Psychiatry Research 282 (2019) 112589

Contents lists available at ScienceDirect

Psychiatry Research

journal homepage: www.elsevier.com/locate/psychres

Review article

A qualitative systematic review of suicide behavior using the cognitive systems domain of the research domain criteria (RDoC) framework

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ARTICLE INFO

Keywords:
Suicide ideation
Suicide attempt
Research Domain Criteria (RDoC)
Cognitive systems
Cognitive control
Transdiagnostic

ABSTRACT

Neurocognitive deficits are associated with both suicide behavior (SB) and psychiatric disorders. Application of a transdiagnostic framework to identify neurocognitive commonalities of SB may clarify important risk factors of SB across psychiatric disorders. The aim of this study was to conduct a qualitative systematic literature review of SB using the Research Domain Criteria (RDoC) Cognitive Systems framework to determine if cognitive deficits exist independently of psychiatric disorders in SB. The following six constructs that encompass the Cognitive Systems domain were assessed: 1) Attention, 2) Cognitive Control, 3) Declarative Memory, 4) Language, 5) Perception, and 6) Working Memory. A total of 1386 abstracts were identified and 74 studies met the inclusion criteria for this review. The majority of studies reviewed (65%) had significant differences in cognition between individuals with and without SB. Seventy-nine percent of studies with a patient control group showed significant cognitive deficits in SB groups. Deficits in cognitive control were associated with SB and had the greatest percentage of studies with significant main findings. Use of the RDoC cognitive systems framework to evaluate SB revealed that cognitive deficits may be a transdiagnostic risk factor for SB, especially alterations in cognitive control.

1. Introduction

Suicide is a significant public health concern with substantial individual and economic burdens. Each year approximately 45,000 Americans die by suicide, and costs associated with suicide total more than 69 billion dollars (CDC, 2018). Despite an abundance of research aimed at prevention and identifying risk factors, suicide rates have risen in nearly every state in the United States (US) since 1999 (Stone et al., 2018). Studies have focused on the clinical, psychological, and biological correlates of suicide; however, our understanding of the mechanisms leading to suicide behavior remains limited.

One area that crosses all three of these domains is neurocognitive function and there is growing number of studies reporting that cognitive deficits play a role in vulnerability for suicide behavior (SB) (Bredemeier and Miller, 2015; da Silva et al., 2011; Jollant et al., 2011). For example, deficits in attention, executive function, memory, and language have been identified as risk factors for SB (Bredemeier and Miller, 2015; Keilp et al., 2008, 2013; Richard-DevantoyBerlim et al., 2015). While further research into the neurocognitive mechanisms of SB may facilitate early detection and intervention targets for high-risk individuals, it is important to build on what has been reported thus far. Studies of cognition and SB have traditionally focused on homogeneous populations based on categorization by psychiatric disorder (Keilp et al., 2001; Richard-Devantoy et al., 2014) or specific cognitive domains (Bredemeier and Miller, 2015; Richard-DevantoyBerlim et al., 2015) which limits generalizability of findings. Additionally, many individuals with psychiatric disorders have neurocognitive deficits that may be associated with their illness, some prior to onset and others remaining during remission.

One of the biggest challenges of identifying neurocognitive deficits that may be attributed specifically to SB is disentangling them from cognitive impairments associated with many psychiatric disorders. This is important, as there is increasing evidence that neurocognitive deficits associated with SB may exist independently of psychiatric illness. For example, (Bredemeier and Miller, 2015) completed a review of 43 studies examining executive function deficits in participants with a history of suicide attempts and found that neurocognitive deficits were not fully accounted for by psychiatric disorders or psychological distress. Moreover, a number of studies with healthy first-degree relatives of suicide decedents found neurocognitive impairments in the absence

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https://doi.org/10.1016/j.psychres.2019.112589
Received 29 May 2019; Received in revised form 23 September 2019; Accepted 26 September 2019
Available online 06 November 2019
0165-1781/

of psychiatric symptoms (Ding et al., 2017; Hoehne et al., 2015). In addition, a recent review (Saffer, 2018) proposed that neurocognitive abilities may distinguish attempters from ideators, so it is critical to further evaluate cognition and the relationship that it might have with progression from ideation to attempts. To parse out neurocognitive deficits in SB and psychiatric disorders, it may be useful to apply a transdiagnostic framework to identify cognitive and behavioral commonalities of SB across all psychiatric disorders.

The National Institutes of Mental Health introduced the Research Domain Criteria (RDoC) initiative in 2008 as an approach to better understand mental illness by evaluating different dimensions of behavior that may align with neurobiological systems. The RDoC model consists of psychological constructs relevant to human behavior and psychiatric disorders. The framework emphasizes developmental trajectories and environmental interactions as well as underlying neurobiology of mental illness (Cuthbert and Kozak, 2013). Units of analysis in the RDoC Matrix (i.e., behavior, circuits, physiology, and self-reports) are measurements used to examine constructs and dimensions that contribute to mental health. Since the RDoC framework is focused on an integrative understanding of behavior and cognitive/emotional processes in a transdiagnostic approach, it is a useful model to apply to SB.

The RDoC Cognitive Systems domain captures the constructs of attention, perception, declarative and working memory, language, and cognitive control. Importantly, this domain also targets constructs connected to brain regions and underlying circuitry that have shown to be associated with SB. For example, neuroimaging studies have demonstrated alterations in the prefrontal regions including the dorsomedial, dorsolateral, and ventrolateral prefrontal cortices (PFC) of patients with SB (Jollant et al., 2011). Additionally, the medial temporal lobe which includes the amygdala and anterior cingulate gyrus have shown to be associated with SB. By examining SB through the RDoC Cognitive System perspective, we are able to focus specifically on neurocognitive risk factors for SB. The purpose of the current study was to conduct an updated systematic review of the suicide literature through the framework of the RDoC Cognitive Systems model with a specific focus on neurocognitive differences between individuals with suicide behavior compared to patients controls and/or healthy controls. A second aim of this review was to identify RDoC Cognitive Systems measures that may distinguish suicide groups and to provide suggested directions for future studies. Evaluating SB using the RDoC Cognitive Systems domain may clarify important neurocognitive risk factors across psychiatric disorders as well as underlying neurophysiological mechanisms associated with SB.

2. Methods

2.1. Sources

A systematic literature search of the PubMed database was performed for studies published from 1980 until April 31st, 2019. The term “suicide” or “suicidal” was combined with the following constructs and subconstructs of the RDoC Cognitive Systems: awareness, higher perceptual processes, and motor action; selective and divided attention; goal selection; response selection; inhibition, suppression, performance monitoring; visual perception, auditory perception, olfactory perception, sensory/multimodal/perception; declarative memory, autobiographical memory, short-term memory, long-term memory; memory, working memory; abstract thinking, concreteness, poverty of speech, and verbal fluency. Additional potential studies were identified through bibliographical references of selected papers and reviews.

2.2. Study selection and classification

Abstracts identified through the literature search were evaluated for the following inclusion criteria: 1) published in a peer-reviewed journal in the English language; 2) included a group with either suicidal attempts (SA) and/or suicidal ideation (SI). A suicide attempt was defined as any act carried out with the intent to die, and was differentiated from non-suicidal self-injury (NSSI); and 3) included at least one cognitive construct as outlined by the RDoC Cognitive Systems framework. Full articles were then obtained for final review. Chart reviews, epidemiological studies, and studies that utilized suicide decedents or high-risk participants with a family history of suicide were not included in this review. A standardized method was used for extracting data from each study, including publication, participants, cognitive tasks, definition of SB, and study results. Six constructs that encompassed the Cognitive Systems domain were used to group studies. These included: 1) Attention, 2) Cognitive Control, 3) Declarative Memory, 4) Language, 5) Perception, and 6) Working Memory. All authors agreed on the inclusion and classification of studies in this review. The review was performed by calculating the percentage of studies with significant findings observed between groups based on the type of suicide behavior. The table in Appendix 1 provides a summary of the number of studies with significant/nonsignificant results for each construct in the cognitive systems domain. See Appendix 2 for the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) checklist. The quality of included studies was assessed using the Newcastle-Ottawa Scale (Appendix 3).

Studies of hallucinations and delusions were reviewed under the *Perception* construct; however, these symptoms also involve the RDoC *Social Processes* domain and fall under the construct of *Perception and Understanding of Self*. Due to the overlap in domains, we excluded any studies that were based on reported or observed clinical symptoms of perception (hallucinations and delusions), since these were not cognitive measures of perception captured through neuropsychological testing. This resulted in the elimination of 34 perception studies. Finally, studies examining attentional bias and decision-making were excluded because the RDoC framework captures these constructs within the *Negative and Positive Valence Systems* domains.

3. Results

Of the 1386 originally identified abstracts, 74 studies met the inclusion criteria for this review (see Fig. 1). Table 1 summarizes the studies reviewed under the six constructs in the Cognitive Systems domain. Thirty-two studies had tests from more than one construct; however, each study was counted only once. The largest number of studies (n = 54) was found under the cognitive control construct and the fewest number of studies (n = 13) were found under the attention category (Table 2).

3.1. Summary of findings

The majority of studies reviewed (65%) had significant between-group differences in cognition between individuals with SB and the comparison group. Deficits in cognitive control were associated with SB and had the greatest percentages of studies (69%) with significant main findings. In contrast, attention and working memory did not differ consistently by SB groups and had the lowest percentages of studies with significant findings, 23% and 20% respectively. Most of the research focused on populations with psychiatric illness and fell within four different categories: depression (n = 21), bipolar disorder (n = 11), and schizophrenia (n = 9). Participants without a psychiatric diagnosis (n = 14) or mixed diagnostic sample (n = 10) were also included.

3.2. Suicidal ideation

Eight studies focused primarily on suicidal ideation (SI) and found that individuals with SI showed deficits in attention (Kim et al., 2015) and cognitive control (Kasckow et al., 2016; Miranda et al., 2012, 2013)

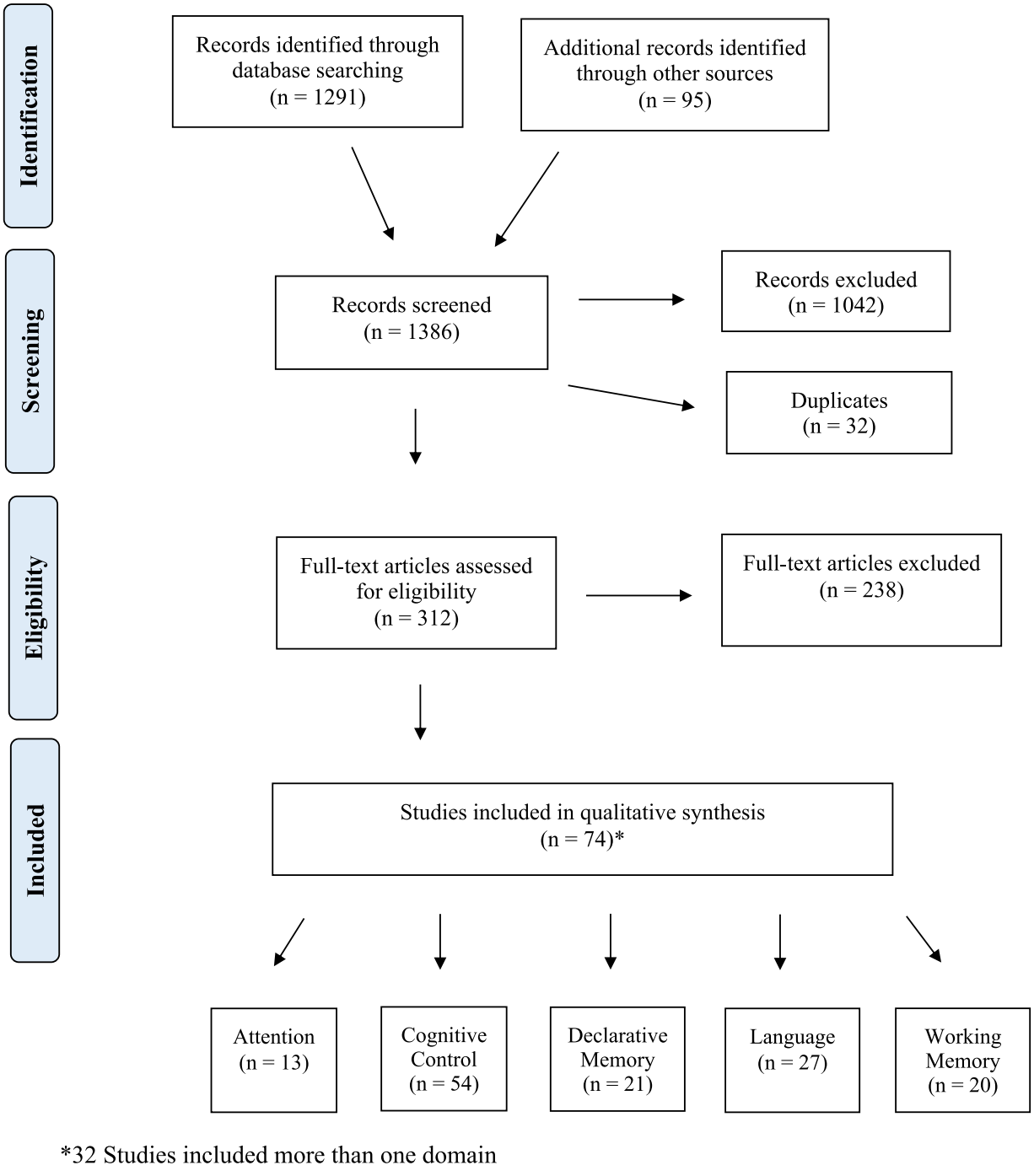

Fig. 1. Flowchart summarizing the study selection process for systematic review.

Table 1
Summary of study findings between suicide groups for constructs in the RDoC cognitive systems domain.

	SA vs. HC	SA vs. Patient Control	SI vs. SA	High Lethality SA vs SB	Patient Controls vs. HC
Working Memory	5+ / 7-	1+ / 15-	0+ / 1-	1+ / 0-	2+ / 7-
Language	11+ / 4-	4+ / 19-	0+ / 1-	2+ / 0-	3+ / 8-
Attention	2+ / 6-	3+ / 9-	0+ / 1-	0+ / 2-	1+ / 6-
Cognitive Control	18+ / 13-	29+ / 15-	5+ / 1-	4+ / 0-	5+ / 16-
Declarative Memory	8+ / 2-	8+ / 13-	0+ / 2-	1+ / 0-	5+ / 6-

+ significant difference between groups.
- no significant difference between groups.

Table 2
Summary findings between suicide groups for cognitive measures in the RDoC cognitive systems domain.

Attention Measure	SA vs. HC	SA vs. Patient Control	SI vs. SA	High Lethality SA vs. SB	Patient Controls vs. HC	Type
CPT	5-	6-		2-	3-	cognitive measure
CANTAB IDED-ED		1-	1-			cognitive measure
Impulse Control Scale		1+				self-report
TOVA		1+				cognitive measure
RBANS	1+	1+				cognitive measure
TMT A		1-				cognitive measure
CAT	1+	1+				cognitive measure
WMS-R	1-	1-		1-	1-	cognitive measure

Cognitive Control Measure	SA vs. HC	SA vs. Patient Control	SI vs. SA	High Lethality SA vs. SB	Patient Controls vs. HC	Type
TMT	1+ / 6-	2+ / 11-	1-	1+	1-	cognitive measure
D-KEFS CWIT	1-	1+ / 2-		1+		cognitive measure
WCST	1+ / 5-	5+ / 8-	1+	2+	2-	cognitive measure
Stroop	7+ / 5-	3+ / 7-	1+	1+	3+	cognitive measure
IMT/DMT	3-	1+ / 3-				cognitive measure
Go-No-Go Paradigm	3+ / 2-	3+ / 4-	2+		1+	cognitive measure
SST	2-	1-				cognitive measure
EXIT25		1+				cognitive measure
TCIP		1+				cognitive measure
Time Estimation Test					1-	cognitive measure
Time Production Task	1-	1-				cognitive measure
BRIEF	1+ /1-	1-				cognitive measure
CPT	2+	1+ / 2-				cognitive measure
HSCT	2-	1+ / 3-				cognitive measure
RSC	1-	1-				cognitive measure
SKIP	1+	1+				cognitive measure
Delayed Alteration Task	1-		1-			cognitive measure
Impulsivity Control Scale	1+					self-report
BIS	4+ / 1-	2+ / 5-				self-report

Declarative Memory Measure	SA vs. HC	SA vs. Patient Control	SI vs. SA	High Lethality SA vs. SB	Patient Controls vs. HC	Type
CVLT	2-	2-			1-	cognitive measure
WASI		1-				cognitive measure
D-KEFS Verbal Fluency Test		1-				cognitive measure
RAVLT	1-	1+ / 2-				cognitive measure
RCF		1+				cognitive measure
EXIT25	1+	2+				cognitive measure
Mattis DRS	1+	1+			1-	cognitive measure
SRT	2+ / 1-	1-			1-	cognitive measure
BVRT	2+ / 1-	1-			1-	cognitive measure
A not B reasoning test	1-	1-		1-	1-	cognitive measure
VLL- Immediate & Delayed Recall		1-				cognitive measure
ROCFT	1-	1-			1+	cognitive measure
Visual reproduction	1+	1+				cognitive measure
WMS-R	1-	2-	1-			cognitive measure
AMT	2+	2+			1+	cognitive measure
RBANS	1+	1+ / 1-			1-	cognitive measure

Language Measure	SA vs. HC	SA vs. Patient Control	SI vs. SA	High Lethality SA vs. SB	Patient Controls vs. HC	Type
COWAT	1+ / 2-	4-				cognitive measure
FAS	3+ / 1-	1+ / 3-			2+	cognitive measure
Design Fluency Test	1+					cognitive measure
WASI		1-				cognitive measure
D-KEFS Verbal Fluency Test		1-				cognitive measure
CVLT	1-	2-		1+	1-	cognitive measure
WAIS-R		1-				cognitive measure
Letter and Category Fluency tasks	1+ / 1-					cognitive measure
Ruff Figural Fluency Test		1-				cognitive measure
Letter 2-back task	1-	1-				cognitive measure
Five Point Test		1-				cognitive measure
Interpret common proverbs	1+					cognitive measure
Verbal Fluency Test	1+	1-			1+	cognitive measure
Verbal working memory	1+	1+				cognitive measure
Semantic verbal fluency	1+	1+				cognitive measure
Swedish MMSE	1-					cognitive measure
RBANS	1+	1+			1-	cognitive measure

Working Memory

(*continued on next page*)

Table 2 (*continued*)

Measure	SA vs. HC	SA vs. Patient Control	SI vs. SA	High Lethality SA vs. SB	Patient Controls vs. HC	Type
WAIS Digit Span	2-	4-			1-	cognitive measure
Add Health word list and number recall task	1-		1-			cognitive measure
Letter Number Sequencing task		1-	1-			cognitive measure
Hopkins Verbal Learning Test		1-				cognitive measure
N-Back Test	3-	1-			2-	cognitive measure
A not B reasoning test	1+ / 2-	1-		1-	2-	cognitive measure
Consonant Trigram Test		1-				cognitive measure
CVLT		1-				cognitive measure
ROCFT	1-	1-			1+	cognitive measure
RVLT	1-	2-			1+	cognitive measure
Letter-Number task		1-				cognitive measure
Trails B		1-				cognitive measure
Spatial N-back	1-					cognitive measure
Verbal working memory	1+	1+				cognitive measure
Semantic verbal fluency	1+	1+				cognitive measure

Table Abbreviations: Barratt Impulsiveness Scale (BIS); Behavioral Rating Inventory of Executive Functions (BRIEF); Benton Visual Retention Test (BVRT); Buschke Selective Reminding Test (SRT); California Verbal Learning Test (CVLT); Cambridge Automated Test Battery Intradimensional/Extradimensional (CANTAB IDED); Clinical Assessment of Attention Deficit (CAT); Continuous Performance Test (CPT); Controlled Oral Word-Association Test (COWAT); Delis–Kaplan Executive Function System (D-KEFS); Delis–Kaplan Executive Function System Color-Word Interference Test (D-KEFS CWIT); Dementia Rating Scale (DRS); Executive interview (EXIT25); F-A-S Test (FAS); Hayling Sentence Completion Test (HSCT); Healthy Controls (HC); Immediate & Delayed Memory Test (IMT/DMT); Mini-Mental Status Examination (MMSE); Repeatable Battery for the Assessment of Neuropsychological Status (RBANS); Rey Auditory Verbal Learning Test (RAVLT); Rey-Osterrieth Complex Figure (ROCF); Rey Complex Figure (RCF); Rule Shift Cards (RSC); Selective Reminding Task (SRT); Single Key Impulsivity Paradigm (SKIP); Stop-Signal Task (SST); Suicidal Ideation (SI); Suicide Attempt (SA); Suicide Behavior (SB); Test of Variable Attention (TOVA); Trail Making Test (TMT); Verbal List Learning (VLL); Wechsler Adult Intelligence Scale (WAIS); Wechsler Abbreviated Scale of Intelligence (WASI); Wechsler Memory Scale, Revised (WMS-R); Wisconsin Card Sorting Test (WCST).

and declarative memory (Crocker et al., 2019); however, differences in working memory (Xie et al., 2018) and verbal fluency (Pu et al., 2015, 2017) were not detected.

3.3. Ideation and attempts

Eighteen studies examined both ideation and attempts. In seven of those studies, cognition was compared for ideators vs. attempters. There were no differences between ideators and attempters in attention (Delaney et al., 2012), declarative memory (Delaney et al., 2012; Gujral et al., 2014), or working memory (Crandall et al., 2018; Delaney et al., 2012). There was evidence of cognitive control differences between attempters and ideators, but the relationship is complex. Minzenberg and colleagues evaluated cognitive control differences between ideators and attempters in three different neuroimaging studies (Minzenberg et al., 2015a, 2015b, 2014). During a cognitive control task completed by schizophrenic patients, there were no between-group differences on task performance; however, attempters had greater activation in the left prefrontal motor cortex during the task when compared to ideators (Minzenberg et al., 2014). In another study of participants with recent onset schizophrenia, attempters were less accurate on a cognitive control task and patterns of dorsal anterior cingulate cortex (ACC) connectivity during conflict monitoring differentiated attempters from ideators (Minzenberg et al., 2015a). In a study of patients with bipolar disorder and depression with psychotic features, ideators had lower accuracy on a cognitive control task, while attempters showed greater control-related activation in the ventrolateral PFC, rostrolateral PFC, and had lower activity in the cuneus and precuneus (Minzenberg et al., 2015b). Furthermore, Burton et al. (2011) found that attempters performed more poorly on inhibition measures, but demonstrated superior problem-solving ability to ideators.

3.4. Lethality and severity of attempts

Cognitive ability was examined in individuals with suicide attempts in 40 studies and 68% of those studies reported that attempters performed worse on all constructs within the Cognitive Systems domain compared to controls. Studies with attempters showed cognitive control deficits and impulsivity in 63% of studies. Attempters had reduced specific memories compared to controls, but in most studies this specificity was not different from psychiatric controls. While measures of suicide severity and lethality of SA were collected in many studies, outcomes of these variables were reported in only seven studies; six with lethality and one with violent SA. Higher lethality of attempts was associated with poorer cognitive control (Keilp et al., 2008; Keilp et al., 2001; McGirr et al., 2012; Richard-DevantoySzanto et al., 2015; Swann et al., 2009), declarative and working memory (Keilp et al., 2001). Violent attempters showed worse performance on cognitive control tasks, but no differences in attention, language, declarative or working memory were evident (Keilp et al., 2013).

3.5. Suicide across the lifespan

A substantial subset of research analyzed (23 studies) focused on either adolescent or elderly populations. Eleven studies focused on elderly populations, defined as participants over the age of sixty. Of the 12 adolescent studies reviewed, 83% showed significant differences between groups with SB and controls; whereas 73% showed significant differences between groups in elderly populations.. Cognitive control studies with adolescents demonstrated significant relationships between higher impulsivity, less response inhibition, or less cognitive flexibility and SB (Buchman-Schmitt et al., 2017; Meza et al., 2016; Miranda et al., 2012, 2013; Mustanski and Liu, 2013; Pan et al., 2011; Weis et al., 2015). Most of the studies on elderly populations fell under the construct of cognitive control (Kasckow et al., 2016; McGirr et al., 2012; Richard-Devantoy et al., 2011, 2016, 2012; Wyart et al., 2016), while the rest focused on language (Olsson et al., 2016; Wiktorsson et al., 2010) and memory (Dombrovski et al., 2008). Three of these studies found no between-group differences (Wiktorsson et al., 2010; Wyart et al., 2016), though King (2000) demonstrated an interactive effect of age and group such that attempters showed greater working memory performance declines with age. Overall, cognitive deficits in all areas with SB were more apparent and significant among youth. Interestingly, both age groups saw an effect on cognitive control, but youth showed more prominent effects.

3.6. Summary of cognitive systems constructs

3.6.1. Attention

Thirteen studies evaluated attention and SB. The Continuous Performance Test (CPT) was used to measure attention in all but two studies. Eighty percent of attention studies did not show a difference between groups, although all of these studies focused on specific psychiatric populations. Conversely, two studies in adolescents that did not focus on a particular psychiatric population showed impairment in attention with SB (Horesh, 2001; Kim et al., 2015). Results from an inpatient sample of adolescents with different diagnoses (e.g., schizophrenia, affective disorders, etc.) revealed that attempters made more commission errors and demonstrated more impulsivity and inattention that non-attempters (Horesh, 2001). Additionally, Kim et al. (2015) found that high school students with higher ideation demonstrated more omission and commission errors on attention tasks independent of depression. Interestingly, a recent study completed with first episode patients with schizophrenia reported higher attention in suicide attempters compared to patient controls (Zhang et al., 2018).

3.6.2. Cognitive control

Fifty-four studies of cognitive control and SB were reviewed and 76% found an association between cognitive control and SB. The Stroop Test, Wisconsin Card Sorting Test (WCST), Trail Making Test (TMT), and the Go/No Go paradigm were the most commonly utilized tasks to assess cognitive control. Seventy-two percent of studies that used the Stroop Test demonstrated a significant difference in inhibition for those with SB. Five studies did not show a significant difference in Stroop performance (Bartfai et al., 1990; Malloy-Diniz et al., 2009; Martínez-Arán et al., 2004; Marzuk et al., 2005; Ponsoni et al., 2018). Although, three of those studies had small sample and group sizes (Bartfai et al., 1990; Malloy-Diniz et al., 2009; Martínez-Arán et al., 2004). The majority of studies (70%) on cognitive control and SB focused on psychiatric populations. All of the cognitive control studies completed with depressed or schizophrenia/schizoaffective disorder populations showed significant between-group differences for SB.

3.6.3. Language

Twenty-seven studies were identified that evaluated language and SB. Fluency was the most common aspect of language assessed. The most common measures of fluency were the Controlled Oral Word-Association Test (COWAT) and the F-A-S Verbal Fluency Test which were present in over half of the studies reviewed. Eleven studies used a validated suicide measure to assess suicidality, while the majority relied on clinical interviews and hospitalization records. Participants with MDD were the most studied group within the language construct (Audenaert et al., 2002; Keilp et al., 2014, 2013; Keilp et al., 2001; King et al., 2000; Pu et al., 2015, 2017; Richard-Devantoy et al., 2016, 2012); however, only 33% of studies focusing exclusively on depression showed significant results between SB and language fluency. Interestingly, one bipolar study showed that patients with a history of lethal suicide attempts had higher verbal fluency scores than those with a history of non-severe attempts (Olie et al., 2015). Only eleven studies found that deficits in language fluency or language learning correlated with suicidal behavior.

3.6.4. Declarative memory

Twenty-one publications that studied aspects of declarative memory and SB were assessed. There was a high amount of variability between studies with regard to the chosen measure of memory. The most repeated measure was the Buschke Selective Reminding Test found in six papers (27%) (Harkavy-Friedman et al., 2006; Keilp et al., 2014, 2013; Keilp et al., 2001). Fifty-nine percent of the studies utilized a validated suicide measure. Depressed participants were also the most studied population evaluating SB and declarative memory, appearing in nine studies (Dombrovski et al., 2008; Gujral et al., 2014; Keilp et al., 2014, 2013; Keilp et al., 2001; Pu et al., 2017; Rohrer et al., 2006). A significant difference between suicide attempters and non-attempters on memory measures was found slightly more than half (57%) of the studies (Canal-Rivero et al., 2018; Crocker et al., 2019; Dombrovski et al., 2008; Gujral et al., 2014; Harkavy-Friedman et al., 2006; Keilp et al., 2013; Keilp et al., 2001; Martínez-Arán et al., 2004; Pollock and Williams, 2001; Rohrer et al., 2006; Zhang et al., 2018).

3.6.5. Working memory

Twenty studies were identified that assessed working memory and SB. Four studies used the A not B reasoning test to assess working memory (Harkavy-Friedman et al., 2006; Keilp et al., 2014, 2013; Keilp et al., 2001), and all but one (Keilp et al., 2001) of those studies gave it in conjunction with the N-back test. One study included a spatial N-back task in the absence of the A not B reasoning test (Raust et al., 2007) and another used a letter N-back test (Long et al., 2018). Three additional studies used the Digit Span task from the Wechsler Adult Intelligence Scale (WAIS) to assess working memory (Legris et al., 2012; Pustilnik et al., 2017; Richard-Devantoy et al., 2016) and two studies used a Letter Number Sequencing task (Delaney et al., 2012; Potkin, 2002). Twelve studies included a validated measure of suicidal behavior. Only three studies of working memory showed a significant difference between groups (Keilp et al., 2014; Keilp et al., 2001; Xie et al., 2018).

4. Discussion

The aim of this systematic review was to examine SB using the RDoC Cognitive Systems model to determine if study findings support the presence of cognitive deficits independent of unique or specific psychiatric disorders that may be present across transdiagnostic disorders. While many cognitive deficits reported in the reviewed literature could be symptomatic of a psychiatric disorder, 79% of studies that included a patient control group showed significant deficits in SB groups when compared to a patient control group. This was most clearly evident in the cognitive control domain, as twenty-nine studies out of forty-four studies that included a patient control group (66%) identified cognitive control deficits in the suicidal group when compared to the patient control group.

A second aim of this review was to examine the specificity of cognitive measures in the RDoC Cognitive Systems model to distinguish between groups with and without SB. Measures in the RDoC Cognitive Systems domain that may be most sensitive to detecting differences in SB appear to fall under the cognitive control domain. We observed that studies which utilized cognitive control assessment paradigms based on the RDoC Matrix, particularly the Stroop and Go/Nogo paradigm showed differences between patient groups with and without SB. Incorporation of these cognitive control paradigms with imaging protocols are needed to further characterize morphological and/or functional mechanisms underlying cognitive components of suicide, especially studies conducted within the RDoC framework.

An additional goal of this review was to determine whether a pattern of cognitive deficits was associated with progression from suicide ideation to suicide attempts. Review of the Cognitive Systems constructs found impairments in cognitive control in each stage of SB (prior to, and during SI and SA). Individuals with suicidal ideation only demonstrated deficits in cognitive control compared to psychiatric controls. It is possible that deficits in cognitive control may occur prior to the onset of psychiatric disorders and increase the risk for suicidal thoughts and behavior. Based on the studies reviewed, neurocognitive differences between psychiatric patients with ideation vs. attempts were only observed in the cognitive control domain for inhibition. Interestingly, one study reported that psychiatric patients with suicide attempts performed more poorly than psychiatric patients with ideation on tasks requiring inhibition, but showed superior problem-solving ability. These results are consistent with imaging studies that have

demonstrated that brain activation and connectivity differ between psychiatric patients with suicide ideation and those with a history of attempts in circuits related to cognitive control. Therefore, deficits in inhibitory function may play a role in the progression from suicidal thoughts to attempts. Further, more lethal suicide attempts in psychiatric patients were associated with deficits in cognitive control, declarative memory, and working memory. In contrast, impaired cognitive control alone was related to use of violent means. Thus, impaired cognitive control may increase risk for SI and contribute to the progression to suicide attempts and more lethal or violent attempts and declarative and working memory deficits may be associated with attempt lethality.

One of the main objectives of the RDoC model is to identify fundamental circuit-based behavioral dimensions with the aim of identifying more effective targets for clinical intervention. Recent neuroimaging findings in studies of SB have reported alterations in brain regions that subserve several key cognitive functions reviewed above using the RDoC approach (Balcioglu and Kose, 2018). Neuroimaging studies have reported structural and functional differences in the frontostraital network and fronto-limbic region including the ventrolateral, dorsomedial, and dorsolateral PFC, the ACC, the amygdala, and the medial temporal cortex with SB (Jollant et al., 2011). In particular, the dorsal regions of the lateral PFC, ACC, and the parietal cortex have been implicated in maintaining cognitive control (Breukelaar et al., 2017) and deficits reported with SB are consistent with abnormalities identified in these areas.

In completing this review, a number of challenges were encountered using the RDoC Cognitive Systems framework to evaluate neurocognitive deficits in SB. A considerable portion of the existing literature on cognition and suicide included cognitive constructs that did not directly translate into the RDoC model. For example, “executive function” has shown to be related to SB, but is not one of the Cognitive Systems domain constructs. However, executive function contains important components of attention, cognitive control, and working memory that are constructs in the RDoC Cognitive Systems domain. Papers that used the term “executive functioning” were not excluded; however, the term “executive functioning” was not used in the search criteria. While a number of studies that were evaluated in this review were conducted after the emergence of the RDoC model in 2008, many studies did not utilize cognitive assessments and paradigms identified in the RDoC Matrix. Additionally, many studies measured constructs outside the cognitive systems domain, yet reported these as “cognitive” territories. We addressed these challenges by defining rigorous inclusion and exclusion criteria for the present study and determined that some constructs fit more appropriately in other domains (e.g., Social Processes and Negative Valence System). Another challenge was that most studies reviewed did not assess severity of illness or use of medications, which may impact both cognitive functioning and risk for suicidal behavior. The rate of positive or negative studies is not sufficient to confirm or invalidate an association. The number of subjects and the quality of studies is also of major importance. A meta-analysis of findings may be necessary.

One major limitation in interpreting study findings was the variability of methods used to characterize suicide behavior across studies. Surprisingly, 48% of studies utilized a single question/item, chart review, or clinical interview to quantify SB. The SCID or KSADS were commonly used clinical interviews, chart review and hospital admissions were often used to confirm SB, and nine studies used only 1–2 questions to determine if SB was present. Studies reviewed also utilized a variety of standard measures to assess SB. The most commonly used measures captured ideation, intensity, type, severity, or lethality and are listed in Appendix 1. However, for many studies SB was not well defined and ideation was combined with attempts in the analyses of 25% of studies. Despite including patient controls with SI in many studies, only a limited number of studies examined differences between groups with ideation compared with suicide attempts. Furthermore, while it appeared that severity and lethality were assessed using standard measures in many studies, only seven studies (less than 10% of all studies) reported outcomes based on severity, lethality, or violence in SB. A recent meta-analysis of neuroimaging studies in suicidal patients demonstrated the importance of examining violent attempts and suggested that use of violent means and family history of suicide may indicate a neural phenotype (Jollant et al., 2018). In order to better understand how SB progresses and changes in severity, individuals with suicidal ideation and suicide attempts need to be examined separately and severity of SB and use of violent means need to be reliably evaluated and reported.

In summary, use of the RDoC cognitive systems framework to evaluate SB revealed that the majority of studies reviewed provide evidence for deficits in cognitive control systems. Features of cognitive control including impulsivity, response inhibition, and cognitive flexibility were found to be associated with SB. Other Cognitive Systems constructs had mixed findings and did not show a strong relationship with SB. Future studies of suicide behavior need to include a comprehensive assessment of suicide to classify and quantify SB, including further analyses of severity, lethality, and use of violent means. Longitudinal studies with healthy children that assess neurocognitive abilities prior to the onset of SB or psychiatric illness are needed to further investigate risk for SB and the progression from risk to SI and SA. While the current study was focused on the Cognitive Systems domain, including facets from all of the RDoC domains may provide a more comprehensive model of SB. While there are a number of challenges associated with incorporating the RDoC framework, it is useful for a transdiagnostic approach to evaluating SB. Use of the RDoC model in future studies of SB may lead to a greater understanding of underlying circuits which is critical to furthering suicide prevention and treatment efforts.

Declaration of Competing Interest

None.

Acknowledgements

This work was supported in part by the Utah Science Technology and Research (USTAR) Initiative. The views in this publication are those of the authors, and do not necessarily represent the official policy or position of the Department of Veterans Affairs or the United States Government.

Appendix 1. Summary of studies included in the review by RDoC cognitive systems constructs

Attention Reference	Population	Cognitive Measure	Suicide Measure	Results	Additional Constructs
Canal-Rivero et al. (2018)	517 patients (51 w/ SB and 466 w/o SB)	CPT - total number of correct responses	Medical records	No difference between groups. CPT performance did not predict SB at follow-up	WM, CC, DM

Delaney et al. (2012)	310 patients w/ SCZ or SZA disorder (63 w/ SI; 48 w/ SA; 172 w/o SA)	CANTAB IDED-ED	SCID -IV (for axis I)	No significant differences between groups	DM, WM
Harkavy-Friedman et al.-(2006)	51 subjects w/ BD (32 w/ BDI; 19 w/ BDII) w/ SA; 58 HCs	CPT d'	SCID -IV	No significant differences between groups	CC, DM, LANG, WM,
Horesh (2001)	60 adolescent inpatients (37 admitted due to SA)	Impulse Control Scale; TOVA	Child Suicide Potential Scale	SA group made more commission errors & had more impulsivity & inattention	
Keilp et al. (2001)	50 unmedicated patients w/ MDD (21 w/o SA;14 w/ low lethality SA; 15 w/ high lethality SA; 22 HCs	CPT, Identical Pairs; Attention/ Concentration subtest of the WMS-R	SCID-III-R (for axis I and II)	No significant difference between groups	CC, DM, LANG, WM
Keilp et al. (2008)	83 MDD subjects w/o SA; 53 MDD subjects w/ low lethality SA; 42 MDD subjects w/ high lethality SA; 66 HCs	CPT	SCID-IV (for axis I and axis II)	No significant difference between groups	CC
Keilp et al. (2013)	152 adults w/ current MDD (72 w/ SB, 80 w/o SB); 56 HC	CPT – Identical Pairs, 4-digits fast condition	C-SSRS; SIS; BLS	No significant difference between groups	CC, DM, LANG, WM
Keilp et al. (2014)	80 subjects s w/ MDD & SA; 81 subjects w/o MDD or SA	Computerized CPT – Identical Pairs	SSI; BLS	Attempters had poorer performance on the CPT, but disappeared after controlling for intelligence. No differences between groups based on lethality or violent attempts.	CC, DM, LANG, WM
Kim et al. (2015)	2,462 students from 8 high schools in South Korea	Comprehensive Attention Test (CAT) – (modified CPT)	SSI	Participants w/ higher SSI scores had more errors on visual sustained attention tasks & divided attention tasks independent of MDD	
Malloy-Diniz et al. (2009)	39 adults w/ BD (21 w/o a hx of SA & 19 w/ SA) & 53 HC	CPT II	Records review; Semi-structured interview	No difference between groups. Number of SA were correlated with amount of errors on the Stroop	CC, DM, WM
Potkin et al. (2002)	188 patients in the InterSePT trial (93 w/ SCZ; 95 w/ SZA)	CPT; TMT A	Clinical Global Impression of Severity of Suicidality; SST	No significant difference between groups	DM, LANG, WM
Yen et al. (2008)	96 patients w/ BDI in remission (9 w/ SB; 87 w/o SB)	CPT	Violence & Suicide Assessment Scale	No significant difference between groups	CC, LANG
Zhang et al. (2018)	357 first-episode patients with SCZ (43 w/ SA and 314 w/o SA) and 380 HCs	RBANS	Question "In your entire lifetime did you ever attempt suicide?" SA confirmed w/ medical records & interviews	SA performed better than non-attempters on attention.	LANG, WM

Cognitive Control Reference	Population	Cognitive Measure	Suicide Measure	Results	Additional Constructs
Andover et al. (2011)	173 male prisoners; 45 NSSI w/ or w/o SA; 52 w/ SA only; 76 w/o NSSI or SA	TMT	2 questions regarding SA and NSSI	No significant difference between groups	DM, LANG
Barrett et al. (2011)	174 patients w/SCZ (53 w/ SA & 121 w/o SA)	D-KEFS CWIT	IDS-C and CDS	No significant difference between groups.	DM, LANG
Bartfai et al. (1990)	9 male inpatients w/ SA; 2 control groups (8 HC male blood donors; 7 patients w/ chronic pain for ≤ 2 years)	WCST; Stroop Test	SA at inpatient admission	No significant difference between groups	LANG
Brenner et al. (2015)	133 veterans (48 w/o TBI or SA; 51 w/ TBI but w/o SA; 12 w/ SA but w/o TBI; 22 w/ SA & TBI	IMT/DMT; WCST	Lifetime Suicide Attempt Self-Injury Interview; SSI	No significant difference between groups	
Buchman-Schmitt et al.-(2017)	105 undergraduates (participants who endorsed SA & SI on screening were prioritized)	General Disinhibition scale from the brief-form Externalizing Spectrum Inventory	Interpersonal Theory of Suicide; Suicide Cognition Scale	Weak inhibitory control was associated with suicidality. Thwarted belongingness & perceived burdensomeness mediated the interaction between disinhibition & SB	
Burton et al. (2011)	77 subjects w/ psychiatric illness hospitalized following SI (N = 40) or SA (N = 37)	Delay = Go Computer Task; TMT, A and B; Stroop Test; WCST	Chart review	Attempters had worse inhibition on Stroop interference but better performance on the WCST (problem-solving) than ideators	LANG
Canal-Rivero et al. (2018)	517 patients (51 w/SB and 466 w/ o SB)	TMT	Medical records	No difference between groups and did not predict SB at follow-up.	ATTN, WM, DM
Chamberlain et al. (2013)	304 young adults (45 w/ SB & 259 w/o SB)	SST	MINI suicidality module	No significant difference between groups	
Crocker et al. (2019)	282 Veterans (50 with SI and 232 w/o SI)	WCST; D-KEFS TMT	Question 9 from BDI-II	No significant difference between groups	DM
Dombrovski et al. (2008)	32 suicidal MDD subjects aged 60+; 32 nonsuicidal MDD subjects	EXIT25	SCID -IV	Suicidal participants performed worse than non-suicidal depressed participants on the total EXIT25	DM
Dougherty et al. (2004)	50 adults (20 controls; 20 w/ a single SA;10 w/ multiple SA)	BIS; IMT/DMT modified CPT	Lifetime Parasuicide Count	Individuals with SA had more commission errors	
Dougherty et al. (2009)	25 adolescents engaging in NSSI w/ SA and 31 w/o SA	BIS; Two Choice Impulsivity Paradigm (TCIP); GoStop Impulsivity Paradigm	Beck SSI	NSSI w/ SA reported worse impulsivity on the TCIP compared to NSSI-only. At follow-up, SI & impulsivity, butNSSI w/ SA had more impulsivity & smaller-sooner choices	
Ellis et al. (1992)	20 suicidal & 27 non-suicidal psychiatric inpatients	TMT; WCST	SA at inpatient admission	No significant difference between groups	

Garcia Espinosa et al. (2010)	42 w/ temporal lobe epilepsy (24 at risk for SA; 12 w/ SA)	WCST (Spanish Version)	Risk for Suicide Scale	Attempters had more perseverative errors, total errors, and other errors on the WCST.	
Gilbert et al. (2011)	67 adults w/ BD	BIS-II; WCST	C-SSRS; Beck SSI	No difference between groups on WCST. Nonattempters reported higher impulsivity on BIS compared to SA. Lower impulsivity associated w/ higher lethality of prior SA	LANG, WM
Harkavy-Friedman et al.-(2006)	51 subjects w/ BD (32 w/ BDI; 19 w/ BDII) w/ SA; 58 HCs	Go-No-Go corrected commission; Time Estimation Test; Stroop % error	SCID -IV	BD performed worse than HCs on Go-No-Go Test. Participants w/ BDII did worse than participants with BDI on the Stroop Test.	ATTN, DM, LANG, WM
Homaifar et al. (2012)	47 adult veterans w/ TBI	WCST (S); IMT/DMT	C-SSRS	Only the WCST perseverative errors score differed significantly between individuals with and without one or more SA	
Kasckow et al. (2016)	468 adults age 60+ w/ MDD who received venlafaxine XR for up to 16 weeks	DKEFS CWIT condition 3 and 4; TMT (B/A) score	SSI	Worse scores on the CWIT were associated with the 'high and persistent suicidal ideation' group.	
Keilp et al. (2001)	50 unmedicated patients w/ MDD (21 w/o SA;14 w/ low lethality SA; 15 w/ high lethality SA; 22 HCs	TMT; WCST; a single-item Stroop task	SCID-III-R (for axis I and II)	High lethality SA performed worse on the WCST failure to maintain, and TMT A not B reaction time. Depressed patients performed more poorly on Stroop interference	ATTN, DM, LANG, WM
Keilp et al. (2008)	83 MDD subjects w/o SA; 53 MDD subjects w/ low lethality SA; 42 MDD subjects w/ high lethality SA; 66 HCs	Stroop Test	SCID-IV (for axis I & II)	Stroop interference was significantly worse in all depressed subjects relative to non-patients, and worse in high lethality suicide attempters relative to all other groups	ATTN
Keilp et al. (2013)	152 adults w/ current MDD (72 w/ SB, 80 w/o SB); 56 HC	WCST; TMT; Go/No-Go Test; N-Back; Stroop Test	C-SSRS; SIS; BLS	Violent SA scored worse than non-violent SA on the Go/No-Go. SA performed worse than controls on Stroop interference independent of SI & depression severity	ATTN, DM, LANG, WM
Keilp et al. (2014)	80 subjects s w/ MDD & SA; 81 subjects w/o MDD or SA	Go-No Go Test; Time Production Task; Stroop Test	SSI; BLS	After controlling for intelligence, attempters had poorer performance the Stroop interference.	ATTN, DM, LANG, WM
Kim et al. (2003)	333 patients w/ SCZ (200 patients w/ SA; 133 w/o SA)	WCST	Structured Interview	Participants who reported lifetime SB had more WCST perseverative errors.	DM, LANG, WM
King et al. (2000)	18 older inpatients w/ current MDD & SA; 29 older MDD inpatients w/o SA	TMT Part B; WCST	SCID-III-R	No differences between groups on all tasks. Attempters showed greater performance declines with age on TMT part B	LANG, WM
LeGris et al. (2012)	42 women w/ BPD; 41 HCs	Stroop interference, SST	SBQ-R	Worse Stroop interference control was related to suicide risk and lifetime SA	WM
Loyo et al. (2013)	75 subjects: 25 SAs w/ MDD; 25 MDD w/o SA, and 25 non-MDD subjects	Stroop Test; WCST; BRIEF	Plutchik Risk of Suicide Scale	Attempters had higher response time in the interference condition and more reading errors on the Stroop.	
Malloy-Diniz et al. (2009)	39 adults w/ BD (21 w/o a hx of SA & 19 w/ SA) & 53 HC	WCST; Stroop	Records review; Semi-structured interview	No difference between groups. Number of SA correlated with errors on the Stroop	ATTN, DM, WM
Martínez-Arán et al. (2004)	30 BD depressed; 34 BD manic; 44 BD euthymic; 30 HCs	WCST, Stroop task; TMT	SCID-IV	No significant correlations between EF scores and past suicide attempts.	DM
Marzuk et al. (2005)	53 adults w/ MDD (25 w/ current SI; 28 w/o current SI)	BIS; WCST; TMT; Stroop Test	SSI	Differences in WCST perseverative errors & TMT performance, controlling for age, IQ, severity of depression and prior SA	LANG
McGirr et al. (2012)	93 adults age 60+ (30 HCs; 29 MDD w/o SA; 20 low-lethality SA; 14 high-lethality SA)	WCST	SIS; BLS	High-lethality SA had poorer performance on the WCST than HCs, MDD subjects, and the low-lethality suicidal group.	
Meza et al. (2016)	228 girls (124 w/ SB w/ ADHD; 16 w/o SB w/ ADHD; 84 w/ SB w/ o ADHD; 4 w/o SB or ADHD)	Commission errors on the CPT	Barkley Suicide Questionnaire; Self-Injury Questionnaire	Response inhibition predicted SI, SA, & NSSI.	
Minzenberg et al. (2014)	35 w/ recent onset of SCZ (17 w/o SI; 18 w/ SI; 10 w/ SI but w/o SB & 8 w/ SI & SB)	fMRI during a cognitive control task, AX-CPT	C-SSRS	SI associated with lower activation with goal-representation demands in multiple PFC sectors. SB associated with lower control-related activation in premotor cortex ipsilateral to the active primary motor cortex	
Minzenberg et al. (2015a)	32 w/ recent onset of SCZ (17 w/o SI & 15 w/ SI (7 had SI only & 8 had SI & SB))	fMRI version AX-CPT	C-SSRS	SI was associated with higher connectivity of the dACC w/ precuneus during conflict monitoring. SB was associated with lower conflict-related dACC connectivity in several PFC, parietal & temporal cortical regions	
Minzenberg et al. (2015b)	17 patients w/ recent onset SCZ and past SI	fMRI during Stroop task	C-SSRS	Difference in activation for SB during reactive control in left PFC motor regions	
Minzenberg et al. (2015c)	30 patients (21 w/ BPD; 9 w/ MDD w/ psychosis) (14 w/ SI; 8 w/ SI & w/o SB; 8 w/ SI & SB)	fMRI version AX—CPT	C-SSRS	SB associated with higher control-related activation in vlPFC, rostrolateral PFC, & frontal operculum/ rostralinsula; and lower activity in midlineparietal regions, including cuneus and precuneus	
Miranda et al. (2012)	45 young adults (13 w/ SA; 32 w/o SA)	WCST	Suicidal Behavior Screening; SHBQ; SSI	Perseverative errors on the WCST, predicted suicidal ideation at 6-month follow-up, among SA, but not among nonattempters	
Miranda et al. (2013)	56 college students followed for 2–3 years	WCST	SHBQ	WCST perseverative errors predicted SI at follow-up. Brooding rumination mediates the relation between cognitive inflexibility & SI.	
Mustanski et al. (2013)	237 LGBT youth	BIS	DISC	Impulsivity was related to hx of SA	

Nangle et al. (2006)	78 patients w/ SCZ or SZA	CPT, TMT	Clinical interview and chart review	Attempters scored significantly better than non-attempters on the Trails B time	LANG
Pan et al. (2011)	44 adolescents (15 MDD w/ SA; 15 w/ SA w/o MDD; 14 HC)	fMRI GoNoGo task	C-SSRS; SIS	During GoNoGo blocks, non-attempters showed greater activity than SA in the right ACC gyrus and greater activity than HC in the left insula.	
Ponsoni et al. (2018)	132 subjects (26 w/ MDD or BD w/ SA & 26 w/ MDD or BD w/o SA); 80 HC	Stroop Test; HSCT; BIS-II	self-report during a semi-structured diagnostic interview	No difference on Stroop or Hayling. SA showed higher self-reported motor and attentional impulsivity on the BIS-11	
Pustilnik et al. (2017)	39 inpatients (24 accidents; 11 chronic illnesses; 4 chronic pain)	WCST; SST	SBQ-R	There were no differences between the two groups on the WCST or the SST.	WM
Raust et al. (2007)	30 euthymic patients w/ SB (MDD, BD, SCZ); 39 controls	BIS (French version); HSCT part B; Stroop Test; Go-noGo task	MADRS suicide item	SB group displayed impaired inhibition in Hayling part B and B–A score. SB made more commission errors on GoNoGo	WM
Richard-Devantoy et al.-(2011)	20 MDD patients (10 w/ a SA w/in 10 days of admission) and (10 w/ o)	TMT; Stroop Test; Go/No-Go	MADRS suicide item	Suicidal depressed patients had worse performance on the Go/No-Go task; No differences for TMT or Stroop interference	
Richard-Devantoy et al., 2-012	60 Participants (20 MDD w/ SA; 20 MDD w/o SA; 20 elderly controls)	TMT; Rule Shift Cards (RSC); Stroop Test; HSCT; Go/No-Go	SA ten days before inpatient admission	MDD w/ SA had longer response time on Stroop and more errors, and showed worse performance on Go/No-go compared to HC	LANG
Richard-Devantoy et al. (2-013a)	Two populations of suicide attempters (Population 1, n = 142; Population 2, n = 119)	TMT; Stroop Test; HSCT	Self-reported SA	Vulnerability to SB may rely on impairments in two distinct anatomical systems, one processing value-based decision-making (associated with ventral prefrontal cortex, among others) and one underlying CC.	
Richard-Devantoy et al.-(2015)	102 subjects age 60+ (17 HC subjects, 38 MDD control subjects, 16 SI, 14 low-lethality SA, 17 high-lethality SA)	CWIT	BLS; SIS	High-lethality attempters took longer to complete inhibition trials after controlling for age, education, MMSE score, processing speed, and accuracy.	
Richard-Devantoy et al. (2-016a)	47 unmedicated MDD patients (25 w/ SA, 22 w/o SA); 27 HCs	Stroop Color Test; TMT; HSCT; fMRI during the Go/No-Go response inhibition task	C-SSRS; SIS; SSI	Attempters had elevated commission errors during the Go/No-Go task. Deficits in cognitive inhibition, in relation to the inferior frontal gyrus, thalamus, orbitofrontal cortex and parietal cortex, related to depressive state	LANG, WM
Swann, et al. (2005)	24 BD subjects w/ a hx of SA; 24 BD subjects w/o a hx of SA	BIS; modified CPT; IMT/DMT	Interviews & medical records	SA was associated with a greater probability of impulsive responses on IMT/DMT and shorter impulsive response latency.	
Swann et al. (2009)	112 BPD (35 w/ SA & 45 w/o SA) & 71 HCs	IMT; Single Key Impulsivity Paradigm (SKIP)	Interviews & medical records	Reaction times were accelerated in all subjects w/ SA, while commission errors were only increased w/ medically severe SA	
Weis et al. (2015)	460 young adults (ages 18–35) (50 w/ suicide risk & 140 w/o)	Impulsivity Control Scale	SBQ-R	Suicidal participants had higher impulsivity scores	
Westheide et al. (2008)	29 inpatients w/ MDD w/ SA in past 3 months (14 w/ current SI & 15 w/o) & 29 HCs	Delayed Alternation Task; BIS; Go/No-Go	SSI; SIS	SI scored worse on go/no-go commission errors and gain scores. BIS-11 motor impulsiveness negatively associated with the days passed since last SA	
Wyart et al. (2016)	35 subjects w/ SA; 52 w/o SA w/ a hx of MDD; 43 HCs	BIS; TMT	Self-report of SA	No difference between groups on the TMT. Attempters scored higher than HC on the BIS	
Yen et al. (2008)	96 patients w/ BDI in remission (9 w/ SB; 87 w/o SB)	WCST; TMT	Violence and Suicide Assessment Scale	No significant difference between groups	ATTN, LANG

Declarative Memory Reference	Population	Cognitive Measure	Suicide Measure	Results	Additional Constructs
Andover et al. (2011)	173 male prisoners; 45 NSSI w/ or w/o SA; 52 w/ SA only; 76 w/o NSSI or SA	CVLT	2 questions regarding SA and NSSI	No difference between groups	CC, LANG
Barrett et al. (2011)	174 patients w/SCZ (53 w/ SA & 121 w/o SA)	WASI, Verbal Fluency Test (D-KEFS), CVLT-II	IDS-C and CDS	No difference in any neurocognitive domains (small difference between currently current SB and non-SB patients- non-significant)	CC, LANG
Canal-Rivero et al. (2018)	517 patients (51 w/ SB and 466 w/o SB)	RAVLT, RCF	Medical records	SB group had significantly worse visual memory after 3 years that controls	ATTN, CC, WM
Crocker et al. (2019)	282 Veterans (50 with SI and 232 w/o SI)	CVLT-II, ROCF	Question 9 from BDI-II	SI had significantly worse memory performance than non-SI	CC
Delaney et al. (2012)	310 patients w/ SCZ or SZA disorder (63 w/ SI; 48 w/ SA; 172 w/o SA)	Logical Memory Subtests I & II (of WMS-R)	SCID -IV (for axis I)	No significant difference between groups	ATTN, WM
Dombrovski et al. (2008)	32 suicidal MDD subjects aged 60+; 32 nonsuicidal MDD subjects	EXIT25	HDRS suicide item	Suicidal patients performed worse on the Memory and Attention subscales of the DRS, as well as on the EXIT25	CC
Gujral et al. (2014)	180 patients w/ MDD (83 w/ hx of SA; 43 w/ hx of SI; 54 w/o hx of SB); 48 HCs (age > 60)	EXIT25 and Mattis DRS	BLS; SSI	SAs and SIs performed more poorly on the EXIT than non-SB groups. No difference between SAs and SIs. SAs and SIs performed worse on DRS Memory section compared to HCs. SIs performed worse DRS total score than non-SB MDD.	
Harkavy-Friedman et al.-(2006)	51 subjects w/ BD (32 w/ BDI; 19 w/ BDII) w/ SA; 58 HCs	SRT total score; VRT errors	SCID-IV	Participants with BD performed significantly worse than controls on both tests. No differences between BDI vs BDII	ATTN, CC, LANG, WM

Keilp et al. (2001)	50 unmedicated patients w/ MDD (21 w/o SA;14 w/ low lethality SA; 15 w/ high lethality SA; 22 HCs	A not B reasoning test	SCID-III-R (for axis I and II)	High lethality group performed significantly more poorly than nonpatients on working memory tasks.	ATTN, CC, LANG, WM
Keilp et al. (2013)	152 adults w/ current MDD (72 w/ SB, 80 w/o SB); 56 HC	SRT; administration D BVRT	C-SSRS; SIS; BLS	Suicidal patients performed significantly worse than non-patients	ATTN, CC, LANG, WM
Keilp et al. (2014)	80 subjects s w/ MDD & SA; 81 subjects w/o MDD or SA	SRT; BVRT	SSI; BLS	No significant results	ATTN, CC, LANG, WM
Kim et al. (2003)	333 patients w/ SCZ (200 patients w/ SA; 133 w/o SA)	Verbal List Learning (VLL)- Immediate & Delayed Recall	Structured Interview	No difference between those w/ and w/o SB	CC, LANG, WM
Malloy-Diniz et al. (2009)	39 adults w/ BD (21 w/o a hx of SA & 19 w/ SA) & 53 HC	Rey Osterheich Complex Figure Test, Brazilian RVLT	Records review; Semi-structured interview	No difference between those w/ and w/o SB, though BDI patients scored worse than HCs on both memory tasks.	ATTN, CC, WM
Martínez-Arán et al. (2004)	30 BD depressed; 34 BD manic; 44 BD euthymic; 30 HCs	CVLT; Visual reproduction; WMS-R	SCID-IV	Impairment of verbal memory was related to suicide attempts.	CC
Pollock et al. (2001)	24 patients w/ one SA; 24 patients w/o SA; 24 HCs	Autobiographical Memory Test (AMT)	History of SA and SSI	SA group produced fewest specific memories and most categoric memories, a trend reversed in HCs.	
Potkin et al. (2002)	188 patients in the InterSePT trial (93 w/ SCZ; 95 w/ SZA)	RAVLT	Clinical Global Impression of Severity of Suicidality; SST	No differences between groups	ATTN, LANG, WM
Pu et al. (2017)	233 patients w/ MDD	Japanese version of the BACS	17-item HRSD	No correlations w/ SI	LANG, WM
Rohrer et al. (2006)	40 patients w/ MDD (17 w/ SA; 23 w/o SA); 44 people w/o MDD (21 w SA; 23 w/o SA)	Autobiographical Memory Test	Admission to inpatient care following a SA	Reduced specific autobiographical memories with either/both MDD and SA.	
Zhang et al. (2018)	357 first-episode patients with SCZ (43 w/ SA and 314 w/o SA) and 380 HCs	Repeatable Battery for the Assessment of Neuropsychological Status (RBANS)	Question "In your entire lifetime did you ever attempt suicide?" SA confirmed w/ medical records & interviews	SA showed lower scores on both immediate and delayed memory.	LANG, WM, DM
Zoghbi et al. (2014)	316 patients w/ SCZ	RBANS (cognitive functioning method)	Interview & confirmed w/ medical records	No differences between groups	

Language Reference	Population	Cognitive Measure	Suicide Measure	Results	Additional Constructs
Andover et al. (2011)	173 male prisoners; 45 NSSI w/ or w/o SA; 52 w/ SA only; 76 w/o NSSI or SA	COWAT	2 questions regarding SA and NSSI	No difference between groups	CC, DM
Audenaert et al. (2002)	20 patients w/ MDD w/ a recent SA and 20 HCs	SPECT and the COWAT subtests letter fluency test and category fluency test	Recent suicide attempt (<7 days)	MDD/SA group showed poorer word production on COWAT letter and category fluency. Blunted increase in perfusion in ACC for the MDD/SA group during both fluency paradigms. Also blunted perfusion in lateral intraparietal cortex in category fluency paradigm. MDD/SA group showed reduced blood flow in left & right gyrus temporalis medius	
Bartfai et al. (1990)	9 male inpatients w/ SA; 2 control groups (8 HC male blood donors; 7 patients w/ chronic pain for at least 2 years)	FAS; Design Fluency Test; COWAT	SA at inpatient admission	No correlation between FAS and IQ scores; significant differences found on the FAS (SA worse than HC). Design fluency correlated with IQ scores (SA worse than HC)	CC
Barrett et al. (2011)	174 patients w/SCZ (53 w/ SA & 121 w/o SA)	WASI, Verbal Fluency Test (D-KEFS), CVLT-II	IDS-C and CDS	No difference between groups	CC, DM
Burton et al. (2011)	77 subjects w/ psychiatric illness hospitalized following SI (N = 40) or SA (N = 37)	COWAT	Chart review	No difference between groups	CC
Gilbert et al. (2011)	67 adults w/ BD	WAIS-R Letter Fluency and Category Fluency	C-SSRS; Beck SSI	No difference between those with and without SB	CC, WM
Harkavy-Friedman et al.-(2006)	32 adults w/ BDI w/ hx of SA; 19 adults w/ BDII w/ hx of SA; 58 HCs	FAS test of letter fluency	Hx of SA	Participants w/BDII worse than controls on FAS. BDI participants not different than controls, nor BDII on this measure.	ATTN, CC, DM, WM
Jollant et al. (2016)	25 patients w/MDD (15 w/ hx of SA; 10 w/o hx of SA); 33 HCs	FAS verbal fluency test	C-SSRS, SIS, SSI	No correlation between verbal fluency and suicide attempt	
J.G. Keilp et al. (2001)	50 unmedicated patients w/ MDD (21 w/o SA;14 w/ low lethality SA; 15 w/ high lethality SA; 22 HCs	FAS test of letter fluency	SCID-III-R (for axis I and II)	High lethality group performed significantly more poorly than nonpatients on memory tasks.	ATTN, CC, DM, WM
Keilp et al. (2013)	152 adults w/ current MDD (72 w/ SB, 80 w/o SB); 56 HC	Letter and Animal/ Category tasks	C-SSRS; SIS; BLS	Suicidal patients performed significantly worse than non-patients.	ATTN, CC, DM, WM
Keilp et al. (2014)	80 subjects s w/ MDD & SA; 81 subjects w/o MDD or SA	Letter and Category Fluency	SIS; BLS	No significant difference between groups	ATTN, CC, DM, WM

Kim et al. (2003)	333 patients w/ SCZ (200 patients w/ SA; 133 w/o SA)	COWAT	Structured Interview	No difference between those with and without suicidality	CC, DM, WM
King et al. (2000)	18 older inpatients w/ current MDD & SA; 29 older MDD inpatients w/o SA	"F-Words" and Ruff Figural Fluency Test	SCID-III-R	No differences between groups on all tasks; Was an effect on age such that performance declined in both groups with increasing age.	CC, WM
Long et al. (2018)	63 first-episode patients with SCZ (18 w/ SI and 45 w/o Si) and 44 HCs	Letter 2-back task	Single suicide item of the CDSS	Participants with SI did not have higher scores on the letter 2-back task	WM
Marzuk et al. (2005)	53 adults w/ MDD (25 w/ current SI; 28 w/o current SI)	COWAT and Five Point Test	SSI	No significant differences in fluency between groups	CC
Nangle et al. (2006)	78 patients w/ SCZ or SZA	FAS test of letter fluency	Clinical interview and chart review	SA showed significantly better ability to generate responses on the timed verbal fluency task	CC
Olié et al. (2015)	343 adults w/ BD (214 w/o hx of SA; 88 w/ hx of non-severe SA; 41 w/ hx of severe SA)	California Verbal Learning Test (CVLT)	Hx of SA	Severe SA outperformed non-severe SA for verbal learning, no between group difference for verbal fluency.	
Olsson et al. (2016)	99 subjects w/ age > 70 w/ SA; 59 at follow up a year later; 115 matched HCs w/o SA	Interpret common proverbs	Receiving emergency medical care following SA	Lower performance in abstract thinking was associated with SA	
Potkin et al. (2002)	188 patients in the InterSePT trial (93 w/ SCZ; 95 w/ SZA)	COWAT	Clinical Global Impression of Severity of Suicidality; SST	No differences between groups	ATTN, DM, WM
Pu et al. (2015)	67 patients w/ MDD (31 w/ SI, 36 w/o), 67 HCs	NIRS during a VFT	HRSD	Hemodynamic changes in right dlPFC, orbitofrontal cortex, and right frontopolar cortex regions smaller in suicidal patients. Changes correlated negatively with severity of SI in patients.	
Pu et al. (2017)	233 patients w/ MDD	Japanese version of the BACS	17-item HRSD	No correlation with SI	DM, WM
Richard-Devantoy et al.-(2012)	60 Participants (20 MDD w/ SA; 20 MDD w/o SA; 20 elderly controls)	Verbal Fluency Test	SA during the ten days before inpatient admission	MDD w/ SA did worse than HCs both on semantic and phonetic verbal fluency. MDD w/o SA did worse than HCs on phonetic verbal fluency.	CC
Richard-Devantoy et al. (2016a)	47 unmedicated MDD patients (25 w/ SA, 22 w/o SA); 27 HCs	FAS	C-SSRS; SIS; SSI	SAs and patient controls exhibited worse fluency than HCs; No difference between SAs and patient controls	CC, LANG, WM
Richard-Devantoy et al. (2013b)	66 subjects w/ MDD (35 w/ SA; 31 w/o SA); 37 HCs	Verbal working memory; Semantic verbal fluency	Hx of SA (violent/ hospitalization for overdose)	SAs performed significantly worse on verbal working memory and semantic verbal fluency tests than both control groups	WM
Wiktorsson et al. (2010)	103 subjects w/ SA; 408 matched HCs	Swedish MMSE	Hospitalization for SA	No association between abstract thinking and SA.	
Yen et al. (2008)	96 patients w/ BDI in remission (9 w/ SB; 87 w/o SB)	COWAT	Violence and Suicide Assessment Scale	No difference between groups	ATTN, CC
Zhang et al. (2018)	357 first-episode patients with SCZ (43 w/ SA and 314 w/o SA) and 380 HCs	Repeatable Battery for the Assessment of Neuropsychological Status (RBANS)	Question "In your entire lifetime did you ever attempt suicide?" SA confirmed w/ medical records & interviews	SA performed worse than non-SA on verbal and visual memory	ATTN, DM

Working Memory Reference	Population	Cognitive Measure	Suicide Measure	Results	Additional Constructs
Canal-Rivero et al. (2018)	517 patients (51 w/ SB and 466 w/o SB)	WAIS-III Backward Digits scale	Medical records	No difference between groups.	ATTN, CC, PERCEP, DC
Crandall et al. (2018)	4192 adults from The National Longitudinal Study of Adolescent to Adult Health	Add Health word list recall task and number recall task	Composite score of: 3 questions about SI, SA, and lethality	No relationship between SA or SI and working memory	
Delaney et al. (2012)	310 patients w/ SCZ or SZA disorder (63 w/ SI; 48 w/ SA; 172 w/o SA)	Letter Number Sequencing task	SCID -IV (for axis I)	No significant difference between groups	ATTN, DM
Gilbert et al. (2011)	67 adults w/ BD	Hopkins Verbal Learning Test	C-SSRS; Beck SSI	No difference between those w/ and w/o SB	CC, LANG
Harkavy-Friedman et al.-(2006)	32 adults w/ BDI w/ hx of SA; 19 adults w/ BDII w/ hx of SA; 58 HCs	N-Back Test; Computerized A not B reasoning test	Hx of SA	Both BD groups did worse than HCs on N-Back, only BDII group worse on A not B Logical Reasoning	ATTN, CC, DM, LANG, PERCEP
Keilp et al. (2001)	50 unmedicated patients w/ MDD (21 w/o SA;14 w/ low lethality SA; 15 w/ high lethality SA; 22 HCs	A not B reasoning test	SCID-III-R (for axis I and II)	High lethality group performed significantly more poorly than nonpatients on working memory tasks.	ATTN, CC, DM, LANG
Keilp et al. (2013)	152 adults w/ current MDD (72 w/ SB, 80 w/o SB); 56 HC	N-Back Test, A not B Logical Reasoning test	C-SSRS; SIS; BLS	No difference between those with and without suicidality	ATTN, CC, DM, LANG
Keilp et al. (2014)	80 subjects s w/ MDD & SA; 81 subjects w/o MDD or SA	A not B reasoning test, N-Back Test	SSI; BLS	SA participants scored significantly worse on the A not B reasoning test, and only marginally worse on the N-Back.	ATTN, CC, DM, LANG
Kim et al. (2003)	333 patients w/ SCZ (200 patients w/ SA; 133 w/o SA)	Consonant Trigram Test	Structured Interview	No difference between those w/ and w/o SB	CC, DM, LANG, PERCEP
King et al. (2000)	18 older inpatients w/ current MDD & SA; 29 older MDD inpatients w/o SA	Total recall from CVLT	SCID–III-R	No differences between groups, only on age	CC, LANG

LeGris et al. (2012)	42 women w/ BPD; 41 HCs	Digit Span of WAIS-III	SBQ-R	No association with suicide risk	CC
Long et al. (2018)	63 first-episode patients with SCZ (18 w/ SI and 45 w/o SI) and 44 HCs	Letter 2-back task	Single suicide item of the CDSS	Participants with SI did not have higher scores on the letter 2-back task	LANG, PERCEP
Malloy-Diniz et al. (2009)	39 adults w/ BD (21 w/o a hx of SA & 19 w/ SA) & 53 HC	Rey Osterheich Complex Figure Test, Brazilian RVLT	Records review; Semi-structured interview	No difference between those w/ and w/o SB, though BDI patients scored worse than HCs on both memory tasks.	ATTN, DM
Potkin et al. (2002)	188 patients in the InterSePT trial (93 w/ SCZ; 95 w/ SZA)	RVLT; Letter–Number task; Trails B	Clinical Global Impression of Severity of Suicidality; SST	No differences between groups	ATTN, DM, LANG
Pustilnik et al. (2017)	39 inpatients (24 accidents; 11 chronic illnesses; 4 chronic pain)	Digit Span	SBQ-R	There were no differences between the two groups on the Digit Span	CC
Pu et al. (2017)	233 patients w/ MDD	Japanese version of the BACS	17-item HAM-D	No correlation w/ SI	DM, LANG
Raust et al. (2007)	30 euthymic patients w/ SB (MDD, BD, SCZ); 39 controls	Spatial N-back	MADRS suicide question	Difference between patients and controls with 1-back and 2-back, less significance with 3-back better explained by motor impulsivity than by group characteristic	CC
Richard-Devantoy et al. (2016a)	47 unmedicated MDD patients (25 w/ SA, 22 w/o SA); 27 HCs	WAIS-IV Digit Span Test (forward and backward)	C-SSRS; SIS; SSI	No statistical difference between any of the three groups on the digit span	CC, LANG
Richard-Devantoy et al. (2013b)	66 subjects w/ MDD (35 w/ SA; 31 w/o SA); 37 HCs	Verbal working memory; Semantic verbal fluency	Hx of SA (violent/ hospitalization for overdose)	Suicide attempters performed significantly worse on verbal working memory and semantic verbal fluency tests than both control groups.	LANG
Xie et al. (2018)	45 patients / MDD (either high or low SI); 25 HCs	CCL; ESFCLT	SSI	CCL significant between patient group and HCs, but not between high or low SI group. High SI patients remembered significantly fewer negative faces on ESFCLT (consider affective nature of stimuli)	

Table Abbreviations: Attention Deficit/Hyperactivity Disorder (ADHD) Barratt Impulsiveness Scale (BIS); Beck Depression Inventory (BDI); Beck Lethality Scale (BLS); Beck Scale for Suicidal Ideation (SSI); Behavioral Rating Inventory of Executive Functions (BRIEF); Benton Visual Retention Test (BVRT); Bipolar Disorder (BD); Bipolar Disorder Type I (BDI); Bipolar Disorder Type II (BDII); Borderline Personality Disorder (BPD); Brief Assessment of Cognition in Schizophrenia (BACS); Buschke Selective Reminding Test (SRT); California Verbal Learning Test (CVLT); Calgary Depression Scale (CDS); Calgary Depression Scale for Schizophrenia (CDSS); Cambridge Automated Test Battery (CANTAB); Child Bipolar Questionnaire (CBQ); Color Change Localization Task (CCL); Columbia Suicide Severity Rating Scale (C-SSRS); Command Auditory Hallucinations (CAH); Continuous Performance Test (CPT); Controlled Oral Word-Association Test (COWAT); Criminal Justice-Drug Abuse Treatment Studies (CJ-DATS); Delis–Kaplan Executive Function System Color-Word Interference Test (D-KEFS CWIT); Dementia Rating Scale (DRS); Diagnosis (dx); Diagnostic Interview for Genetic Studies (DIGS); Diagnostic Interview Schedule for Children (DISC); Dorsolateral Prefrontal Cortex (dlPFC); Dorsal Anterior Cingulate Cortex (dACC); Emotional Schematic Face Change Localization Task (ESFCLT); Executive Function (EF); Executive interview (EXIT25); F-A-S Test (FAS); Functional Magnetic Imaging (fMRI); Hamilton Depression Rating Scale (HDRS); Hayling Sentence Completion Test (HSCT); Healthy Controls (HC); History (Hx); Immediate & Delayed Memory Test (IMT/DMT); International Statistical Classification of Diseases-10th Version (ICD-10); InterSePT Scale for Suicidal Thinking (ISST); Inventory of Depressive Symptoms–Clinician rated (IDS-C); Intelligence (IQ); Lesbian, Gay, Bisexual, Transgender (LGBT); Magnetic Resonance Spectroscopy (MRS); Major Depressive Disorder (MDD); Mini-International Neuropsychiatric Inventory (MINI); Mini-Mental Status Examination (MMSE); Montgomery-Asberg Depression Scale (MADRS); Near-infrared spectroscopy (NIRS); Non-Suicidal Self Injury (NSSI); Prefrontal Cortex (PFC); Repeatable Battery for the Assessment of Neuropsychological Status (RBANS); Risk Rescue Rating Scale (RRRS); Rey Auditory Verbal Learning Test (RAVLT); Rey-Osterrieth Complex Figure (ROCF); Rey Complex Figure (RCF); Scale for Suicidal Ideation (SSI); Schizophrenia (SCZ); Schizoaffective Disorder (SZA); Self-Harm Behavior Questionnaire (SHBQ); Single Photon Emission Computed Tomography (SPECT); Stop-Signal Task (SST); Structured Clinical Interview (SCID); Structured Interview for Prodromal Syndromes (SIPS); Suicidal Ideation (SI); Suicide Attempt (SA); Suicide Behavior (SB); Suicide Behaviour Questionnaire-Revised (SBQ-R); Suicide Intent Scale (SIS); Test of Variable Attention (TOVA); Trail Making Test (TMT); Traumatic Brain Injury (TBI); Ventral Lateral Prefrontal Cortex (vlPFC); Wechsler Adult Intelligence Scale (WAIS); Wechsler Abbreviated Scale of Intelligence (WASI); Wechsler Memory Scale, Revised (WMS-R); Wisconsin Card Sorting Test (WCST); With (w/); Without (w/o)

Additional Constructs Abbreviations: ATTN – Attention; CC – Cognitive Control; DM – Declarative Memory; LANG – Language; WM – Working Memory

Appendix 2. PRISMA checklist

Section/topic	#	Checklist item	Reported on page #
TITLE			
Title	1	Identify the report as a systematic review, meta-analysis, or both.	1
ABSTRACT			
Structured summary	2	Provide a structured summary including, as applicable: background; objectives; data sources; study eligibility criteria, participants, and interventions; study appraisal and synthesis methods; results; limitations; conclusions and implications of key findings; systematic review registration number.	2
INTRODUCTION			
Rationale	3	Describe the rationale for the review in the context of what is already known.	3–5

Objectives	4	Provide an explicit statement of questions being addressed with reference to participants, interventions, comparisons, outcomes, and study design (PICOS).	5
METHODS			
Protocol and registration	5	Indicate if a review protocol exists, if and where it can be accessed (e.g., Web address), and, if available, provide registration information including registration number.	N/A
Eligibility criteria	6	Specify study characteristics (e.g., PICOS, length of follow-up) and report characteristics (e.g., years considered, language, publication status) used as criteria for eligibility, giving rationale.	5–6
Information sources	7	Describe all information sources (e.g., databases with dates of coverage, contact with study authors to identify additional studies) in the search and date last searched.	5
Search	8	Present full electronic search strategy for at least one database, including any limits used, such that it could be repeated.	5–7
Study selection	9	State the process for selecting studies (i.e., screening, eligibility, included in systematic review, and, if applicable, included in the meta-analysis).	6
Data collection process	10	Describe method of data extraction from reports (e.g., piloted forms, independently, in duplicate) and any processes for obtaining and confirming data from investigators.	6
Data items	11	List and define all variables for which data were sought (e.g., PICOS, funding sources) and any assumptions and simplifications made.	6 and Appendix 1
Risk of bias in individual studies	12	Describe methods used for assessing risk of bias of individual studies (including specification of whether this was done at the study or outcome level), and how this information is to be used in any data synthesis.	7 and Appendix 3
Summary measures	13	State the principal summary measures (e.g., risk ratio, difference in means).	6
Synthesis of results	14	Describe the methods of handling data and combining results of studies, if done, including measures of consistency (e.g., I^2) for each meta-analysis.	N/A
Risk of bias across studies	15	Specify any assessment of risk of bias that may affect the cumulative evidence (e.g., publication bias, selective reporting within studies).	7 and Appendix 3
Additional analyses	16	Describe methods of additional analyses (e.g., sensitivity or subgroup analyses, meta-regression), if done, indicating which were pre-specified.	N/A
RESULTS			
Study selection	17	Give numbers of studies screened, assessed for eligibility, and included in the review, with reasons for exclusions at each stage, ideally with a flow diagram.	6–7 and Fig. 1
Study characteristics	18	For each study, present characteristics for which data were extracted (e.g., study size, PICOS, follow-up period) and provide the citations.	Appendix 1
Risk of bias within studies	19	Present data on risk of bias of each study and, if available, any outcome level assessment (see item 12).	7 and Appendix 3
Results of individual studies	20	For all outcomes considered (benefits or harms), present, for each study: (a) simple summary data for each intervention group (b) effect estimates and confidence intervals, ideally with a forest plot.	Appendix 1
Synthesis of results	21	Present the main results of the review. If meta-analyses are done, include for each, confidence intervals and measures of consistency.	7–14
Risk of bias across studies	22	Present results of any assessment of risk of bias across studies (see Item 15).	Appendix 3
Additional analysis	23	Give results of additional analyses, if done (e.g., sensitivity or subgroup analyses, meta-regression [see Item 16]).	N/A
DISCUSSION			
Summary of evidence	24	Summarize the main findings including the strength of evidence for each main outcome; consider their relevance to key groups (e.g., healthcare providers, users, and policy makers).	14–17
Limitations	25	Discuss limitations at study and outcome level (e.g., risk of bias), and at review-level (e.g., incomplete retrieval of identified research, reporting bias).	17–18
Conclusions	26	Provide a general interpretation of the results in the context of other evidence, and implications for future research.	18–19
FUNDING			
Funding	27	Describe sources of funding for the systematic review and other support (e.g., supply of data); role of funders for the systematic review.	20

Appendix 3. Modified Newcastle-Ottawa Quality Assessment Scale

This scale has been adapted from the Newcastle-Ottawa Quality Assessment Scale to perform a quality assessment of studies for a qualitative systematic review of suicide behavior using the framework of the Research Domain Criteria (RDoC) Cognitive Systems domain.

Selection: (Maximum of 3 points)

1 **Representativeness of the sample**

1 point: Population is truly representative of suicide behavior. Suicide groups are clearly defined.
0 points: Population is not truly representative of suicide behavior. Suicide groups are not clearly defined.

1 **Sample size**

1 point: Sample size was adequate and there was sufficient power to detect a difference in the outcome.
0 points: Sample size was small and there was not enough power to test the outcome of interest.

1 **Ascertainment of suicide behavior**

1 point: The study used a validated measurement tool.
0 points: The study used a non-validated measurement tool or no description was provided.

Comparability: (Maximum of 1 point)

1 point: The subjects in different outcome groups are comparable, based on the study design or analysis. Confounding factors are controlled.
0 points: The subjects in different outcome groups are not comparable and/or confounding factors are not controlled.

Outcome: (Maximum of 2 points)

1 Assessment of the outcome

1 point: The study provides a detailed description of the outcome measure(s) which are appropriate for the outcome of interest.
0 points: The study provides limited information on the methods of measuring the outcome and the measure is not appropriate considering the outcome.

1 Statistical test

1 point: The statistical test used to analyze the data is clearly described and appropriate, and the measurement of the association is presented, including confidence intervals and the probability level
0 points: The statistical test is not appropriate, not described or incomplete.

Total: (Maximum of 6 points)

The individual components listed above are summed to generate a total modified Newcastle-Ottawa risk of bias score for each study. Total scores range from 0 to 6. For the total score grouping, studies were judged to be of low risk of bias (≥ 3 points) or high risk of bias (< 3 points).

Quality assessment of studies using a modified Newcastle-Ottawa scale

Study	Selection			Comparability	Outcome		Total
	Representative	Sample size	Ascertainment of SB		Assessment of Outcome	Statistical Test	
Andover et al. (2011)	0	1	0	1	1	1	4
Audenaert et al. (2002)	1	0	0	0	1	1	3
Barrett et al. (2011)	1	1	0	1	1	1	5
Bartfai et al. (1990)	1	0	0	0	1	1	3
Brenner et al. (2015)	0	1	1	1	1	1	5
Buchman-Schmitt et al. (2017)	0	0	1	0	0	1	2
Burton et al. (2011)	0	0	0	1	1	1	3
Canal-Rivero et al. (2018)	0	1	0	1	1	1	4
Chamberlain et al. (2013)	0	1	0	1	1	1	4
Crandall et al. (2018)	0	1	0	1	0	1	3
Crocker et al. (2019)	0	1	0	1	1	1	4
Delaney et al. (2012)	1	1	1	1	1	1	6
Dombrovski et al. (2008)	1	0	1	1	1	1	5
Dougherty et al. (2004)	0	0	1	1	1	1	4
Dougherty et al. (2009)	1	0	1	1	1	1	5
Ellis et al. (1992)	0	0	0	1	1	1	3
Garcia Espinosa et al. (2010)	0	0	1	0	1	1	3
Gilbert et al. (2011)	1	1	1	1	1	1	6
Gujral et al. (2014)	1	1	1	1	1	1	6
Harkavy-Friedman et al. (2006)	0	1	1	0	1	1	4
Horesh (2001)	1	0	1	0	1	1	4
Homaifar et al. (2012)	1	0	1	1	1	1	5
Jollant et al. (2016)	1	0	1	0	1	1	4
Kasckow et al. (2016)	0	1	1	0	1	1	4
J.G. Keilp et al. (2001)	1	1	1	1	1	1	6
Keilp et al. (2008)	1	1	1	0	1	1	5
Keilp et al. (2013)	1	1	1	1	1	1	6
Keilp et al. (2014)	1	1	1	1	1	1	6
Kim et al. (2003)	1	1	0	0	1	1	4
Kim et al. (2015)	1	1	1	1	1	1	6
D.A. King et al. (2000)	1	0	1	1	1	1	5
LeGris et al. (2012)	0	1	1	0	1	1	4
Long et al. (2018)	1	0	1	0	1	1	4
Loyo et al. (2013)	1	1	1	1	1	1	6
Malloy-Diniz et al. (2009)	1	0	1	1	1	1	5
Martínez-Arán et al. (2004)	0	1	1	1	1	1	5
Marzuk et al. (2005)	1	0	1	1	1	1	5
McGirr et al. (2012)	1	1	1	1	1	1	6
Meza et al. (2016)	0	1	1	0	1	1	4
Minzenberg et al. (2014)	1	0	1	1	1	1	5
Minzenberg et al. (2015a)	1	0	1	1	1	1	5
Minzenberg et al. (2015b)	1	0	1	0	1	1	4
Minzenberg et al. (2015c)	0	0	1	1	1	1	4
Miranda et al. (2012)	0	0	1	1	1	1	4
Miranda et al. (2013)	0	0	1	1	1	1	4
Mustanski et al. (2013)	0	1	1	1	0	1	4
Nangle et al. (2006)	1	1	1	1	1	1	6
Olié et al. (2015)	1	1	1	1	1	1	6
Olsson et al. (2016)	1	1	0	1	0	1	5

Pan et al. (2011)	1	0	1	1	1	1	5
Pollock et al. (2001)	1	1	1	1	1	1	5
Ponsoni et al. (2018)	1	1	0	1	1	1	5
Potkin et al. (2002)	0	1	1	0	1	0	3
Pu et al. (2015)	1	0	0	1	1	1	4
Pu et al. (2017)	1	0	0	1	1	1	4
Pustilnik et al. (2017)	0	0	1	1	1	1	4
Raust et al. (2007)	0	0	0	1	1	1	3
Richard-Devantoy et al. (2011)	1	0	0	1	1	1	4
Richard-Devantoy et al. (2012)	1	0	0	1	1	1	4
Richard-Devantoy et al. (2013a)	0	1	0	1	1	1	4
Richard-Devantoy et al. (2013b)	1	1	0	1	1	1	5
Richard-Devantoy et al. (2015)	1	1	1	1	1	1	6
Richard-Devantoy et al. (2016)	1	0	1	0	1	1	4
Rohrer et al. (2006)	1	1	0	0	1	0	3
Swann, et al. (2005)	1	0	1	0	1	1	4
Swann et al. (2009)	1	1	1	0	1	1	5
Xie et al. (2018)	0	0	1	1	1	1	4
Weis et al. (2015)	0	1	1	1	0	1	4
Westheide et al. (2008)	0	0	1	0	1	0	2
Wiktorsson et al. (2010)	0	1	0	1	1	1	4
Wyart et al. (2016)	1	1	0	1	1	1	5
Yen et al. (2008)	1	1	1	0	1	0	4
Zhang et al. (2018)	1	1	1	1	1	1	6
Zoghbi et al. (2014)	1	1	1	1	1	1	6

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