotional outcomes, along with significant neurophysiological changes in EEG recordings (Saunders et al., 2015). Specifically, the P3a event-related potential component in response to novelty stimuli, which is characteristically abnormal among individuals with PTSD, became more normalized. Participants' initially slow alpha peak frequency, which has been implicated in impaired cognitive processing, also improved after the training. In a related study, a computerized cognitive control training program based on the modified Reading Span WM tasks showed some promise in decreasing re-experiencing symptoms and improving WM functioning (as assessed by the Operational Span Task) among female adults with PTSD secondary to sexual trauma, though the mechanism of change remained unclear and the training involved non-emotional stimuli (Bomyea et al., 2015). Schweizer et al. (2017) reported that adolescents with PTSD showed improvements in PTSD symptoms and cognitive control capacity using an affective dual n-back training program as compared with a control training task (i.e., a feature match task). These findings suggest the applicability of WM training as a potential intervention for individuals with PTSD.

1.1. Current study

This pilot investigation sought to examine whether an emotional WM training can be applied to an adult sample of Veterans with PTSD (clinicaltrials.gov identifier NCT02766296). We hypothesized that an emotional *n*-back training would outperform a 1-back training in improving WM and reducing PTSD severity (particularly, re-experiencing/intrusion symptoms).

2. Method

2.1. Participants

Seventy-six veterans between ages 18 and 70 were recruited from the Milwaukee Veteran Affairs (VA), University of Wisconsin – Milwaukee, and surrounding Milwaukee region (see Fig. 1 for full study flow). Participants first completed a study consent and prescreening questionnaire. Participants moved on to a full screening if they met initial inclusion criteria: spoke fluent English, had access to a private high-speed internet connection, and scored above a 38 on the PTSD Checklist for DSM-5 (PCL-5; Weathers et al., 2013). The full screening procedure, based on the full Mini International Neuropsychiatric Interview 6.0, chart review, and self-report, assessed the following exclusion criteria: "high" suicidality, substance use disorder within the past three months, psychotic disorders, bipolar disorder (if not well managed), brain injury, neurocognitive disorder, organic mental disorder, or neurological disorder diagnosis.[1] Of the 76 participants who completed the prescreen, 21 completed the posttest session (eWM = 11 vs. cWM = 10) and comprise our final sample ($n = 21$, 5 females, age $m = 52$). The training and placebo groups did not differ significantly from each other on the PCL-5 at the pretest, $F(1, 20) = 0.586$, $p = .453$). All participants met criteria for PTSD based on the MINI.

2.2. Materials and procedure

Eligible participants were asked to complete a pretest, 15 sessions of at-home computerized training (up to 4 sessions weekly), posttest, and a one-month follow-up session. The pretest, posttest, and follow-up sessions were identical in procedures and consisted of questionnaires, attention, cognitive, and working memory tasks.

2.2.1. Self-report assessment of symptoms

The PTSD Checklist (PCL-5; Weathers et al., 2013) was used to measure participants' PTSD symptoms. It contains 20 items rated using a 5-point Likert scale (from 0(*not at all*) to 4 (*extremely*)). The main measure of PTSD severity was the total PCL-5 score, but we also examined each of the four symptom clusters: reexperiencing, avoidance, negative alterations in cognition and mood, and hyperarousal. The PCL-5 has good test-retest reliability ($r = 0.82–0.84$), good internal consistency ($\alpha = 0.94–0.96$), and good convergent and discriminant validity in samples of trauma-exposed college students and Veterans (Blevins et al., 2015; Bovin et al., 2016).

The Depression Anxiety and Stress Scale (DASS-21) was used to measure depression, anxiety, stress, and general negative affect (Lovibond and Lovibond, 1995). The DASS-21 has good internal consistency for the total score ($\alpha = 0.93$), Depression scale ($\alpha = 0.82$), Anxiety scale ($\alpha = 0.90$), and Stress scale ($\alpha = 0.93$), and good convergent and discriminant validity with other measures of anxiety and depression (Henry and Crawford, 2005).

2.2.2. WM measures

Participants completed the Automated Complex Span Tasks, which consist of three computerized span tasks measuring WM capacity (Oswald et al., 2015). In the operation span task, participants solve a series of math operations while trying to remember a set of unrelated numbers. The reading span tasks requires participants to read a set of sentences of approximately 10–15 words in length and determine if they make sense while trying to remember a set of numbers. The symmetry span task consists of a set of 8x8 matrices of black and white squares that participants must respond as either symmetrical or asymmetrical along a vertical line, while also remembering the location of a red square positioned in a 4x4 matrix. Stimuli were presented using E-Prime 2.0 (Psychology Software Tools, Pittsburgh, PA). We employed

[1] We did not use "the stability of other concurrent treatments" as an exclusion criterion because it would not be ethically justifiable to potentially discourage participants from modifying their primary treatment course when needed, given the chronic nature of their PTSD and the novelty of the current preliminary training approach. Nevertheless, a thorough chart review revealed that (a) the only 3 participants who did not receive other treatments were all in the eWMT group (which makes it more unlikely that the symptom reduction in this group would be attributable to other ongoing treatment rather than the WM training), and (b) only three participants in each group underwent some notable change in their treatment status (for eWMT – 1 started cognitive therapy and a medication (Prazosin) at the beginning of the study, 1 received an inpatient treatment after the training, and 1 received exposure therapy after the training; for cWMT – 1 increased the dose of Hydroxezine early in the study, 1 received an inpatient treatment after the training, and 1 received exposure therapy after the training).

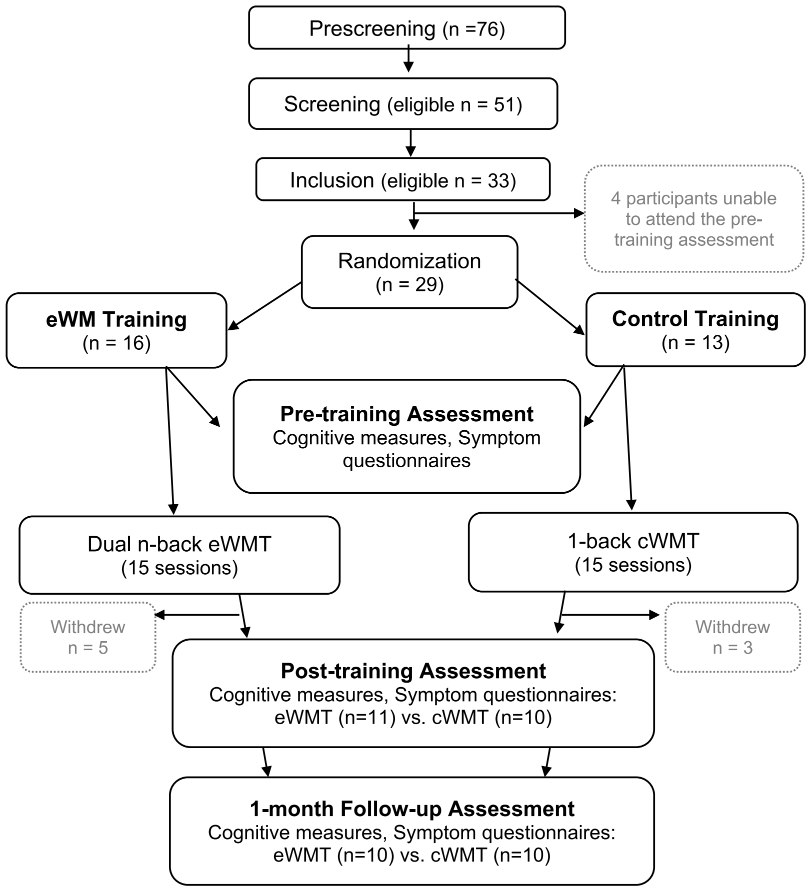

Fig. 1. The flow of the study.

the Automated Complex Span Tasks to examine whether the current WM training would display its impact on various aspects of WM functioning (i.e., operational, verbal, and spatial WM capacity) on the untrained tasks (i.e., transfer effects, see Jaeggi et al., 2010).

2.3. Computerized WM training

Following the pretest session, participants were randomly assigned to one of the two training conditions: active emotional WM training (eWMT, *n*-back) or the control emotional WM training (cWMT, 1-back). For eWMT, participants completed 15 sessions (20 min each) over a 5-week period of the Adaptive Dual *n*-Back paradigm. Participants who completed at least 80% of the trainings were considered treatment completers and administered the post-training assessment. The average number of completed training sessions were 14.9 ($SD = 0.3$) and 15.0 ($SD = 0$) for the eWMT and cWMT, respectively (no significant group difference, $t = -0.95$, $p = .35$). On a weekly basis, 3.1 (SD = 1.2) and 2.4 (SD = 0.4) sessions were completed by eWMT and cWMT, respectively. The average highest n achieved in the eWMT group was 3.00 ($SD = 1.1$) by the final session (Fig. 3). The eWMT was adopted from a study from Jaeggi et al. (2008), which involves constant updating of information stored in WM and shifting between two different modes of stimuli (visual and auditory). This version of the task utilizes eight different faces with fearful expressions (4 males and 4 females) and eight different negative words (female voice; e.g., terrible, failure, cancer, abused),[2] replacing original filled squares and consonant letters (Fig. 2).

Participants were instructed to continuously indicate with button presses whether either the face or word from the current trial matches the corresponding face or word that appeared *n*-positions ago in the block of trials. Thus, participants needed to remember both stimuli on the current trial and the *n*-position back trials in order to respond correctly. There were four trial types: face change, no word change; no face change, word change; no face change, no word change; face change, word change. For the eWMT group, each training session started at the 1-back level, and increased in difficulty by one level (2-back, 3-back, 4-back) if performance was above 95% accuracy for the given block of both modalities (faces & words), or decreased by one level if performance for that block fell below 75% accuracy. For cWMT, the training was the same except that it only consisted of the 1-back level. Performance during these blocks did not affect the difficulty and therefore did not change levels. For both training conditions, each session consisted of 20 blocks of $20 + n$ trials, including face-word pairs (e.g., 4-back, $20 + 4 = 24$ trials). Each block lasted approximately 1 min.

3. Results

3.1. Group comparisons on baseline characteristics

The *n*-back ($n = 11$) and 1-back ($n = 10$) groups did not differ on any of the demographic and clinical characteristics at baseline,

[2] Evidence exists that PTSD is characterized by difficulty in inhibiting attention toward triggers of trauma-related memories (Catarino et al., 2015) and disengaging attention from trauma-related stimuli (Pineles et al., 2009). Thus, WM-focused training is expected to be rendered most relevant and ecologically

(*footnote continued*)
valid when utilizing trauma-relevant negative stimuli. Schweizer et al. (2017) also suggest that any interventions designed to enhance cognitive control in PTSD should implement training in affective contexts.

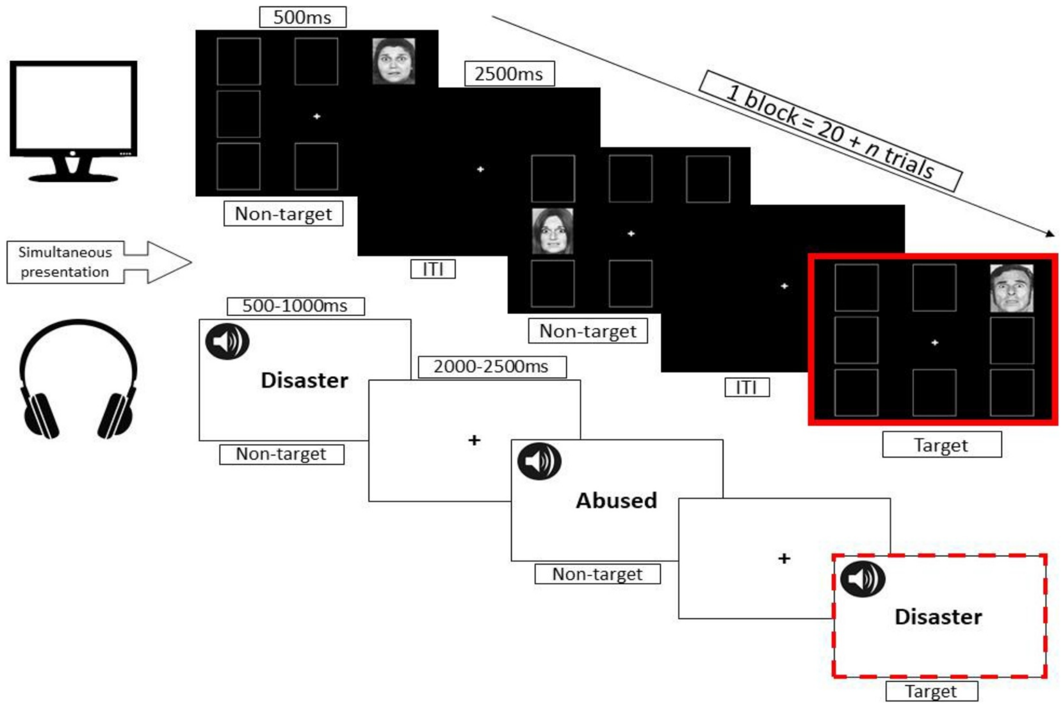

Fig. 2. Emotional dual *n*-back training. For an example, in the 2-back block, participants are asked to indicate whether the word or the location of the face in the current trial matches those two trials earlier.

including age, gender, ethnicity, race, marital status, overall severity of PTSD symptoms, general emotional distress, psychiatric diagnostic status, and working memory performance indices (see Table 1). Nearly all participants had been receiving mental health treatment for years prior to participating in the study, which is quite common among veterans with chronic PTSD symptoms.

3.2. PCL-5 symptom change over time between the two groups

To examine PTSD symptom change, we conducted a two-factor repeated-measures ANOVA: 2 Group (*n*-back vs. 1-back) by 3 Time (Pre, Post, vs. 1-month Follow-up) on the PCL-5 total scores. There was a significant main effect of Time, $F(2,36) = 12.78$, $p < .001$, partial $\eta^2 = 0.42$, indicating an overall significant reduction in PTSD severity in the current sample. However, the Time X Group interaction was not statistically significant, $F(2,36) = 0.1.57$, $p = 0.22$, partial $\eta^2 = 0.08$.[3]

The symptom reductions rates were 25% (*n*-back) vs. 24% (1-back) at post-training; and 26% (*n*-back) vs. 10% (1-back) at follow-up, as compared with baseline PTSD symptom severity. Current psychometric data suggest that a reduction of at least 10 points on the PCL-5 indicates a clinically meaningful improvement (Weathers et al., 2013). Based on that, we also compared the proportion of patients who displayed a clinically meaningful change (i.e., a minimum of 10 point reduction on PCL-5 total). At post-training, 73% ($n = 8$) in *n*-back and 60% ($n = 6$) in 1-back displayed a clinically meaningful reduction in PCL-5 total, $\chi2 = 0.38$, $p = .54$. At follow-up, 55% ($n = 6$) in *n*-back and 40% ($n = 4$) in 1-back displayed a clinically meaningful reduction in PCL-5 total, $\chi2 = 0.44$, $p = .51$. The eWMT group showed numerically higher improvement rates than the cWMT group based on the amount of PTSD symptom reduction, but the group differences did not reach statistical significance.[4]

Additionally, we examined the symptom clusters of PCL-5 separately via a series of repeated measures ANOVAs, as the WM training may particularly improve the cluster of intrusions/re-experiencing symptoms (that are thought to reflect the filtering failure of WM functioning). The main effect of Time was significant for all 4 symptom clusters (all *ps* < 0.05). The Time X Group interaction was not significant for all clusters with the exception that there was a marginally significant interaction for intrusion/re-experiencing: $F(2,36) = 3.13$, $p = .056$, partial $\eta^2 = 0.15$, indicating that there was a trend for the *n*-back group to show a greater degree of reduction in this symptom cluster compared to the 1-back group at end-point assessment (31% reduction for *n*-back vs. 7% reduction for 1-back).

To examine the specificity of the impact of working memory training on PTSD symptom reduction, we examined whether there were changes in general depression and anxiety symptoms. The mixed factor repeated measure analyses showed neither the main effect of Time nor the Time X Group interaction effect on the level of depressive symptoms

[3] We repeated the main analysis of the current study, using the intent-to-treat sample (i.e., all participants who were randomized: eWMT [n = 16] and cWMT [n = 13]) and employing the last observation carried forward (LOCF) method to handle the missing data. A mixed-factor repeated-measures ANOVA (2 Group [eWMT vs. cWMT] by 3 Time [Pre, Post, vs. 1-month Follow-up]) on the PCL-5 total scores showed an overall similar pattern of results. There was a significant main effect of Time, $F(2,54) = 11.65$, $p < .001$, partial $\eta^2 = .30$, indicating a significant overall reduction in PTSD severity, but the Time X Group interaction was not significant, $F(2,54) = 1.29$, $p = .28$, partial $\eta^2 = .05$. The mean PCL5 total scores across the baseline, post-training, and FU assessments were 54.69 (SD = 10.52), 45.31 (SD = 12.66), and 45.06 (14.00) in the eWMT group; and 50.23 (SD = 13.62), 41.00 (SD = 15.83), and 46.23 (SD = 17.81) in the cWMT group, respectively. The symptom reductions rates were 17% (*n*-back) vs. 18% (1-back) at post-training; and 18% (*n*-back) vs. 8% (1-back) at follow-up, as compared with baseline PTSD symptom severity.

[4] We computed the pre-to-post effect size with a formula ($d = \frac{|m_1 - m_2|}{\sqrt{s_1^2 + s_2^2 - (2rs_1s_2)}}$) commonly used for this type of data, to examine the magnitude of PTSD symptom reductions on the PCL-5 in our sample. For the cWMT group, the computed effect size *d* was 0.82 for pre-to-post change, and 0.31 for pre-to-FU change. For the eWMT group, the computed effect size *d* was 1.92 for pre-to-post change, and 1.70 for pre-to-FU change. Although the pre-to-post effect size can be cofounded by other non-specific factors, the observed effect size for the eWMT condition is commensurate with the overall pre-to-post effect size of psychotherapy for PTSD ($d = 1.43$) in a meta-analysis (Bradley et al., 2005).

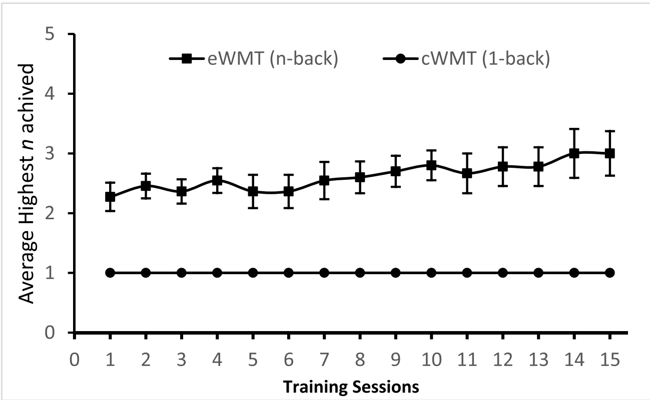

Fig. 3. Average Highest *n* Achieved across Training Sessions. Error bars indicate standard errors of the mean. The average highest *n* achieved in the eWMT group was 3.00 (SD = 1.10). The cWMT group maintained 1-back throughout the training.

for the DASS Depression or Anxiety scores (all *ps* > 0.05). The mean changes in general emotional distress were also negligible (see Table 2). Thus, the significant overall symptom reduction was observed only for PTSD after training in the current sample, not for general depressive or anxiety symptoms.

3.3. Change in working memory over time between the two groups

To examine the change in working memory indices over time by group, we conducted a two-factor repeated-measures ANOVA: 2 Group (*n*-back vs. 1-back) by 3 Time (Pre, Post, vs. 1-month Follow-up) on each of the three WM Span tasks. No significant main effects of Time or Time X Group interaction effects were observed. The means and standard deviations of those who completed all three assessment sessions are presented in Table 2 across the three assessment points.

3.4. Training progress and symptom reduction on PCL-5

We also examined whether training progress in the eWMT condition was associated with the amount of PTSD symptom reductions. The progress in training was indexed by the average of highest *N* values and mean *N* values across 15 training sessions (i.e., averaged highest *N* and average *N*). Despite the small sample size of the analysis ($n = 10$), the overall PTSD symptom reduction (from pre to FU) was correlated with the averaged highest *N* at 0.30 ($p = .20$) and with the average *N* at 0.23 ($p = .26$), indicating an overall medium-sized strength of association.

3.5. Correlations between change scores on PCL-5 and WM indices

We computed pre-to-post and pre-to-FU residual change scores for PCL-5 and WM indices to examine the association among these change scores. As shown in Table 3, pre-to-post residual change scores on the Operational Span Task (OSPAN) was significantly associated with pre-to-post residual changes scores in PTSD severity ($r = 0.52, p < .05$) and with pre-to-follow-up residual change scores in PTSD severity ($r = 0.52$, $p < .05$). A similar pattern and magnitude of associations was observed for the eWMT group (*r* between pre-post residual changes in the PCL5 total and pre-post residual changes in the OSPAN = 0.54 ($p = .09$); and *r* between pre-FU residual changes in the PCL5 total and pre-post residual changes in the OSPAN = 0.52 ($p = .12$)) and the cWMT group (*r* between pre-post residual changes in the PCL5 total and pre-post residual changes in the OSPAN = 0.52 ($p = .12$)); and *r* between pre-FU residual changes in the PCL5 total and pre-post residual changes in the OSPAN = 0.55 ($p = .10$), respectively. These findings

Table 1
Baseline demographic and clinical characteristics.

	N-Back ($n = 11$)		1-Back ($n = 10$)		*t*-test / χ2	*p*
	Mean	*SD*	Mean	*SD*		
Age	53.18	12.17	52.40	13.37	0.14	0.89
Gender (% Male)	82% (*n* = 9)		70% (*n* = 7)		0.40	0.53
Ethnicity (% Hispanic)	0% (*n* = 0)		0% (*n* = 0)		n.s.	
Race					2.33	0.51
White	45% (*n* = 5)		60% (*n* = 6)			
African American	45% (*n* = 5)		20% (*n* = 2)			
Native American	0% (*n* = 0)		10% (*n* = 1)			
Multiracial	9% (*n* = 1)		10% (*n* = 1)			
Education					1.82	0.61
Some High School	0% (*n* = 0)		10% (*n* = 1)			
Some College	64% (*n* = 7)		50% (*n* = 5)			
Bachelor's Degree	27% (*n* = 3)		20% (*n* = 2)			
Master's Degree	9% (*n* = 1)		20% (*n* = 2)			
Marital status					1.29	0.53
Never married	18% (*n* = 2)		10% (*n* = 1)			
Married	45% (*n* = 5)		70% (*n* = 7)			
Divorced/Annulled	36% (*n* = 4)		20% (*n* = 2)			
PCL-5	54.00	12.06	50.00	11.84	0.77	0.45
DASS-21	66.91	23.87	52.20	23.99	1.41	0.18
Psychiatric diagnosis						
MDD	72.7% (*n* = 8)		50.0% (*n* = 5)		1.15	0.28
Panic disorder	81.8% (*n* = 9)		50.0% (*n* = 5)		2.39	0.12
Social phobia	45.5% (*n* = 5)		20.0% (*n* = 2)		1.53	0.22
Specific phobia	18.2% (*n* = 2)		50.0% (*n* = 5)		2.39	0.12
OCD	18.2% (*n* = 2)		20.0% (*n* = 2)		0.01	0.92
PTSD	100% (*n* = 11)		80.0% (*n* = 8)		2.43	0.12
GAD	36.4% (*n* = 4)		20.0% (*n* = 2)		0.69	0.41
RSPAN_Partial	16.91	4.13	17.10	5.92	−0.09	0.93
SSPAN_Partial	9.09	5.89	9.90	4.31	−0.36	0.73
OSPAN_Partial	16.45	8.62	11.90	6.81	1.33	0.20

Note. PCL-5 = PTSD symptom checklist (ver 5); DASS-21 = Depression, anxiety, and stress scales. RSPAN = Reading span task; SSPAN = Symmetry span task; OSPAN = Operation span task.

Table 2
Means and standard deviations of outcome measures across pre, post, and follow-up assessments.

		N-Back (n = 10)		1-Back (n = 10)	
		Mean	*SD*	Mean	*SD*
PCL-5	Pre	54.40	12.63	50.00	11.84
	Post	40.90	12.11	38.00	13.56
	FU	40.50	14.21	44.80	17.50
DASS-D	Pre	24.22	11.51	17.00	7.90
	Post	21.33	12.17	19.80	9.31
	FU	23.33	13.38	21.00	12.45
DASS-A	Pre	15.60	11.96	19.11	10.25
	Post	16.60	11.74	18.44	10.81
	FU	18.40	12.10	20.67	12.92
DASS-S	Pre	19.60	7.71	23.78	10.17
	Post	22.00	8.69	20.44	10.04
	FU	26.20	8.61	24.89	11.19
SSPAN	Pre	10.00	5.33	9.90	4.31
	Post	12.90	5.61	9.10	4.77
	FU	8.40	4.90	8.00	3.80
OSPAN	Pre	17.00	8.88	11.90	6.81
	Post	18.10	9.15	16.20	10.72
	FU	16.80	7.71	17.50	10.78
RSPAN	Pre	17.20	4.24	17.10	5.92
	Post	18.30	6.53	14.60	6.36
	FU	17.90	6.52	16.30	8.98

Note. OSPAN = Operation span task; RSPAN = Reading span task; SSPAN = Symmetry span task.

indicate that in the current study sample, the improvement in WM capacity as assessed by the OSPAN task is positively associated with the improvement in overall PTSD symptom reductions (Fig. 4). However, residual change scores on the RSPAN and SSPAN were not correlated with changes in PTSD severity.

4. Discussion

This pilot randomized trial sought to examine the application of a dual emotional *n*-back paradigm as a potential clinical intervention for Veterans displaying elevated PTSD symptoms, in comparison with emotional dual 1-back training. This is a timely, and clinically significant research topic: considering existing WM training findings (Schweizer et al., 2013; Soveri et al., 2017), there is growing evidence supporting the use of a WM training intervention, even in a population with significant complexity and comorbidity (Saunders et al., 2015).

Table 3
Pearson correlations among residual change scores of the PCL and WM span tasks.

	PCL5[P]	OSPAN[P]	RSPAN[P]	SSPAN[P]	PCL5[F]	OSPAN[F]	RSPAN[F]
OSPAN[P]	**.52*** (0.02)						
RSPAN[P]	0.14 (0.55)	0.34 (0.13)					
SSPAN[P]	0.13 (0.58)	0.18 (0.44)	0.36 (0.10)				
PCL5[F]	.89** (0.00)	**.52*** (0.02)	0.25 (0.29)	0.20 (0.40)			
OSPAN[F]	0.28 (0.23)	.64** (0.00)	0.39 (0.09)	0.27 (0.24)	0.23 (0.32)		
RSPAN[F]	0.17 (0.48)	0.41 (0.07)	.71** (0.00)	0.17 (0.47)	0.14 (0.56)	.46* (0.04)	
SSPAN[F]	−0.03 (0.89)	0.32 (0.17)	0.18 (0.46)	.51* (0.02)	0.00 (0.98)	0.21 (0.37)	0.18 (0.45)

Note.
[P] Pre-to-post residual change scores;
[F] pre-to-follow-up residual change scores; OSPAN = Operation span task; RSPAN = Reading span task; SSPAN = Symmetry span task.

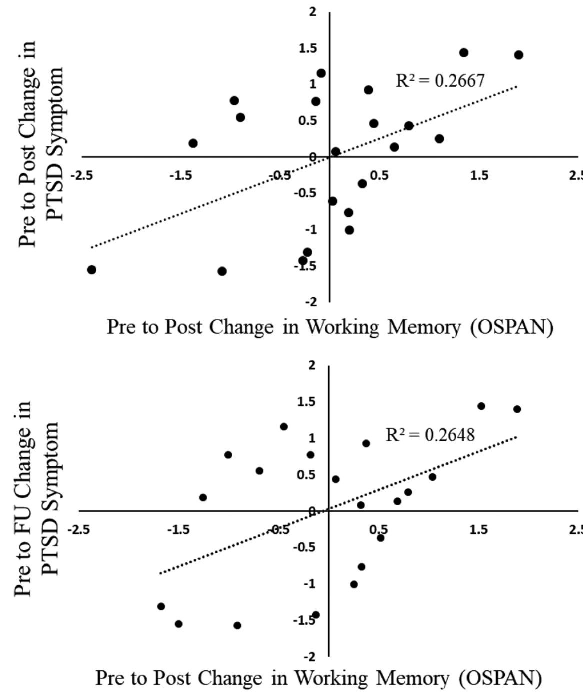

Fig. 4. The association between improved working memory and improved PTSD symptoms. For the entire study sample, pre-to-post residual change scores on the operational span task (OSPAN) was significantly associated with pre-to-post residual changes scores in PTSD severity (r = 0.52, $p < .05$) and with pre-to-follow-up residual change scores in PTSD severity (r = 0.52, $p < .05$).

Overall, contrary to hypotheses, we did not find a significant difference in the improvement of PTSD symptoms or WM indices between the *n*-back and 1-back training groups. However, there are important aspects of the findings that deserve further discussion. First, we observed an overall significant and sizable reduction in PTSD symptoms in both groups. Overall, 73% in *n*-back and 60% in 1-back groups displayed a reduction of 10 points or greater on the PCL total scores at post-training (which is considered a clinically meaningful change on this measure; Weathers et al., 2013), and 55% in *n*-back and 40% in 1-back also displayed a clinically meaningful level of symptom reductions at 1-month follow-up. It is interesting to note that improvements in PTSD were observed in both training groups, especially in the 1-back group, which was employed as a minimally-effective control condition. Anecdotally, our participants found both the 1-back and the *n*-back interventions quite challenging (in comparison to student populations undergoing a similar intervention at a partnering university). Thus, it may be that in this population, even the 1-back condition was challenging enough to produce detectable training effects on PTSD symptom reduction. Thus, future studies may need to systematically examine the level of training difficulties for the Veteran population suffering from PTSD symptoms by adapting the current *n*-back and 1-back training programs to optimize the training intensity of *n*-back and show a differentiation from a less effective control condition. Taken together, considering the observed reductions in PTSD symptoms, the *n*-back or 1-back programs may be further developed and refined to function as a clinically useful intervention tool.

Second, it is encouraging to see that the *n*-back condition marginally outperformed the 1-back control condition in improving reexperiencing symptoms, as this symptom cluster was theorized to be the most relevant training target of the WM-focused intervention. Thus, the current study offered useful pilot data suggesting that *n*-back training can yield its clinical impact by primarily reducing reexperiencing symptoms (which are highly likely to indicate the presence of impaired WM functioning and consequent experiences of mental intrusions).

Consistent with our findings, a recent PTSD study for computerized cognitive control training (Bomyea et al., 2015) produced quite similar results: (a) training significantly reduced re-experiencing PTSD symptoms with no effect on avoidance or arousal symptoms, (b) training improved WM functioning as assessed by the Operational Span Task, and (c) training's effect was not observed on general depression or anxiety symptoms. Taken together, our findings add to the emerging literature suggesting that WM or cognitive control-focused training may be developed as a potentially effective intervention for PTSD.

Despite these findings, the current pilot investigation has several limitations. First, the current preliminary study was focused on testing the feasibility and applicability of the *n*-back training using a small sample of veterans with PTSD, and thus was not sufficiently powered. Nevertheless, the numeric pattern and effect size of the observed symptom reductions indicate that continuing research using a more diverse and larger clinical sample with PTSD is warranted to examine the efficacy of the affective WM-focused cognitive intervention for this debilitating disorder.

Second, the two training groups did not produce significant differences in the WM indices, as assessed by the span tasks, although they were the primary cognitive outcomes. It is possible that the Automated Complex Span Tasks were not sufficiently sensitive or directly relevant to detect the change in WM functioning induced by the *n*-back training for the current study sample. It is imperative for future studies to address which WM measures are (a) sensitive to changes in WM functioning, (b) sensitive to the training effects produced by the *n*-back paradigm, and (c) relevant for WM functioning impairments associated with PTSD symptomatology. This is a crucial issue to address in this line of investigations, as the *n*-back paradigm may yield its training effects on inhibitory control or filtering abilities (rather than WM capacity; Owens et al., 2013; Sari et al., 2016), which the Automated Complex Span Tasks would not be able to capture sensitively.

Third, given the PTSD symptom reduction observed in both groups, we cannot exclude the possibility that the observed effects were driven by WM-irrelevant non-specific factors. For instance, improvements may be related to factors such as spontaneous recovery (though this is unlikely given the chronicity of PTSD and long-term nature of treatment in our sample), attention from the investigation team, or habituation due to repeated exposure to trauma-related material over the course of the study. Further, although emotional WM training is theoretically more relevant for PTSD due to its emphasis on emotion regulation (Badour and Feldner, 2013; Ehring and Quack, 2010; Klemanski et al., 2012), we cannot rule out the possibility that the observed effects were merely due to WM training per se regardless of its affective valence. Our study design does not allow us to draw a definitive conclusion as to the role of the affective component of the current WM training due to the lack of a control group based on non-affective stimuli. Thus, future studies need to examine the impact of affective *n*-back training while employing more rigorous control groups that can address these non-specific/non-emotional contextual or training factors (e.g., no-treatment assessment-only group, WM-*irrelevant* general cognitive training, or non-emotional WM training).

It should be noted that some of our data (i.e., moderate correlation between training progress in eWMT and PTSD symptom reduction, and large correlation between changes in OSPAN performance and PTSD symptom reduction) hint at the possibility that the PTSD symptom reduction in the context of *n*-back training may be related to the change in working memory-related processes. It is beyond the scope of the current feasibility study to examine the mediational mechanism of the emotional working memory training as a potential intervention for PTSD. Much research is needed to adequately understand the mechanism of change for this intervention, and how to utilize such technology-based interventions in the most helpful way for those with PTSD.

Finally, there was no formal assessment of training adherence to determine whether participants followed training instructions while staying focused. However, considering the nature of dual *n*-back training (which demands intensive effort and attention to progress to the next, more difficult level), our training progress data (i.e., eWMT achieved $n = 3.00$ by the final session) indirectly indicate that our participants put forth a reasonable level of effort with a good understanding of training instructions. Nevertheless, future investigations need to incorporate a formal assessment of training adherence to evaluate whether the intervention is implemented with its full potency and methodological rigor.

Despite the limitations, the observed PTSD symptom reduction in the current study sample points to the potential clinical utility of the emotional *n*-back training as a novel computerized cognitive intervention for PTSD symptoms. These preliminary findings justify the effort for developing a new WM-focused PTSD intervention for complex, vulnerable populations, particularly as online trainings can improve accessibility.

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