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Association between neurocognitive functioning and suicide attempts in U. S. Army Soldiers

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Background: Suicide is a serious public health problem, including among U.S. Army personnel. There is great interest in discovering objective predictors of suicide and non-fatal suicidal behaviors. The current study examined the association between neurocognitive functioning and pre-military history of suicide attempts (SA) and post-enlistment onset of SA. Methods: New Soldiers reporting for Basic Combat Training (N = 38,507) completed a comprehensive computerized neurocognitive assessment battery and self-report questionnaires. A subset of Soldiers (n = 6216) completed a follow-up survey, including assessment of lifetime SA, 3–7 years later. *Results:* Six hundred eighty-nine Soldiers indicated lifetime SA at baseline and 210 Soldiers indicated new-onset SA at follow-up. Regression analyses, adjusted for demographic variables, revealed significant bivariate associations between neurocognitive performance on measures of sustained attention, impulsivity, working memory, and emotion recognition and lifetime SA at baseline. In a multivariable model including each of these measures as predictors, poorer impulse control and quicker response times on an emotion recognition measure were significantly and independently associated with increased odds of lifetime SA. A second model predicted new-onset SA at follow-up for Soldiers who did not indicate a history of SA at baseline. Poorer impulse control on a measure of sustained attention was predictive of new-onset SA. Limitations: Effect sizes are small and of unlikely clinical predictive utility.
Conclusions: We simultaneously examined multiple neurocognitive domains as predictors of SA in a large, representative sample of new Army Soldiers. Impulsivity most strongly predicted past and future SA over and beyond other implicated cognitive-emotional domains.

1. Introduction

Identifying potential treatment targets to mitigate risk of suicidality is a high priority for the United States Army, which has encountered increased rates of suicidality in military personnel since its involvement in the Iraq and Afghanistan wars (Kuehn et al., 2009; Schoenbaum et al., 2014; Ursano et al., 2015). When military suicide rates exceeded U.S. civilian rates in 2008, the U.S. Army and the U.S. National Institute of Mental Health founded the Army Study to Assess Risk and Resilience in Servicemembers (Army STARRS, 2012) in an effort to address this national concern (Black et al., 2011; Kessler et al., 2013; Ursano et al., 2014). Army STARRS and its successor, STARRS-LS (Study to Assess Risk and Resilience in Servicemembers — Longitudinal Study), are multi-study projects aimed at identifying risk and resilience factors for suicidal behavior and related mental and behavioral health issues in U.S. Army Soldiers. One of the five components within Army STARRS, the New Soldier Study (NSS), was designed to evaluate the prevalence of lifetime *Diagnostic and Statistical Manual of Mental Disorders, Fourth*

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Edition (DSM-4; American Psychiatric Association, 1994) psychiatric disorders and neurocognitive functioning of new Soldiers as they entered Basic Combat Training. The neurocognitive test battery used in the NSS was explicitly designed to focus on neurobiologically-based cognitive and emotion processing domains that have been implicated in suicidal behavior (Moore et al., 2019). The neurocognitive component of NSS offered objective measures that could be considered in relation to risk for suicide attempts (SA).

Although numerous studies have evaluated sociodemographic and mental health risk factors for suicidal behavior in U.S. Army soldiers (Bachynski et al., 2012; Bernecker et al., 2019; Gilman et al., 2014; Kessler et al., 2015; Logan et al., 2012; Nock et al., 2018; Schoenbaum et al., 2014; Stein et al., 2018; Ursano et al., 2015, 2016, 2018), comparatively few studies have examined neurocognitive risk factors for SA within this population. Of the growing body of literature that has examined the neurocognitive risk factors associated with suicidal behavior in psychiatric patients and healthy controls, studies have linked suicide attempt with poorer performance on a wide range of neurocognitive measures, including domains of executive functioning, impulsivity, attention, learning, verbal fluency, and memory (Bredemeier and Miller, 2015; Burton et al., 2011; Jollant et al., 2011; Richard-Devantoy et al., 2015). The scope of the neurocognitive domains implicated in suicidal behavior suggests that assessment of neurocognitive abilities may be useful for identifying individuals who are at increased risk for attempting suicide. Less is known, however, about which abilities are most strongly linked to SA when multiple neurocognitive domains are examined concurrently. If neurocognitive variables share substantial variance and only a core few are found to largely explain the effect of the others, suicide prevention efforts could focus on targeting the factor(s) with the greatest explanatory power. In addition, the majority of prior studies primarily investigated measures of "cold" cognition (i.e., cognition independent of emotion) compared to "hot" cognition processing (i.e., cognition influenced by emotion; Rosier and Sahakian, 2013), leaving a gap in the literature about the role that emotion-related cognitive processing may play in conferring risk for SA.

Beyond the need to address the aforementioned limitations of prior research, assessing the neurocognitive correlates of SA in U.S. Army Soldiers is especially pertinent given that they comprise a population susceptible to considerable amounts of stress and cognitive demand (Orasanu and Backer, 1996) and that intact neurocognitive functioning is vital in regulating stress reactivity and promoting adaptative responses (Sandi, 2013). The current study seeks to build upon the findings of Naifeh et al. (2017), who utilized administrative data from Army STARRS to examine associations between neurocognitive functioning and subsequent suicidal events among Regular Army enlisted Soldiers. This study utilized the Army's Automated Neuropsychological Assessment Metrics Traumatic Brain Injury Battery (ANAM4™ TBI, version 4) computerized test battery and found that a general neurocognitive factor - composed of measures of associated learning, processing speed, visual-spatial memory, and delayed memory - was associated with suicide ideation and attempt. It is possible, however, that dysregulation within any one domain may exacerbate risk. Simultaneously investigating individual measures of neurocognitive function across several domains may elucidate which cognitive processes account for the most variance in SA.

The current study extends prior research by concurrently analyzing multiple "cold" and "hot" cognitive processing domains that have been implicated in suicidal behavior using a previously validated computerized neurocognitive test battery. Neurocognitive performance was examined in a large, representative sample of U.S. Army Soldiers in relation to presence of lifetime SA. Soldiers' neurocognitive performance was first examined cross-sectionally in relation to presence of prior lifetime SA before entering the military. Then, neurocognitive performance was examined prospectively in relation to presence of new-onset lifetime SA since entering the military.

2. Method

2.1. Participants

Army Soldiers volunteered to participate without compensation in the Army STARRS NSS (Kessler et al., 2013; Ursano et al., 2014). NSS participants completed a self-administered questionnaire (SAQ) and a battery of computerized neurocognitive tests prior to the start of Basic Combat Training. The sample included 38,507 participants from three Army bases. Participants were tested between February 2011 to November 2012. All Soldiers provided informed written consent to complete the SAQ, link administrative records to SAQ responses, and participate in future data collections prior to participation. The recruitment, consent, and data protection procedures were approved by the Human Subjects Committees of the Uniformed Services University of the Health Sciences for the Henry M. Jackson Foundation (the primary grantee), the Institute for Social Research at the University of Michigan (the organization collecting the data), all other collaborating organizations, and in accordance with the latest version of the Declaration of Helsinki. The sample was predominantly male (83%), White (61%), and non-Hispanic (78%). Participants had a mean age of 20.97 years (SD = 3.57) and the majority completed high school as the highest level of education (80%) at the time of survey completion.

Subsequent to participation in the NSS study, Soldiers were provided the opportunity to participate in the STARRS Longitudinal Survey (STARRS-LS). The STARRS-LS sample was enriched for women, special operation forces (SOF), and individuals with a history of suicidality. The current prospective analysis sample (n = 6216) included all Soldiers from the NSS sample who completed a follow-up survey a mean of 5.25 (SD = 0.71) years later. Individuals in this sample were predominantly male (79%), non-Hispanic White (62%), and had a mean age of 21.68 years (SD = 4.20) at baseline. The majority had never deployed (76.3%) and reported completing high school as their highest level of education (70%). Additional demographic characteristics for both samples are

Table 1
Demographic characteristics of participants at baseline and follow-up.

Variables	Army STARRS NSS		STARRS-LS	
	n	*M (SD)* or %	*n*	*M (SD)* or %
Age	38,507	20.97 (3.57)	6216	21.68 (4.20)
Sex	38,507		6216	
Male	31,966	83.0	4881	78.5
Female	6541	17.0	1335	21.5
Race/Ethnicity	38,507		6216	
Non-Hispanic White	23,429	61.0	3875	62.3
Non-Hispanic Black	6563	17.0	909	14.6
Hispanic	5779	15.0	925	14.9
Other	2736	7.0	507	8.0
Education	38,507		6216	
High school	30,844	80.0	4372	70.3
Less than high school	4389	11.0	928	14.9
Some college/college graduate	3274	9.0	916	14.7
Marital status	38,507		6216	
Never married	33,846	88.0	5300	85.3
Currently/previously married	4661	12.0	916	14.7
Service Component	38,507		6216	
Regular	21,840	5.0	3055	49.1
Guard	10,950	28.0	2046	32.9
Reserve	5717	15.0	1115	17.9
Lifetime suicide attempt[a]	38,507		6074	
No	37,818	98.0	5864	94.3
Yes	689	2.0	210	3.4

Note. LS = Longitudinal Study. [a] The analysis of lifetime suicide attempt in the STARRS-LS excluded participants that reported a lifetime suicide attempt at baseline (n = 142); thus, all cases of suicide attempt reported for STARRS-LS represent new-onset of suicide attempt during the 3–7 year interval between the baseline and follow-up surveys.

presented in Table 1.

2.2. Measures

2.2.1. Clinical assessments

Participants completed the SAQ to assess lifetime prevalence of DSM-IV mental disorders and prior suicidal behavior. The primary outcome measure of this study, presence of a lifetime suicide attempt, was assessed using a modified/expanded version of the C-SSRS and determined by those who responded yes to the question "Did you ever make a suicide attempt (i.e., purposefully hurt yourself with at least some intention to die)?" The prospective analysis only examined new-onset SA at follow-up due to limitations in how questions about SA following the baseline assessment were asked in STARRS-LS.

2.2.2. Neurocognitive assessments

The majority of the neurocognitive measures in the assessment battery were taken from the Penn Computerized Neurocognitive Battery (Gur et al., 2001, 2010) and were expressly included based on functional neuroimaging research linking cognitive and emotion processing domains and psychopathology of interest in Army STARRS (i.e., suicidal and impulsive behavior, posttraumatic stress disorder (PTSD), mood disorders, and substance use disorders), normative data from large samples, and feasibility for group administration (Moore et al., 2019). One additional measure, the Go/No-Go (GNG), was added to enhance the specificity of the battery given that it is a well-established measure that has been related to suicide (Moore et al., 2019). All measures have been previously well-validated and the battery as a whole has demonstrated good psychometric properties (Moore et al., 2019). Neurocognitive characteristics for both samples are presented in Table 2. Pearson correlations among the neurocognitive measures are presented in Table 3.

2.2.2.1. Executive function and mental flexibility. The Penn Conditional Exclusion Test (PCET; Kurtz et al., 2004) assesses a participant's ability to learn rules and adapt to unexpected changes in learned rules. Participants were presented with a set of objects that could vary on one of three characteristics: size, shape, and thickness of lines. Participants were asked to select which object in the group was unlike the others based on the determining characteristic and were immediately told whether they chose correctly or incorrectly. They were given 48 trials to learn which characteristic determined whether an object would belong. After correctly identifying 10 consecutive objects, the target characteristic changed, and the participant was challenged to recognize this rule change and to determine the new characteristic. The PCET score was based on a composite of total correct responses and the number of rules the participant learned. Specifically, the composite accuracy was calculated from the following equation: (number of categories achieved +1) (number of correct responses/number of total responses). Higher scores indicated better performance. The PCET was used as a measure of "cold" cognition.

Table 2
Neurocognitive characteristics of participants at baseline and follow-up.

Neurocognitive Measure	Army STARRS		STARRS-LS	
	n	*M (SD)*	*n*	*M (SD)*
PCET Accuracy	26,675	2.38 (0.80)	4257	2.38 (0.81)
PCPT True Positive Responses	31,924	50.19 (11.02)	5272	51.40 (10.41)
PCPT True Positive Response Time (ms)	31,924	467.60 (72.72)	5272	464.95 (68.54)
PCPT False Positive Responses	31,924	17.01 (13.17)	5272	15.71 (12.44)
PCPT False Positive Response Time (ms)	31,782	463.36 (108.83)	5238	461.40 (107.22)
SLNB True Positive Responses	26,710	14.56 (4.14)	4338	14.89 (4.12)
GNG False Positive Responses	31,930	10.77 (6.91)	5234	10.15 (6.61)
PFMT Total Correct Responses	30,731	29.88 (4.62)	5207	30.16 (4.50)
PFMT Median Total Correct Response Time (ms)	30,731	1640.94 (366.13)	5207	1646.53 (371.30)
ER40 Correct Responses	32,338	32.84 (3.72)	5253	32.84 (3.63)
ER40 Median Correct Response Time (ms)	32,332	2156.04 (414.82)	5250	2134.61 (396.72)

Note. LS = Longitudinal Study; PCET = Penn Conditional Exclusion Test; PCPT = Penn Continuous Performance Test; ms = milliseconds; SLNB = Short Letter N-Back; GNG = Go/No-Go; PFMT = Penn Face Memory Test; ER40 = Penn Emotion Recognition Test.

2.2.2.2. Working memory. The Short Letter N-Back (SLNB), a "cold" cognition measure, was used to evaluate participants' ability to actively maintain and refresh goal-related information. During this task, letters flashed on the computer screen one at a time at 1 Hz, and participants were instructed to press the spacebar key whenever the letter on the screen was the same as two previous (i.e., 2-back). Participants were given 2.5 s to respond. The SLNB was scored based on the total number of true positives, with higher scores indicating better performance.

2.2.2.3. Sustained attention. The Penn Continuous Performance Test (PCPT; Kurtz et al., 2001) was used as a "cold" cognition measure of sustained visual attention. Participants were shown a series of configurations comprised of red 7-segment displays and were asked to press the spacebar key when the stimulus presented as a number (first half of the task) or a letter (second half of the task). Each trial lasted 1 s and the stimulus was presented for 300 ms (ms) followed by a blank screen displayed for 700 ms. The total number of correct responses (i.e. true positives) and response times were recorded. Higher numbers of correct responses indicated better performance.

2.2.2.4. Memory for faces. The Penn Face Memory Test (PFMT) presented participants with black-and-white photographs of 20 faces for 5 s each that they were asked to identify later. Immediately after learning the faces, participants were shown a series of 40 faces consisting of the 20 target faces and 20 distractor faces. Participants were asked to decide whether they had previously seen each face by choosing "definitely yes"; "probably yes"; "probably no"; or "definitely no". All faces were rated as having neutral facial expressions and balanced for age and gender (Gur et al., 1993; Gur,2001). Correct responses (i.e. true positives) and response time were recorded with a higher number of correct responses and quicker response time indicating better performance. The PFMT was used as a "cold" cognition measure.

2.2.2.5. Emotion recognition. The Penn Emotion Identification Test (ER40) measured participants' ability to recognize specific emotions being expressed by a model. Participants were shown a series of 40 faces and asked to choose whether the emotion expressed by the model was Happy, Sad, Anger, Fear, or No Emotion. There were four male and four female faces for each emotion. The total number of correct responses, with a higher number indicating better performance, and response time for correct responses were recorded. The ER40 was used as a measure of "hot" cognition.

2.2.2.6. Impulsivity. The Go/No-Go (GNG) is a measure of impulse control that requires participants to respond to designated targets and to inhibit responding to non-targets. Participants were presented with a series of Xs and Ys, which were quickly displayed at different positions on the screen for 300 ms. Each stimulus was followed by a uniform black screen for 900 ms. Participants were instructed to press the spacebar key if and only if an X appeared in the upper half of the screen. The GNG was scored based on the number of false positives (i.e., incorrect responses), with higher scores indicating worse performance. The GNG was used as a "cold" cognition measure of response inhibition. The total number of incorrect responses (i.e., false positives) on the PCPT was additionally

Table 3
Pearson correlations between neurocognitive variables at baseline.

	1	2	3	4	5	6	7	8	9	10	11
1. PCET Accuracy	–										
2. PCPT True Positive Responses	.15	–									
3. PCPT True Positive RT	-.08	-.34	–								
4. PCPT False Positive Responses	-.16	-.37	.09	–							
5. PCPT False Positive RT	-.07	-.32	.66	.15	–						
6. SLNB True Positive Responses	.16	.20	-.10	-.18	-.10	–					
7. GNG False Positive Responses	-.09	-.31	.05	.39	-.01	-.22	–				
8. PFMT Total Correct Responses	.12	.19	-.08	-.18	-.06	.26	-.24	–			
9. PFMT Median Total Correct RT	.04	.05	.06	-.08	.03	.03	-.13	.07	–		
10. ER40 Correct Responses	.14	.18	-.10	-.17	-.08	.13	-.14	.16	.01	–	
11. ER40 Median Correct RT	-.06	-.07	.15	.03	.10	-.08	-.02	-.08	.29	-.15	–

Note. PCET = Penn Conditional Exclusion Test; PCPT = Penn Continuous Performance Test; RT = response time in milliseconds; SLNB = Short Letter N-Back; GNG = Go/No-Go; PFMT = Penn Face Memory Test; ER40 = Penn Emotion Recognition Test.

used as a measure of cognitive inhibition.

2.3. Statistical analysis

All statistical analyses were conducted in R, Version 3.6.3. The cross-sectional analysis includes all NSS participants who completed the SAQ, had their SAQ data successfully linked to their Army/DoD administrative records, and had neurocognitive assessment data available. Test sessions were flagged if participant response patterns were consistent with hardware/software malfunction, subject inattention, misunderstanding, or noncompliance. Criteria for whether a test session was flagged were established for each of the tests and varied by test. For example, sessions for the PCPT were flagged if there were 10 consecutive responses or 20 consecutive nonresponses. Sessions for the ER40 were flagged if the same emotion was selected ≥ 7 times in a row or if there was at least 1 response time $\leq$ 250 ms. Flagged test sessions were excluded from analysis on a measure by measure basis; therefore, some participants had data for only some of the individual tests. The percentage of flagged test results for each measure were as follows: PCET (5.9%), PCPT (7.0%), SLNB (13.5%), GNG (6.0%), PFMT(14.1%), and ER40 (3.3%).

Separate logistic regression models were first run for each of the neurocognitive variables predicting presence of lifetime SA (i.e., pre-enlistment) as the outcome. Models were adjusted for age, sex, race/ethnicity, education, marital status, service component (Regular, Guard, or Reserve), and site of Basic Combat Training. All neurocognitive variables were standardized to the sample before entering the model. A multivariable logistic regression model predicting presence of lifetime SA with each of the significant neurocognitive measures from the initial models entered as predictors was then run. A second prospective analysis utilizing the same predictors from the multivariate model at baseline was conducted to predict new-onset SA at follow-up for Soldiers who did not indicate a history of SA at baseline. The model was adjusted for age, sex, race/ethnicity, education, marital status, service component, site, deployment status ("ever deployed?"), and years between baseline and the LS survey.

3. Results

Results from the separate logistic regression models showed that performance on neurocognitive measures of sustained attention (adjusted odds ratio [*AOR*] = 1.19 per *SD* decrease in true positives on the PCPT, 95% confidence interval (CI) [1.08, 1.31], $p < .001$, *AOR* = 1.14 per *SD* increase in response time for true positives on the PCPT, [1.02, 1.27], $p = .02$, and *AOR* = 1.32 per *SD* increase in false positives on the PCPT [1.21, 1.44], $p < .001$), working memory (*AOR* = 1.12 per *SD* decrease in true positive on the SLNB, [1.02, 1.22], $p = .02$), and impulsivity (*AOR* = 1.25 per *SD* increase in false positives on the GNG, [1.14, 1.37], $p < .001$) was associated with increased odds of presence of a lifetime SA. Quicker performance on a neurocognitive measure of emotion recognition (*AOR* = 1.19 per *SD* decrease in true positive response time on the ER40, [1.08, 1.32], $p < .001$) was associated with increased odds of presence of lifetime SA (see Table 4). Of the significant predictors in the bivariate models, the percent increase/decrease in adjusted odds of lifetime SA associated with neurocognitive test scores ranged from 12% to 32%.

Results from the multivariable logistic regression model predicting presence of lifetime SA as the outcome with each of the significant neurocognitive measures from the initial models as predictors revealed that less impulse control (*AOR* = 1.22 per *SD* increase in false positives on the GNG, [1.06, 1.40], $p = .007$, and *AOR* = 1.18 per *SD* increase in false positives on the PCPT, [1.04, 1.35], $p = .013$) and quicker responses to a measure of emotion recognition (*AOR* = 1.17 per *SD* decrease in true positive response time on the ER40, [1.01, 1.36], $p = .048$) were associated with increased odds of lifetime SA while controlling for demographic, service, and site variables (see Table 5). Of the significant predictors in the multivariable model, the percent increase/decrease in adjusted odds of lifetime SA associated with neurocognitive test scores ranged from 17% to 22%.

Table 4
Separate logistic regression models predicting presence of lifetime suicide attempts at baseline.

Neurocognitive Measure	*n*	*AOR*	95% CI	Wald χ^2	*p*
PCET Accuracy	26,675	0.92	[0.83, 1.03]	2.22	.136
Fewer PCPT True Positive Responses	31,924	1.19	[1.08, 1.31]	12.52	<.001
PCPT True Positive RT	31,924	1.14	[1.02, 1.27]	5.43	.02
PCPT False Positive Responses	31,924	1.32	[1.21, 1.44]	38.84	<.001
PCPT False Positive RT	31,782	1.10	[0.99, 1.23]	2.97	.085
Fewer SLNB True Positive Responses	26,710	1.12	[1.02, 1.22]	5.40	.02
More GNG False Positive Responses	31,930	1.25	[1.14, 1.37]	21.58	<.001
More PFMT Total Correct Responses	30,731	1.01	[0.90, 1.15]	0.04	.834
PFMT Median Total Correct RT	30,731	0.89	[0.78, 1.02]	2.67	.102
More ER40 Correct Responses	32,338	0.92	[0.85, 1.01]	3.36	.067
Quicker ER40 Median Correct RT	32,332	1.19	[1.08, 1.32]	11.87	<.001

Note. AOR = adjusted odds ratio; CI = confidence interval; PCET = Penn Conditional Exclusion Test; PCPT = Penn Continuous Performance Test; RT = response time in milliseconds; SLNB = Short Letter N-Back; GNG = Go/No-Go; PFMT = Penn Face Memory Test; ER40 = Penn Emotion Recognition Test. Models were adjusted for age, sex, race/ethnicity, education, marital status, service component, and site.

Table 5
Multivariable logistic regression model predicting presence of lifetime suicide attempts at baseline.

Variable	*AOR*	95% CI	Wald $\chi 2$	*p*
Fewer PCPT True Positive Responses	1.07	[0.92, 1.25]	0.82	.365
Quicker PCPT True Positive RT	1.13	[0.99, 1.30]	3.24	.072
More PCPT False Positive Responses	1.18	[1.04, 1.35]	6.22	.013
Fewer SLNB True Positive Responses	1.01	[0.90, 1.15]	0.04	.833
More GNG False Positive Responses	1.22	[1.06, 1.40]	7.38	.007
Quicker ER40 Median Correct RT	1.17	[1.00, 1.37]	3.92	.048
Age	0.97	[0.92, 1.03]	1.07	.301
Gender–Female[a]	2.17	[1.51, 3.13]	17.24	<.0005
Race–Non-Hispanic Black[b]	0.73	[0.48, 1.11]	–	–
Race–Hispanic	0.72	[0.46, 1.13]	–	–
Race–Other	1.36	[0.82, 2.25]	6.08	.108
Education–Less than high school[c]	0.62	[0.37, 1.04]	–	–
Education–Some college/College graduate	0.43	[0.19, 0.97]	6.33	.042
Currently/previously married[d]	0.51	[0.29, 0.87]	6.19	.013
Service Component–Guard[e]	1.44	[1.03, 2.02]	–	–
Service Component–Reserve	1.16	[0.75, 1.79]	4.57	.102

Note. $n = 20{,}447$. AOR = adjusted odds ratio; CI = confidence interval; PCPT = Penn Continuous Performance Test; RT = response time in milliseconds; SLNB = Short Letter N-Back; GNG = Go/No-Go Task; ER40 = Penn Emotion Recognition Test. The model was also adjusted for site. Area under the receiver operating characteristic curve = 0.67. [a] Reference group is Male. [b] Reference group is Non-Hispanic White. [c] Reference group is High school. [d] Reference group is Never Married. [e] Reference group is Regular.

Table 6
Multivariable logistic regression model predicting presence of new-onset suicide attempts at follow-up.

Variable	*AOR*	95% CI	Wald $\chi 2$	*p*
Fewer PCPT True Positive Responses	1.06	[0.80, 1.39]	0.15	.699
Quicker PCPT True Positive RT (ms)	1.03	[0.83, 1.28]	0.07	.793
More PCPT False Positive Responses	1.30	[1.01, 1.68]	4.00	.046
Fewer SLNB True Positive Responses	0.89	[0.67, 1.19]	0.60	.438
More GNG False Positive Responses	0.97	[0.74, 1.26]	0.07	.797
Quicker ER40 Median Correct RT (ms)	1.12	[0.86, 1.47]	0.71	.399
Age	0.96	[0.83, 1.11]	0.37	.545
Gender- Female[a]	2.12	[1.22, 3.68]	7.06	.008
Race- Non-Hispanic Black[b]	0.94	[0.45, 1.97]	–	–
Race- Hispanic	1.41	[0.72, 2.80]	–	–
Race- Other	1.60	[0.73, 3.51]	2.03	.567
Education- Less than high school[c]	0.82	[0.42, 1.59]	–	–
Education- Some college/College graduate	0.11	[0.03, 0.41]	11.20	.004
Currently/previously married[d]	0.93	[0.35, 2.42]	0.02	.874
Service Component- Guard[e]	0.79	[0.45, 1.39]	–	–
Service Component- Reserve	0.71	[0.34, 1.49]	1.13	.568
Deployed	0.75	[0.40, 1.40]	0.82	.366
Time between surveys (years)	1.66	[1.12, 2.46]	6.35	.012

Note. $n = 3354$. AOR = adjusted odds ratio; CI = confidence interval; PCPT = Penn Continuous Performance Test; RT = response time; ms = milliseconds; SLNB = Short Letter N-Back; GNG = Go/No-Go Task; ER40 = Penn Emotion Recognition Test. The model was also adjusted for site. [a] Reference group is Male. [b] Reference group is Non-Hispanic White. [c] Reference group is High school. [d] Reference group is Never Married. [e] Reference group is Regular.

Table 6 contains the multivariable logistic regression model predicting new-onset SA at follow-up with the PCPT number of true positive responses, PCPT true positive response time, PCPT number of false positive responses, SLNB number of true positive responses, ER40 median correct response time, and GNG150 number of false positive responses entered as predictors. The model was adjusted for age, sex, race/ethnicity, education, marital status, service component, site, deployment status, and years between baseline and the LS survey. Of the neurocognitive measures, only the number of false positive responses on the PCPT was predictive of new-onset SA ($p = .046$).

4. Discussion

The primary aim of the study was to better understand the associations between neurocognitive functioning and lifetime SA among U.S. Army Soldiers. Bivariate models revealed significant associations between worse performance on measures of sustained attention, working memory, and impulsivity and increased risk of lifetime SA at baseline, independent of sociodemographic and service variables. In addition, a quicker response time to correctly identify emotions was associated with increased risk of lifetime SA. These findings are consistent with previous research linking aberrations in these domains to suicidal behaviors and to psychiatric disorders known to contribute to suicidal behavior (Arsenault-Lapierre et al., 2004; Christopher and MacDonald, 2005; Fertuck et al., 2009; Kelip et al., 2005, 2008; Masten et al., 2008; Powers et al., 2017; Shaw et al., 2009). We also found that less education was a significant predictor of SA in both multivariable models. This finding is consistent with prior literature linking less education to suicidal behavior in US Servicemembers and the U.S. general population (Naifeh et al., 2017; Philips and Hempstead, 2017).

When evaluating the unique variance accounted for by each of the neurocognitive variables in the multivariable model, the two most robust predictors of increased risk of lifetime SA were both indicators of impulsivity (i.e., greater number of false positives on the GNG and on the PCPT). This finding is consistent with previous literature suggesting a link between poor impulse-control and suicidal behavior (Jollant et al., 2011), and adds to the literature by suggesting that impulsivity is independently related to lifetime SA above and beyond other neurocognitive domains in U.S. Army Soldiers. The urgency theory postulates that individuals who are characterized as high on impulsivity are prone to act without regard to potential long-term consequences under extreme emotions (Cyders and Smith, 2009). It is possible that a propensity for impulsive behavior may exacerbate cognitive disinhibition and hamper cognitive resources in other domains, and in turn, may compromise emotion regulation and problem-solving skills, and potentially increase likelihood of acting on suicidal thoughts. It is also possible, conversely, that difficulties with emotion regulation may result in an individual's inability to effectively problem-solve and lead to impulsive suicidal behavior (Rajappa et al., 2012). In addition, we found that quicker response time on the ER40 was associated with increased

risk of lifetime SA at baseline. This finding is in contrast to prior literature linking impaired affect processing abilities in individuals with psychiatric conditions such as depression and schizophrenia (Kohler et al., 2003; Naranjo et al., 2011). Yet, there is some research suggesting that individuals with history of abuse, PTSD, and borderline personality disorder demonstrate enhanced emotion recognition processing (Fertuck et al., 2009; Masten et al., 2008; Powers et al., 2017). Individuals who are quicker to respond to facial expressions may be more sensitive to the emotional and behavioral responses of others and more susceptible to communication errors, both of which may exacerbate interpersonal problems and psychopathology linked to SA. Alternatively, the finding in the present study may have also been a reflection of individuals who adopted a less deliberate response with regard to emotion recognition processing. It is also worth noting that across models, both "cold" and "hot" cognitive processes were predictive of lifetime SA. Results from the multivariable model, however, suggest that measures of emotionally independent information processing may be stronger indicators of suicidal behavior than those of emotionally laden information processing (e.g., ER40). Additional research that integrates neural and behavioral approaches may be helpful in better understanding the role of "hot" and "cold" cognitive processes in suicidal behavior. Notably, the neurocognitive measures found to significantly predict SA reflect cognitive abilities mainly mediated by the prefrontal cortex (Baddeley and Della Sala, 1996; Durston et al., 2002; Horn et al., 2003; Takashima et al., 2006). Although many of the battery measures were explicitly chosen based on prior neuroimaging research that has associated the prefrontal cortex with suicidal behavior, these findings further highlight the importance of examining this specific brain region and its corresponding executive control abilities to better understand suicidal behavior.

When examining the prospective associations between neurocognitive functioning and new-onset of SA among participants in the STARRS-LS, poorer impulse control as measured by a greater number of false positives on a measure of sustained attention (i.e., PCPT) was significantly predictive. This prospective finding further highlights the importance of better understanding the relation between the neurocognitive domain of impulsivity and SA. It is consistent with prior literature linking impulsivity as a predictor of future suicidal behavior (Klonsky & May 2015). Notwithstanding, the associations reported in previous research and the present study suggest small to modest effects and utilize varying definitions of impulsivity. Given this and the multifaceted nature of impulsivity (Dalley et al., 2011), an unmet need remains to concurrently examine different types of impulsivity (e.g., trait, behavioral, cognitive) as predictors of future SA in large, prospective studies. In the context of U.S. servicemembers, the current finding is compatible with the work of Naifeh et al. (2017) that provided preliminary evidence of global neurocognitive impairment predicting suicidal ideation, SA, and death by suicide. Although both studies provided support for a relation between cognition and suicidal behavior, there are several important distinctions between the present study and that of Naifeh et al. (2017), which utilized administrative record review of SA data, different neurocognitive measures, and prospective examination of any type of subsequent SA (i.e., new-onset or recurrent). First, administratively documented SA and self-reported SA may have generated varying results. Second, the present study only prospectively examined new-onset SA in Soldiers who did not indicate pre-enlistment SA and did not investigate potential effects of neurocognitive functioning on repeat SA. In the current study, the limited number of associations may have also been the result of inadequate statistical power given the comparatively small proportion of individuals in the follow-up sample. In addition, the statistically significant effect sizes found from the baseline analysis, which involved a larger number of participants than the LS sample, were generally small (i.e., 12%–32% increase/decrease in the odds of a lifetime SA). It is nevertheless worth noting that though the effects of the predictors were small, they were significantly associated with a serious public health outcome.

The strengths of this study include its large, representative sample and use of a comprehensive battery of well-validated neurocognitive tests of domains that have previously been shown to be associated with suicidal behavior. To the best of the authors' knowledge, and recognizing that past studies have evaluated neurocognitive performance and SA, this is the first study to have examined independent neurocognitive predictors in relation to retrospective and prospective SA in U.S. Army Soldiers. The present study was able to make direct comparisons among various neurocognitive domains and provided initial evidence for which neurocognitive processes were most strongly linked to history of lifetime SA. Findings further add to the literature by comparatively examining how "cold" and "hot" cognition domains relate to suicidal behavior among new U.S. Army Soldiers.

Several limitations must be considered alongside the current findings. The first limitation relates to external validity. Findings from this study may not represent all new Soldiers and may not also generalize to non-military samples and/or military Soldiers who have deployed. In addition, the presence of lifetime SA was assessed via Soldiers' self-report, which may have been influenced by external factors such as stigma or inaccurate recall. The utilization of administrative or medical data may be more informative in future studies, although such records are often also incomplete with regard to SA. In addition, the assessment battery did not include psychometrically established performance validity measures. Assessing the impact of the use of such validity indices on measurement of neurocognitive performance within this sample would be a valuable future direction. Our analyses also did not control for other potentially influential variables (e.g., history of traumatic brain injury, life stressors, personality traits). Due to limitations in the way questions about SA subsequent to baseline were asked, the prospective analysis only investigated the relationship between baseline neurocognitive functioning and new-onset SA at follow-up. Given that history of a prior SA is a major risk factor for a subsequent SA, further research is necessary to investigate the relationship between baseline neurocognitive functioning and subsequent repeat SA. Future studies should also consider examining the neurocognitive predictors of suicidal ideation versus SA within this population to elucidate the particular cognitive and emotional processes that contribute to the transition between suicidal thoughts and actions. Time between baseline and follow-up surveys was a significant predictor of new-onset SA. As such, it is important to acknowledge that an increased time between surveys offers a greater likelihood of capturing a future SA. Although we controlled for such differences in our model, research that utilizes a set timeframe between baseline and follow-up surveys for prospective examination of SAs is warranted. We did not include other factors (i.e., mental health disorders, substance use, sleep, personality traits) in the current study as the goal was to focus specifically on neurocognitive predictors of SA. As a limitation, then, is the likelihood of such confounders in this relationship and is an important topic to examine in the next iteration of this research (see Rosellini et al., 2015 for previously reported prevalence rates of psychopathology in the NSS sample). Finally, when examining the specificity and sensitivity of the multivariable logistic regression model predicting lifetime SA at baseline, the area under the receiver operating characteristic curve = 0.67, suggesting the model demonstrated weak class separation ability and is not clinically actionable in its present form.

Considering these limitations, the results of this study support previous work suggesting a link between neurocognitive functioning and SA. These findings expand upon prior research addressing neurocognitive predictors of SA in Army personnel by highlighting which specific cognitive processes, both "hot" and "cold", are most strongly linked to SA above and beyond other implicated domains. Additional longitudinal studies are needed to clarify the role of neurocognitive assessment measures, particularly those of impulsivity, in estimating risk of future suicidal behavior among military personnel, and in determining whether interventions geared toward reducing impulsivity would have therapeutic benefits for suicide prevention.

Author statement

Contributors: Author contributions are as follows: study concept and design (Stein, Taylor, Hoffman, Gur); drafting of the manuscript (Hoffman, Taylor, Stein); critical revision of the manuscript for important intellectual content (Hoffman, Taylor, Stein, Thomas, Campbell-Sills, Sun, Jain, Naifeh, Kessler, Ursano, Gur); statistical analysis (Jain, Sun); obtained funding (Kessler, Stein, Ursano); and study supervision (Kessler, Stein, Ursano, Gur). All authors contributed to the interpretation of the findings. All authors approved the manuscript for publication and agreed with the order of authorship.

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Declaration of competing interest

All other authors declare no conflict of interest.

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