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Reading the mind in the eyes in PTSD: Limited Moderation by the presence of a service dog

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ABSTRACT

Persons with posttraumatic stress disorder (PTSD) frequently experience relationship failures in family and occupational domains resulting in loss of social supports. Prior research has implicated impairments in social cognition. The Reading the Mind in the Eyes Test (RMET) measures a key component of social cognition, the ability to infer the internal states of other persons based on features of the eyes region of the face; however, studies administering this popular test to persons with PTSD have yielded mixed results. This study assessed RMET performance in 47 male U.S. military Veterans with chronic, severe PTSD. Employing a within-subjects design that avoided selection biases, it aimed specifically to determine whether components of RMET performance, including accuracy, response latency, and stimulus dwell time, were improved by the company of a service dog, an intervention that has improved social function in other populations. RMET accuracies and response latencies in this PTSD sample were in the normal range. The presence of a familiar service dog did not improve RMET accuracy, reduce response latencies, or increase dwell times. Dog presence increased the speed of visual scanning perhaps consistent with reduced social fear.

1. Introduction

Social cognition and related constructs such as theory of mind and mentalizing capture aspects of the individual's ability to infer the mental states, motivations, and future behaviors of others. Adequate social cognition promotes beneficial relationships with romantic partners, children, peers, and supervisors. Relationship failures such as estrangement from partners and children, and conflicts with supervisors and peers, have been documented in persons with posttraumatic stress disorder (PTSD; reviewed in Rodriguez et al., 2012), raising the possibility that deficits in this domain may erode social supports and so contribute to the maintenance of the disorder. In their meta-analytic review, Stevens and Jovanovic (2019) concluded that PTSD is associated with "a consistent large deficit in social cognitive performance" (p.1. See also Plana et al., 2014). The largest group of controlled experimental studies these authors considered employed facial emotion recognition tasks. Among the latter, the most common was the Reading the Mind in the Eyes Test (RMET) developed by Baron-Cohen for the assessment of social cognition in Autism Spectrum Disorder (ASD: Baron-Cohen et al., 1997; Baron-Cohen et al., 2001). The goal of this study was to test the impact of intensive, extended contact with a service dog, an intervention which has yielded improvements in social function, on RMET performance in veterans with PTSD.

The RMET is comprised of 36 black-and-white photographs of silent film actors cropped to reveal only the eyes regions. Approximately half of the pictures represent females, though some are ambiguous as to sex/gender. All are relatively light-skinned, and none represent African, Asian, or Pacific Islander races. A range of adult ages are included. Each photograph is accompanied by four printed words describing internal states. Subjects are asked to select the word best describing the state conveyed by the eyes image. In Baron-Cohen et al. (2001), the ASD sample correctly identified approximately 60% of internal states while control subgroups correctly identified 75–80%. The task is easy to administer and engaging. Higher scores have been associated with empathy (Gonzalez-Liencres et al., 2013) and cooperation (Paal and Bereczkei, 2007; Woolley et al., 2010). In addition to ASD, lower scores

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have been associated with schizophrenia (Joseph Fortuny et al., 2020) and bipolar disorder (Espinos et al., 2018). Better RMET performance has also been associated with older age, female gender, and higher education, and white ethnicity (Dodell-Feder et al., 2020).

The RMET is aligned with research identifying the eyes region of the face as carrying critical information regarding affective state, especially negatively-valenced states (Schurgin et al., 2014). An overlapping literature indicates that the amygdala, possibly via dense interconnection with the face-processing region in the fusiform gyrus (Di et al., 2017; Gschwind et al., 2012), drives attention to the eyes when assessing fear and complex "social" emotions such as "flirtatiousness" (Adolphs, 2008; Adolphs et al., 2002, 2005). Direct evidence of involvement of the amygdala in RMET performance was provided by Shaw et al. (2005) who observed that participants with focal right amygdala lesions were impaired on the RMET relative to those with amygdala-sparing lesions and controls. Rice et al. (2014) found that right amygdala volume (assessed with Freesurfer v5, Fischl et al., 2002) was positively correlated with accuracy on RMET items categorized as "affective" but not those categorized as "cognitive".

Modified amygdala function is implicated in PTSD (Etkin and Wager, 2007; Hayes et al., 2012; Liberzon and Phan, 2003; Pitman et al., 2001), and "fearful faces" have been shown to induce exaggerated amygdala activations in persons with this diagnosis (Armony et al., 2005; Killgore et al., 2014; Rauch et al., 2000; Shin et al., 2005; Simmons et al., 2011). While suggesting that face processing could be modified in PTSD, the evidence reviewed above does not yield a clear prediction regarding directionality and published results have been inconsistent. Schmidt and Zachariae (2009) compared 32 Bosnian refugees with and without PTSD and observed that the former were correct on only 53% of trials, an accuracy level even lower than the ASD samples studied by Baron-Cohen et al. (2001). Bosnian-speaking controls performed in the normal range with 70.5% correct responses. Mazza et al. (2012) made a similar observation in 35 military police with and without PTSD exposed to combat in Iraq. Participants diagnosed with PTSD correctly matched targets on only 47% of trials, whereas controls were correct on 75%. In contrast, Nietlisbach et al. (2010) compared 16 non-treatment-seeking persons with full or partial PTSD to 16 controls and found no significant group difference (67% vs 75%). Nazarov et al. (2014) compared 31 women with PTSD secondary to childhood abuse to 20 controls and also found no effect of diagnosis on accuracy (rates were unreported). Shu et al. studied 32 U.S. military veterans with PTSD differing in comorbid mild traumatic brain injury (mTBI). Both groups scored in the normal range (PTSD-mTBI, 71%; PTSD + mTBI, 73%).

There is evidence that engagement with a service dog can improve social function in psychiatrically-compromised patients. Such findings have been observed in persons with ASD (Tseng, 2022), with PTSD (Whitworth et al., 2019), in residents of nursing homes (Fick, 1993; Filan and Llewellyn-Jones, 2006; Thodberg et al., 2016) and in mixed psychiatric inpatients (Virues-Ortego et al., 2012). O'Haire and Rodriguez (O'Haire and Rodriguez, 2018) reported improved social function in veterans with PTSD engaged with service dogs on PROMIS measures, *Ability to Participate in Social Activities*, *Social Isolation,* and *Companionship*. The mechanism(s) underlying such effects are unknown. One proposal in the case of ASD is that dogs present a "less complex" social target with behavioral generalization leading to increased interaction with humans (Dollion et al., 2021). Face-to-face interactions and the interpretation of facial emotion are key components of social function and are predicated on attention to faces. Intranasal oxytocin restores attention to faces in ASD (Kanat et al., 2017; Quintana et al., 2017), and improves RMET performance in ASD (Anagnostou et al., 2012), and in normals (Domes et al., 2007; but see Radke and de Bruijn, 2015). Such effects may be moderated by baseline oxytocin (Parker et al., 2017) (See also Bartz et al., 2019). Reduced baseline oxytocin as has been demonstrated in some PTSD samples (Frijling et al., 2015) but not others (Engel et al., 2021). There is some evidence that extended canine contact is associated with elevation of oxytocin, at least in volunteers for a study including this manipulation (Odendaal, 2000). Nagasawa et al. (2015) provided evidence that an oxytocingergic mechanism may mediate mutual gaze between a dog owner and their dog, with higher levels of circulating oxytocin associated with extension of gaze.

Among the relationships between PTSD and the neurobiology of social cognition just reviewed, there are many junctures in need of exploration. The particular goal of this study was to assess whether engagement with a service dog improved RMET performance in a sample of PTSD patients. Performance measures collected included accuracy, response latency, and stimulus dwell time. The presence of a service dog was predicted to increase accuracy, reduce response latency, and increase dwell time. Accuracy and response latency are ubiquitous performance measures. We included dwell time based on an assumption that sustained attention to a facial stimulus aligns with better social cognition. Finally, we considered the rapidity of visual scanning of the stimuli. Interest in this measure was driven by the results of Xia et al. (2020) who observed that healthy control subjects decreased visual scan path length when viewing a fear-conditioned stimulus of constant duration, a finding attributable to longer fixations. In the current context of variable dwell times, decreased scan path length corresponded to the slowing of visual scanning speed (scan path length divided by time). Woodward et al. (2017) observed, in a subset of the current sample, that service dog contact reduced attentional bias to angry faces, suggesting that reduction of social fear could be an alternative avenue by which the presence of a service dog might improve social function. The presence of a service dog was therefore predicted to increase the speed of visual scanning of the eyes region stimuli.

PTSD is a heterogeneous disorder, and phenotypic variation within the PTSD sample was also of interest. In particular, our own work and that of others has highlighted the importance of comorbid major depression disorder (MDD) in moderating a range of findings in PTSD (Kennis et al., 2013; Nijdam et al., 2013; Woodward et al., 1996; Yuan et al., 2019). Comorbid MDD and dysphoria have also been shown to moderate RMET performance in surprising ways. Harkness et al. (2005) reported that dysphoric college students were significantly *more* accurate on the RMET than non-dysphoric students. Harkness et al. (2010) observed, in a sample with remitted MDD, that a positive mood induction *reduced* RMET accuracy. In light of these findings, the presence/absence of comorbid MDD was included when modeling RMET outcomes. Finally, the affective/cognitive categorization demonstrated by Rice et al. (2014) to be associated with amygdala volume was included as a predictor in light of the prominent role amygdala function is thought to play in PTSD.

2. Methods

2.1. Participants and setting

Testing took place from April 2015 to September 2019. Participants were 47 male U.S. military veterans representing all branches, especially the U.S. Army and Marine Corps. They were engaged in residential treatment for service-related PTSD at the Trauma Recovery Program (TRP), VA Palo Alto Health Care System (VAPAHCS). The TRP delivered, in broad sequence, psychoeducational and treatment-readiness interventions, evidence-based PTSD treatments, and case-management preparatory to discharge. A typical length of stay was 90 days. Patients could also engage in adjunctive interventions such as a service animal training intervention (SATI). Through the SATI, patients supplied early training/socialization to purpose-bred service dogs supplied by a non-profit organization, Paws for Purple Hearts (PHH), under the supervision of professional trainers. The dogs were service-dogs-in-training rather than fully-trained PTSD service dogs. To enroll in the SATI, patients had to obtain TRP staff approval which required engagement in residential PTSD treatment, relative behavioral stability, and low fall risk. PPH staff approval was based upon appropriate interaction with the dogs during preliminary training. After recruiting from among patients who had been approved for the SATI program, the current study applied further exclusions for acute somatic disease, psychosis or mania, greater than mild traumatic brain injury (TBI), and use of medication which could constrain heart rate responses (not considered here).

2.2. Study procedures

Study participants underwent psychodiagnostic assessments within two weeks of admission, then waited approximately six weeks to be matched with their service dog. At that time, ecological momentary assessments (EMA) and ambulatory electrocardiography (ECG) were initiated (Woodward et al., 2021). Participants returned to the lab for weekly testing sessions that took place on a Thursday or Friday with the result that participants had spent most of the preceding three or four days with (or without) the continuous company of their service dog. The RMET required 10 min and was administered first in a sequence of five tasks that included two attention bias tasks (cf. Woodward et al., 2017), a startle assessment, and either a math stressor or the Cyberball task (Williams and Jarvis, 2006). Testing lasted approximately 1 h. Sensors were applied allowing collection of ECG, respiratory movement, corrugator electromyogram, and electrodermal activity measured across the distal phalanges of the non-dominant hand. (These sensors were necessary for assessments performed later in the testing session and not reported here.) Participants were then seated in a comfortable chair in the testing chamber approximately 100 cm from a 58 cm (diagonal) computer monitor. Calibration of eye tracking, described in detail below, required five to 10 min. When present, the service dog lay on the floor next to the participant and, in most cases, slept throughout the session. Written instructions were provided on the computer monitor prior to each task with an investigator present to answer questions. The RMET instructions were as follows. *"During this task you will see sets of eyes on the screen. Underneath the eyes will be four words. Choose which word best describes what the person in the picture is thinking or feeling. You may feel that more than one word applies, but please choose the word you think best. Be sure to read all four words. When you have chosen, say the word out loud."*

2.3. Psychiatric assessment

Selected psychiatric diagnoses were assessed via the Structured Clinical Interview for DSM-5 (SCID-5; First et al., 2014), the Clinician Administered PTSD Scale for DSM-5 (CAPS-5; Weathers et al., 2013), and the Brief Traumatic Brain Injury Screen (BTBIS; Schwab et al., 2005). The SCID-5 is the gold-standard structured psychiatric interviewed designed to determine psychiatric diagnoses corresponding to the Diagnostic and Statistical Manual of Mental Disorders, 5th Edition (American Psychiatric Association, 2013). The CAPS-5 is a structured clinical interview corresponding to and expanding upon the DSM-5 PTSD nosology. BTBIS is a three-item screening assessment of originating injury, acute alterations of consciousness, and persisting sequelae. It has been judged "overly inclusive" in identifying traumatic brain injury (National Academies of Sciences Engineering and Medicine Health and Medicine Division Board on Health Care Services Committee on the Review of the Department of Veterans Affairs Examinations for Traumatic Brain Injury, 2019), a bias compatible with its use as an exclusionary screener.

2.4. Reading the mind in the Eyes Test

As described above, the conventional RMET employs cards containing the eyes region photographs with stimulus words presented at the four corners of those photographs and is untimed. In addition to presentation of the eyes images on a computer monitor, two modifications were introduced for this study. First, the eyes region photographs were initially presented for 6 s without the stimulus words to provide an opportunity to assess attention to the eye stimuli in the absence of verbal cues (hereafter, the "pre-task" period). The subsequent "task" period during which words were also presented lasted 8 s. Response latency was determined by the onset of the verbal response. Second, the four words were arrayed in a line beneath the photographs rather than at the corners. This obviated the need for a participant's gaze to transit the photographs in order to read the words, reducing ambiguity in the measurement of dwell time.

Fig. 1 pairs a presentation version and a review version of an RMET stimulus with the latter overlayed with the eye tracking results of a single participant. Eye-region stimuli were 22 by 7.5 cm, or approximately 12.5×4.3 degrees of visual angle, far exceeding foveal scope and so requiring scanning saccades (Atkinson and Smithson, 2020). Words were 0.5 cm in height and presented in Arial typeface. Participants responded verbally; their responses were digitally recorded at 22 kHz; and response accuracies and latencies scored off-line. If a participant did not respond within 8 s of the appearance of the words, the trial was scored as incorrect and the response latency was scored as missing. Six orderings of the RMET stimuli were employed, with participants

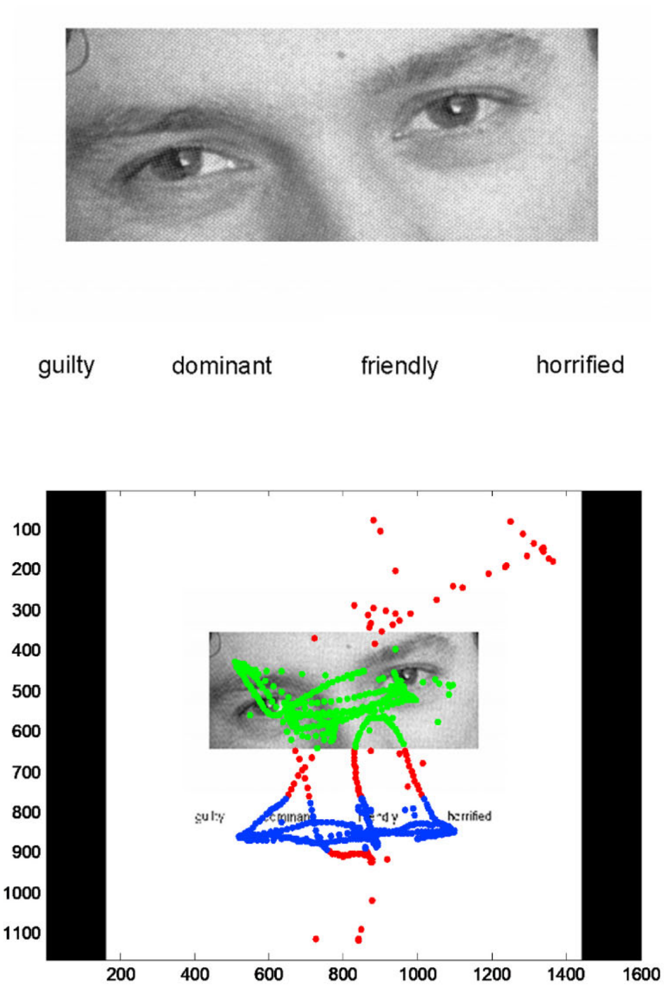

Fig. 1. An example RMET stimuli accompanied by a review version demonstrating the gaze tracking of one participant viewing that stimulus. The color coding of tracking samples indicates the boundaries of the regions defined *a priori* as representing eyes region attention (green) and word region attention (blue).

viewing a different order in each session. This manipulation decoupled fatigue and practice effects from stimulus characteristics such as valence. Stimulus presentation and the digitization of verbal responses were performed using ePrime.[1]

As described above, researchers employing the RMET have found it useful to consider stimulus factors such as item difficulty and valence when interpreting their results. As reviewed by Hudson et al. (2020), stimulus valence has proven illuminating in studies of mood-disordered samples such as the current sample many of whom met criteria for comorbid major depressive disorder (MDD). This study used the dimensional valence ratings of the RMET stimuli developed by Hudson et al. (2020) who averaged the categorical ratings (of the images/target word compounds) provided by 200 undergraduates. An "affective/cognitive" categorization was developed by Rice et al. (2014) for their studies of relations between RMET performances and lateralized amygdala volumes. The affective category included target words "accusing", "defiant", "desire", "despondent", "distrustful", "flirtatious", "friendly", "hostile", "insisting", "nervous", "playful", "regretful", "suspicious", "uneasy", and "upset", while the cognitive category included "anticipating", "cautious', "concerned", "confident", "contemplative", "decisive", "doubtful", "fantasizing", "interested", "pensive", "preoccupied", "reflective", "sceptical", "serious", "tentative", "thoughtful", and "worried".

2.5. Eye tracking

The eye tracking apparatus (facelab™, Seeing Machines, Canberra, Australia) used two infra-red (IR) cameras mounted in front of the computer display. The calibration process established the best tracking mode for a participant (mote vs iris boundary) and the locations of facial and ocular landmarks allowing the triangulation of gaze direction. Calibration culminated with the participant tracking a moving target on the stimulus display monitor enabling verification of tracking accuracy. Typical error at the end of calibration was less than one degree of visual angle. Per session aggregated eye tracking was reviewed off-line blind to stimulus characteristics and dog presence. This review disclosed a number of sessions in which eye tracking had failed partially or completely. This typically occurred with participants with light-colored blue or gray eyes resulting in low contrast under IR illumination, a known liability of eye tracking systems (Hessels et al., 2015). Accordingly, the following quantitative eye tracking quality criteria were imposed prior to analyzing dwell times and scanning speeds. Consistent with published data on the lower limits of dwell time required to identify basic facial emotions, a minimum of 200 msec of contiguous-in-time, within-target gaze samples were required in order to register a dwell time. Pre-task and task (eyes region) dwell times were then summed per trial, assuming that participants could perform the task by inspecting the eyes region during either period exclusively. The proportion of trials in which total pre-response, eyes region dwell times fell below 200 msec was calculated, with 61 sessions retaining fewer than 80% of such trials were excluded. No participants were lost as a result of these exclusions. Missing trials were not imputed because the source of missingness, whether due to true inattention or recording failure, could not be determined.

Manual review of eye tracking also sometimes revealed that the centroid of eye movements aggregated over trials was displaced in the vertical dimension, error attributable to drift in participants' postures in the anterior-posterior dimension between calibration and task performance. Accordingly, constants were added to or subtracted from the coefficients capturing vertical gaze so that the centroids of aggregated movements overlapped the facial and verbal domains of the stimuli (which were invariant over trials). This adjustment was performed blind to dog presence/absence and, as it employed aggregated trials only, conferred no bias relative to other predictors of visual attention to the RMET stimuli. The sampling rate of gaze detection was 60 Hz so that the dwell time within the aforementioned regions could be calculated by summing the number of 16.67 msec sample periods falling within them. Fixations and saccades were not distinguished. The strict restriction of "on-target" gaze to the eyes and word regions as described was consistent with the rapid fall-off of facial emotion detection (Smith and Rossit, 2018) and word reading (Legge et al., 2001) outside of central vision.

2.6. Analytic plan

Statistical analyses were performed in SPSS v24 and R v4.0.3. Linear and binary logistic mixed effects modeling was performed using the lme4 package (Bates et al., 2015). Predictors included in all models were trial (1–36) and session number (1–6), and a proxy for amount of inpatient treatment (participation beginning before or after 50 days post-admission, the midpoint of hospitalization duration for the sample). Comorbid MDD was included as a measure of dysphoria over and above PTSD. Item valence (Hudson et al., 2020), the affective/cognitive factor (Rice et al., 2014), comorbid MDD, and the presence of a service dog were also tested as well as their two-way interactions. All models included a random intercept capturing inter-subject variability in mean outcomes and other unmeasured covariates. Continuous predictors were standardized and centered. Correct/incorrect responses were complete. The correlation between the valence and affective/cognitive factors was rho = 0.31, indicating less than 10% shared variance in this sample. Accordingly, they were considered as independent predictors. A small number of response latencies (4%) and a moderate number of dwell times (pre-task: 19%; , task, eyes regions: 22%, task, word regions: 33%) were missing due to recording system malfunctions. Missing data were treated as MCAR and imputed using the Multiple Imputation by Chained Equations (MICE) package in R (van Buuren and Groothuis-Oudshoorn, 2011). Though eyes image and word dwell times during the task period were expected to be negatively correlated, the actual correlation was rho = −0.07 indicating that these variables shared negligible variance. Hence, they were also analysed independently.

3. Results

3.1. Study sample

Table 1 presents demographic and psychometric measures by MDD group. The only differences between participants with and without comorbid MDD were in CAPS total severity score (higher in PTSD + MDD) and lifetime SUD (more prevalent in PTSD-MDD). The racial/ethnic distribution was representative of the VA patient population. All participants met criteria for PTSD and had experienced deployment-related trauma. All participants were free of moderate to severe TBI. Across the sample, prescribed medication use was as follows: specific serotinergic reuptake inhibitors/serotonin-norepinephrine reuptake inhibitors, 74%, anticonvulsant/mood stabilizers, 43%, alpha-1 noradrenergic antagonists, 26%, opioid antagonists, 22%, atypical anti-psychotics, 17%, trazodone, 17%, mirtazapine, 17%, opioids, 13%, anxiolytics, 13%, tricylic antidepressants, 4%, and buproprion, 4%.

3.2. Accuracy

Grand mean accuracy over all participants and sessions was 71%. (All fixed effects and confidence intervals are provided in Supplementary eTable 1.) Accuracy exhbited no effects or interactions involving service dog presence, nor did the inclusion of service dog presence improve accuracy model fit ($\chi^2(4) = 5.36$, $p = 0.25$). Stimulus valence interacted with comorbid MDD (effect = −0.27, $z = -4.68$, $p < 0.0001$) such that the PTSD-MDD participants were relatively inaccurate when labeling negative targets (61% at the Hudson scale minimum), but increased their accuracy rapidly as targets became more positive (5.6% per Hudson scale unit, $z = 2.19$ $p = 0.029$; See Fig. 2). In constrast, PTSD + MDD participants demonstrated no effect of stimulus valence (−0.8% per Hudson scale unit, $z = -0.34$, $p = 0.73$). The affective/cognitive

[1] Stimulus materials and ePrime code are available from the first author.

Table 1
Patient Characteristics by MDD Diagnosis.

	MDD-		MDD+	
N	13		34	
	mean	SD	mean	SD
Age	38.1	12.9	38.3	13.7
Education (years)	13.0	1.2	13.2	1.9
	percent of cases		percent of cases	
White, non-Hispanic	46%		62%	
African-American	15%		3%	
White, Hispanic	8%		24%	
Native American	8%		3%	
Hawaiian/Pacific Islander	8%		6%	
Multi-racial	8%		3%	
Decline to state	8%		0%	
Air Force	0%		12%	
Coast Guard	0%		3%	
Army	69%		59%	
Marines	15%		21%	
Navy	15%		12%	
Married	46%		29%	
Divorced	38%		44%	
Separated	8%		26%	
Never Married	8%		0%	
Current Alcohol Use Disorder	46%		68%	
Lifetime Alcohol Use Disorder	92%		91%	
Current Substance Use Disorder	38%		26%	*
Lifetime Substance Use Disorder	85%		47%	
Natural Disaster	0%		3%	
Transportation accident	0%		3%	
Physical assault	0%		3%	
Sexual assault	15%		21%	
Combat trauma	69%		71%	
Violent death	8%		0%	
Perpetration	8%		0%	
Other trauma	15%		0%	
	mean	SD	mean	SD [1]
Child Trauma Qestionaire	49.7	19.1	50.3	23.4 [2]
Life Events Checklist (categories)	8.5	3.4	11.0	5.6 [3]
Combat Exposure Scale	13.4	9.7	19.8	10.7 **
CAPS-5 Total Score	36.1	8.0	42.1	5.5
Height (meters)	1.8	0.2	1.8	0.2
Weight (Kg)	92.1	13.9	93.3	15.7

* $p < 0.05$, ** $p < 0.01$.
[1] Missing cases = 2/6.
[2] Missing cases = 0/1.
[3] Missing cases = 1/3.

categorization interacted with comorbid MDD such that PTSD-MDD participants exhibited no effect of this factor (z = 1.46, p = 0.14), while PTSD + MDD participants were 4% less accurate when labeling affective versus cognitive stimuli (z = −2.676, p = 0.007). Overall, accuracy increased as stimulus valence become more positive (5.6% per Hudson scale unit; z = 3.64, p < 0.0003). There was also a trend for PTSD + MDD participants to be more accurate overall (+8%, z = 2.01, p = 0.036). Accuracy tended to increase slightly over sessions (0.80% per session, z = 2.12, p = 0.034), but decreased over trials within sessions (−0.19% per trial, z = −4.07, p < 0.0001). Valence and the affective/cognitive factor did not interact to influence accuracy. As the effect of session was small, repeated sessions were alternatively evaluated as retests. The intra-class correlation coefficient (model 2, single measurement, random raters) was 0.69 (F(15,55) = 275.00, p < 0.0001) indicating good test-retest reliability for the RMET in this sample.

3.3. Response latency

Grand mean response latency was 4014 msec (SE = 193 msec). (All fixed effects and confidence intervals are provided in Supplementary eTable 2.) The inclusion of service dog presence did not improve response latency model fit ($\chi^2(4) = 7.37$, p = 0.12). Comorbid MDD interacted with stimulus valence (effect = 138.04, t(6562) = 4.03, p < 0.0001) such that for PTSD-MDD participants more positive valence was associated with faster responses (−220 msec per Hudson scale unit, t (6149) = 5.46, p < 0.0001; See Fig. 3.). In contrast, in PTSD + MDD participants, response latency increased modestly as valence became more positive (48 msec per Hudson scale unit, t(2247) = 0.96, p = 0.36). Response latency decreased over sessions (−69.6 msec/session, t(4820) = −7.44, p < 0.0001), but increased over trials (12.1 msec/trial, t (3003) = 10.5, p < 0.0001) within sessions. Response latency also exhibited an interaction of stimulus valence and the affective/cognitive factor (t(7160) = −9.11, p < 0.0001) in which response latency decreased with increasing positive valence for affective stimuli (−197 msec per Hudson scale unit, t(3749) = −5.24, p < 0.0001), but increased non-significantly with valence for cognitive stimuli (132 msec per Hudson scale unit, t(4880) = 1.00, p = 0.32; See Fig. 4.).

3.4. Dwell time

Supplement eFig. 1 presents grand median eye movement trajectories from 238 administrations of the task superimposed upon a review-formatted, stimulus. Considered in aggregate, participants initially focused on the nasion. By second five, aggregate gaze lowered in apparent anticipation of the appearance of the words. Surprisingly, over seconds 11–14, aggregate gaze returned to the nasion region despite the fact that the explicit task had been completed. Grand mean eyes region dwell time for the 6-s pre-task period was 2863 msec (std. err. = 277 msec), for the task period, eyes region, 1594 msec (SE = 170 msec), and for the task perioid word region, 1509 msec (SE = 176 msec). (All fixed effects and confidence intervals are provided in Supplementary eTablea 3a,b,c.) Eye and word region dwell times were normally distributed. Inclusion of service dog presence improved dwell time model fits for the pre-task period (χ^2 (4) = 16.13, p = 0.003), task-period/eyes region (χ^2

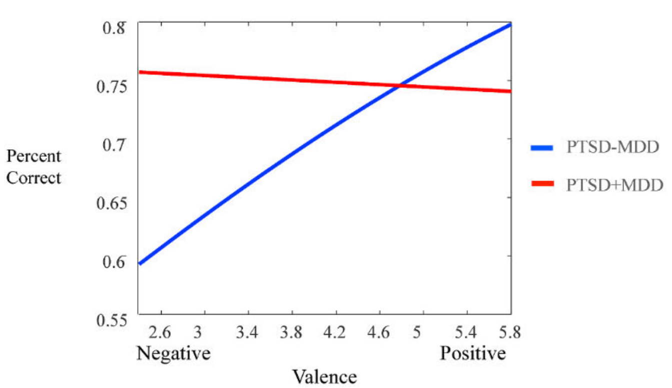

Fig. 2. The interaction of valence and comorbid MDD on accuracy. The main effect of target valence is also apparent.

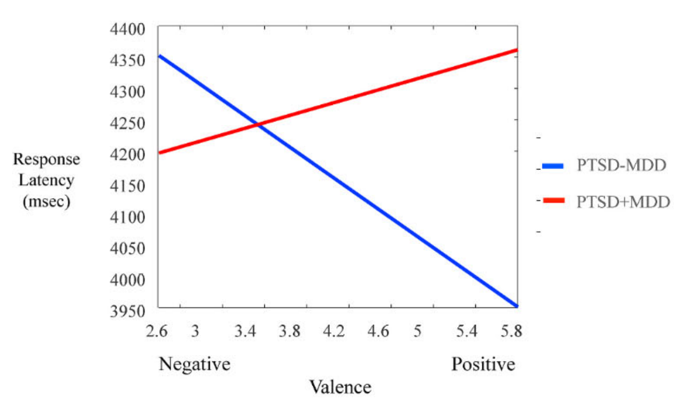

Fig. 3. A plot of the interaction of valence and MDD diagnosis on response latency.

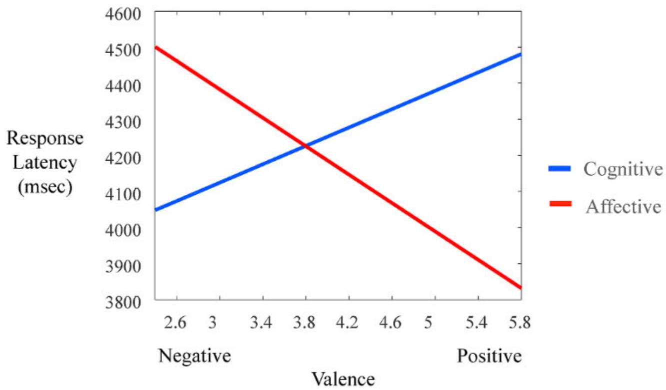

Fig. 4. Valence and affective/cognitive category interacting to influence response latency.

(4) = 17.06, p = 0.002), and task-period/word region (χ^2 (4) = 12.47, p = 0.014). Service dog presence interacted with comorbid MDD to influence eyes region dwell times during both pre-task (t(6240) = −3.12, p = 0.002) and task periods (t(5967) = −4.06, p < 0.0001; See Fig. 5.). During the pre-task period, in PTSD-MDD participants, service dog presence was associated with increased inspection of the eyes region (effect = 262 msec, t(1505) = 2.22, p = 0.027), and decreased inspection of the eyes region during the task period (effect = −184 msec, t (1436) = −2.367, p = 0.018). Neither of these effects were observed in PSTD + MDD participants. Service dog presence was also associated with a trend toward *increased* eyes region dwell time during the pre-task period (effect = 204 msec, t(6236) = 2.48, p = 0.014), but *decreased* eyes region dwell time during the task period (effect = −162 msec, t (5964) = 2.48, p = 0.004). Later sessions (pre-task period: −92 msec/session, t(6241) = −8.94, p < 0.0001); task period, eyes: −27 msec/session, t(5968) = −4.51, P < 0.0001; task period, words: −41 msec/session; t(5090) = 8.08, p < 0.0001) and later trials (pre-task period: −16 msec/trial, t(6204) = −12.05, p < 0.0001; task period, eyes: 3 msec/trial, t(5927) = 2.96, p = 0.003; task period, words: 0.2 msec/trial, t(5058)) = 1.45, p = 0.146) were typically associated with shorter stimulus dwell times. The exceptions to this trend were task period eyes and word region dwell times. Word region dwell times exhibited an interaction of valence and the affective/cognitive categorization (t (5055) = −6.62, p < 0.0001) such that increasing positive valence was associated with significantly decreasing word region dwell times for affective stimuli (−146 msec per Hudson scale unit, t(5384) = −3.05 p < 0.002), but not for cognitive stimuli (50 msec per Hudson scale unit, t (2928) = 0.42, p = 0.68).

3.5. Scanning speed

Scanning speed was log-transformed to increase normality. Scanning speed within the task period was not divided between eyes and word regions as it was presumed that saccades could encompass both. (All fixed effects and confidence intervals are provided in Supplementary eTables 4a,b.) Inclusion of service dog presence improved model fit for visual scanning speed during the pre-task period (x^2 (4) = 44.76, p < 0.0001), but not for the task period (X^2 (4) = 8.073, p = 0.089). Faster visual scanning was associated with service dog presence during the pre-task period (t(6369) = 3.71, p = 0.0002),. Visual scanning speed increased over sessions (pre-task period: t(6369) = 4.26, p < 0.0001; task period: t(6546) = 6.40, p < 0.0001) and over trials (pre-task period: t(6343) = 12.79, p < 0.0001; task period: t(6512) = 7.69, p < 0.0001) within sessions.

3.6. Relations among inspection times and accuracy

Pre-task and task eyes and word region dwell times were regressed on accuracy in sessions in which gaze-tracking met the quality criterion, controlling also for the expected inverse relationship between response latency and accuracy. This analysis found that correct matches were associated with *shorter* eyes region dwell times during the task period (0.85% per −100 msec, z = −2.74, p < 0.006). Task-period eyes region dwell time interacted with response latency such that the former accounted for less variance in accuracy as the latter became longer. The slope of the relationship between word dwell time and accuracy was also consistently negative. (All fixed effects and confidence intervals are provided in Supplementary eTable 5.)

4. Discussion

The primary aim of this study was to test, using a within-subjects design, whether extended and intensive service dog contact improved RMET performance in U.S. military veterans with deployment-related PTSD. Little support was obtained for this proposition in the context of grossly normal performance levels. The predicted effects of service dog presence on RMET accuracy, response latency, and dwell time were not observed. Service dog presence was not associated with a mood-induction effect reminiscent of Harkness et al. (2010) despite the fact that outside of the laboratory service dog contact was associated with

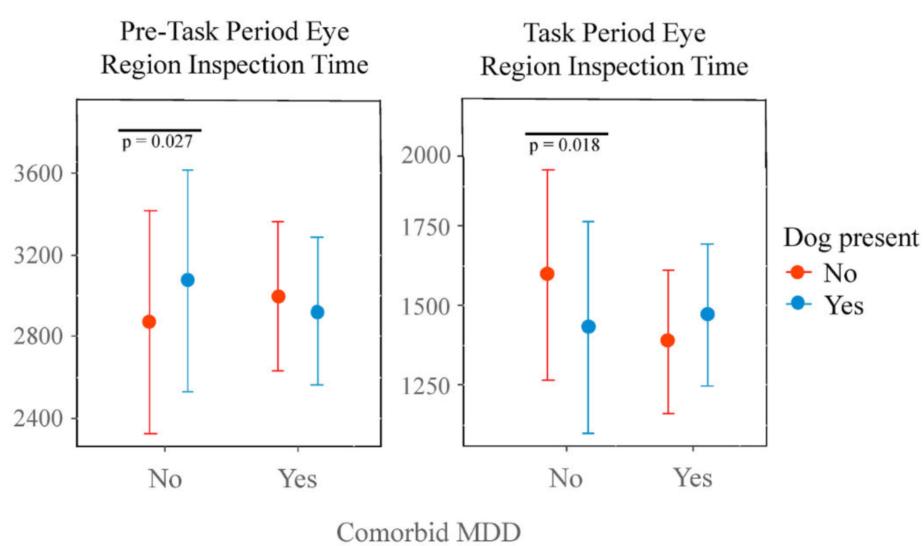

Fig. 5. A comparison of the interactions of service dog presence and comorbid MDD on a) pre-task dwell times and b) task/eyes region dwell times.

reduced negative and increased positive affect (Woodward et al., 2021). Although service dog presence improved dwell time model fits in the pre-task and task periods, the sole specific main effect of service dog presence surviving correction for multiple comparisons was *reduced* dwell time allocated to the eyes region during the task period. This finding directly contradicted our prediction. Service dog presence interacted with comorbid MDD to influence dwell time during the pre-task and task periods. In both periods, participants without comorbid MDD exhibited stronger effects of dog presence than participants with comorbid MDD, though these effects were in the opposite direction across pre-task and task periods. We note that nine of the 13 MDD-negative participants were in remission from a prior MDD episode, which may explain why the lability of their inspection behavior roughly paralleled the expressly remitted participants in Harkness et al. (2010).

4.1. Scanning speed

Service dog presence exhibited a significant positive effect on visual scanning speed in the predicted direction during the pre-task period accompanied by a similar trend during the task period. This interpretation of visual scanning speed as inversely related to induced fear rests on a single study (Xia et al., 2020); however, it supports the researchable proposition that reduction of social fear may underly the improvements in social function resulting from service dog interventions. Measuring fear responses to social stimuli has proven useful in the study of social phobia (Myllyneva et al., 2015). It is noteworthy in this connection that service dogs are increasingly used to increase the tolerability of judicial proceedings requiring traumatized children to testify under the gaze of their alleged victimizers (Mariani, 2020).

4.2. RMET accuracy and interpersonal sensitivity

This sample of male Veterans engaged in inpatient treatment for PTSD achieved a mean percent correct facial emotion labeling accuracy of 70% in session one. This figure is not far below the 74% accuracy exhibited by the very large ($n = 9271$), older, mixed-gender sample studied by Dodell-Feder et al. (2020), especially considering that younger age, male gender, lower education, and non-white ethnicity were associated with lower accuracy in that study. The mean response latency observed for session one, 4014 msec, was also similar to the mean latency of 4470 msec reported by Eddy and Hansen (2020) in their sample of 180 undergraduates undergoing a single administration of the RMET (See also Harkness et al., 2012). It is possible that the modified version of the task used here was easier than the original because the faces were initially presented alone and target words were presented in a familiar horizontal array; but any such increment is likely to be small as the original task is untimed. In sum, impaired processing of facial emotion may not mediate deficits in social cognitive in PTSD, which however leaves many other candidates as reviewed by Stevens and Jovanovic (2019).

If these and similar results are confirmed, PTSD would not be alone among psychiatric conditions which have produced normative accuracy levels on the RMET. Conditions which have demonstrated even *higher* RMET accuracies than control samples in at least one study include dysphoria (Harkness et al., 2005), borderline personality disorder (BPD; Fertuck et al., 2009), social anxiety (Nikolic et al., 2019), and schizotypy-related social anxiety (Eddy and Hansen, 2020). Harkness et al. (2005) have proposed that “interpersonal sensitivity” may lead to improved performance on the RMET. The trend observed here toward improved accuracy in the subgroup with comorbid MDD is aligned with that possibility. It is unusual for unipolar depressed individuals to perform better on a cognitive task than non-depressed individuals (Roca et al., 2015), though such comparisons have not been extended to the presence/absence of comorbid depression in PTSD. Findings of enhanced RMET accuracy in children of depressed mothers (Harkness et al., 2011) and adults neglected as children (Rnic et al., 2018; Weinstein et al., 2016; reduced response latency), both risk factors for mood disorder and BPD, lend support to the possibility that operant conditioning could contribute to enhanced development of skill in facial decoding. Harkness et al. (2010) have also demonstrated the sensitivity of RMET accuracy to a positive mood induction such that, in a sample with remitted MDD, the induction actually *worsened* RMET performance. Converse et al. (2008) and Zainal and Newman (2018) provide further examples of negative mood inductions (the former sadness, the latter, worry) positively impacting social cognition. While these studies have imposed controlled mood inductions, such findings raise the possibility that uncontrolled contextual factors differing across studies could contribute to variance in study outcomes and further complicate the interpretation of RMET outcomes in psychopathology. Sensitivity to context may explain why valence effects and interactions of valence with mood are both commonly observed and notably inconsistent in the RMET literature.

4.3. PTSD without MDD – preserved appetitive motivation?

The chronic severe PTSD patients studied here were less accurate when labeling eyes region photographs to stimulus valence became more *negative*. This association was driven by the PTSD-MDD group as the PTSD + MDD group was similarly accurate across valence levels. PTSD-MDD group also responded faster to more positively-valenced stimuli. Though few studies have specifically compared PTSD patients with and without comorbid MDD, the current results suggest the latter group manifested a distinctive performance differential in favor of positively-valenced versus negatively-valenced stimuli. We may speculate that such a performance bias points to preserved appetitive motivational function in the PTSD-MDD subgroup, and note that they also increased facial stimulus dwell time during the pre-task period when the dog was present, though this effect did not carry into the task period. The observation that PTSD with comorbid MDD was associated with uniformly high accuracies independent of valence may be contrasted with the findings of Rnic et al. (2018) that participants with primary MDD were especially *inaccurate* when interpreting negatively-valenced facial stimuli resembling our PTSD-MDD group. Relative insensitivity to positive facial stimulus valence may characterize PTSD as it is commonly compounded by MDD.

4.4. The RMET: an untimed test of a rapid robust process

RMET viewing times observed here were on the order of 4500 msec; however, humans can detect basic facial emotions with less than 50 msec of viewing time (Neath and Itier, 2014). Judgements of trustworthiness can be obtained in 100 msec or less (Bar et al., 2006; Willis and Todorov, 2006) and are associated with amygdala activations (Freeman et al., 2014) in line with Ledoux’s “low road” from superior colliculus to pulvinar to amygdala (Johnson et al., 2011). Furthermore, Poncet et al. (2021) have recently reported that errors of facial emotion recognition are associated with excessive inspection of uninformative facial features, a finding in line with the negative relationship between dwell times and accuracy observed here. We are forced to conclude that, in the non-speeded context of the RMET, most of the visual inspection of facial stimuli does not contribute to performing the task, even when taking in to consideration inspection time allocated to the words. If the balance of eyes region inspection time is not contributing to labeling accuracy, it is also not surprising that accuracy and response latency, on one hand, and inspection time and scanning rate, on the other, were found to be associated with different covariates. Effects and interactions involving service dog presence/absence were exclusively associated with the latter. In prior work, persons who scored higher on measures of empathy viewed social stimuli for longer periods (Cowan et al., 2014; Hedger et al., 2018); but if a presumable sub-operation of empathy, the extraction of basic emotions, can be accomplished in a fraction of a second, what further empathy-supporting operations take place over typical RMET reviewing times? This question is only sharpened by the current observations that longer viewing times were associated with lower accuracy. Unfortunately, this study did not obtain convergent measures of empathic accuracy.

The RMET exhibited remarkably small practice effects. Improvements in accuracy and response latency across the six sessions were small, less than 4% and 8%, respectively. Reductions in response latencies and dwell times over sessions were small, as well. Task-period dwell times were not reduced over trials, perhaps indicative of sustained effort. Accuracy exhibited good test-retest reliability, and no performance parameter varied over groups tested earlier or later during an intensive inpatient psychiatric hospitalization. These results are consistent with the operation of a robust system that has evolved to perform a critical task quickly and reliably. In light of this robustness, the frequency of effects and interactions involving valence and presence/absence of comorbid MDD, particularly during the decisional period, is compatible with other results indicating that rapid interface with motivational systems is a fundamental feature of this system (Adolphs, 2008, 2010; Adolphs et al., 2002; Ohman, 2009; Whalen et al., 1998, 2004). That said, the modifiability of RMET performance by mood inductions in other studies serves to emphasize the lack of impact by service dog contact observed here, though it should be noted that mood inductions manipulations of RMET performance have not been attempted with persons with PTSD.

The affective/cognitive categorization was associated with no main effects in this sample. This categorization interacted with valence such that word region dwell times shortened as stimulus valence became more positive for affective stimuli, only. While this was the sole effect on word region dwell times (besides a session effect), it was accompanied by a parallel interaction influencing response latencies which also shortened as stimulus valence became more positive for affective stimuli, only. In combination, these results speak to the complex, multicomponential character of the RMET in which accuracy versus timings are distinct outcomes and the labeling component is a distinct subtask separable from facial emotion perception (Dodell-Feder et al., 2020; Peterson and Miller, 2012). At this time, tt cannot be concluded, for example, whether the mood induction effects observed on RMET performance reflect modifications of the facial emotion perception or the emotion labeling components of the test.

4.5. Limitations

A number of limitations should be considered when interpreting the results of this study. The sample was small, exclusively male, exclusively military Veterans, and relatively young. The generalization of these results to demographically distinct samples remains to be demonstrated. No information was obtained regarding prior or current pet ownership nor about the strength of the bond participants experienced with their SATI service dogs, covariates which, at a minimum, might have increased statistical power. No estimates of subjective social support, a potentially revealing convergent outcome, or empathic or empathic accuracy, were obtained from participants during the study. Finally, no estimates of concurrent distress or mood were obtained from participants during the RMET, a regrettable omission in light of the strength of induction effects observed in other studies.

5. Conclusions

In conclusion, neither PTSD nor service dog presence were found to impact the most common RMET outcomes, which also appeared robust to repeated administrations and concurrent inpatient psychiatric treatment. As key components of face processing can occur very rapidly, requiring only approximately 5–10% of the time that our participants spent looking at RMET stimuli, future work with the RMET might benefit from parsing the inspection period more finely using fixation control, very brief stimuli, and backwards masking. Additional manipulation of motivational systems to which face processing is sensitive, for example, by employing a "fear of shock" condition (see also Ridinger and McBride, 2015), could be more revealing of associations with experimental factors, such as service dog presence, hypothesized to impact facial emotion processing and social cognition. Of note, as well, Hariri et al. have developed a non-verbal emotional face matching task (Hariri et al., 2000, 2003) based on the NimStim stimulus set (Tottenham et al., 2009) which strongly engages the amygdala. To date, no study has applied this task to the study of social cognition in PTSD or combined it with backwards-masking to constrain viewing time to the window during which basic facial emotion processing executes.

Author statement

To Whom it May Concern:

Re *Reading the Mind in the Eyes in PTSD: Limited Moderation by a Service Dog.*

Contributors:

Steven H. Woodward, Ph.D., designed the study, performed statistical analyses, and led the writing of the manuscript.

Andrea L. Jamison, Ph.D., participated in the design the study, coordinated the execution of study, and contributed to the manuscript.

Christina Khan, M.D., Ph.D., performed medical review of study participants.

Sasha Gala, J.D., recruited and assessed participants.

Chloe Bhowmick, Ph.D., assessed participants.

Diana Villasenor, B.A., assessed participants.

Gisselle Tamayo, B.A., coordinated the study and assessed participants.

Melissa Puckett, M.S., coordinated the provision of service dogs.

Karen J. Parker, Ph.D., participated in the design of the study and contributed to the manuscript.

Funders

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All work was performed in accordance with APA ethical standards and with the written approval of the Stanford/VA Institutional Review Board. We have followed the APA style.

The data are original and never-before published. This report has not been pre-posted. It is not under consideration for publication elsewhere.

Its publication is approved by all authors and tacitly or explicitly by the responsible authorities where the work was carried out. If accepted, it will not be published elsewhere in the same form.

We would appreciate full color figures.

Declaration of competing interest

The authors have no declarations of financial interest.

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Appendix A. Supplementary data

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