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Toward objective characterizations of suicide risk: A narrative review of laboratory-based cognitive and behavioral tasks

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Abstract

Although suicide is a leading cause of preventable death worldwide, current prevention efforts have failed to substantively mitigate suicide risk. Suicide research has traditionally relied on subjective reports that may not accurately differentiate those at high versus minimal risk. This narrative review supports the inclusion of objective task-based measures in suicide research to complement existing subjective batteries. The article: 1) outlines risk factors proposed by contemporary theories of suicide and highlights recent empirical findings supporting these theories; 2) discusses ongoing challenges associated with current risk assessment tools and their ability to accurately evaluate risk factors; and 3) analyzes objective laboratory measures that can be implemented alongside traditional measures to enhance the precision of risk assessment. To illustrate the potential of these methods to improve our understanding of suicide risk, the article reviews how acute stress responses in a laboratory setting can be modeled, given that stress is a major precipitant for suicidal behavior. More precise risk assessment strategies can emerge if objective measures are implemented in conjunction with traditional subjective measures.

Keywords

suicide; objective measures; laboratory tasks; risk mitigation; stress response

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Declaration of Interest

Dr. Zarate is listed as a co-inventor on a patent for the use of ketamine in major depression and suicidal ideation; as a co-inventor on a patent for the use of (2*R*,6*R*)-hydroxynorketamine, (*S*)-dehydronorketamine, and other stereoisomeric dehydroxylated and hydroxylated metabolites of (*R,S*)-ketamine metabolites in the treatment of depression and neuropathic pain; and as a co-inventor on a patent application for the use of (2*R*,6*R*)-hydroxynorketamine and (2*S*,6*S*)-hydroxynorketamine in the treatment of depression, anxiety, anhedonia, suicidal ideation, and post-traumatic stress disorders. He has assigned his patent rights to the U.S. government but will share a percentage of any royalties that may be received by the government. All other authors have no conflict of interest to disclose, financial or otherwise.

1.0 Introduction

Suicide is a global public health concern and a leading cause of death worldwide, contributing to 700,000 deaths annually (World Health Organization, 2014). In the United States, suicide was among the top nine leading causes of death in 2021 for individuals aged 10 to 64, accounting for over 48,000 deaths (Centers for Disease Control and Prevention, 2023). An even greater number of American adults have attempted or thought about suicide, with 1.7 million people attempting and 12.3 million seriously considering suicide in 2021 (Substance Abuse and Mental Health Services Administration, 2022).

Although suicide is within the top 10 causes of preventable mortality worldwide (Naghavi, 2019), current prevention efforts have largely been unsuccessful. Such prevention strategies rely on our ability to understand suicidal states as well as identify those at highest risk for future attempts. Currently, most suicide research is conducted within the confines of subjective assessment, mostly through patient self-report questionnaires. Various issues surrounding the subjective reporting of suicidal states have recently generated concerns about the reliability and validity of such methods, particularly when used in isolation (Blanchard & Farber, 2020; Hom et al., 2017; Maple et al., 2020). In addition to these concerns, most of the knowledge about suicide risk factors is derived from subjective measures of suicide history. These measures, particularly single-item assessments that are commonly used in research and clinical practice, can lead to the misclassification of prior suicidal thoughts and behaviors (STBs) (Hom, Joiner, & Bernert, 2016). For example, self-report scales have generated poor reliability in differentiating low from high-risk individuals (Velupillai et al., 2019). Such lack of specificity likely arises from a multitude of risk factors in these models (e.g., psychiatric symptoms, age, sex) that pertain to many people with no history of STBs (Chan et al., 2016; Franklin et al., 2017). Thus, improvements in research methodology are urgently needed to better conceptualize suicide risk. In this context, the National Action Alliance for Suicide Prevention's Research Prioritization Task Force (2014) outlined a series of aspirational goals necessary to advance suicide research. Three of the main objectives address the critical need to improve research methodology:

a. Characterize suicide risk using effective assessments:

> "Determine the degree of suicide risk (e.g., imminent, near term, long-term) through feasible and effective screening and assessment approaches."

b. Use reliable tools to identify high-risk patients:

> "Distinguish suicidal ideation from imminent risk for suicidal behavior by developing and implementing reliable clinical tools."

c. Model suicide precipitants in a laboratory setting:

> "Know what leads to, or protects against, suicidal behavior and learn how to change those things to prevent suicide. Find clear targets for intervention through better understanding of the interplay among biological, psychological, and social risk factors, and understand how to model these effects scientifically."

As the Task Force goals underscore, little progress has been made to advance these objectives despite several decades of research, necessitating a major shift in suicide research frameworks. This article offers a comprehensive narrative review examining each of the aforementioned action items and offering an analysis of recent research that has significantly advanced our understanding of suicide. In particular, the review: 1) examines suicide risk factors within the context of contemporary theories of suicide, with an emphasis on recent findings that support various fundamental elements within these theories, as well as current gaps in the literature; 2) reviews ongoing challenges and limitations associated with standard risk assessment tools; 3) analyzes objective laboratory-based measures of suicide risk, arguing that researchers should use these methods in conjunction with traditional self-report measures to enhance our understanding of suicide risk; and 4) highlights the prospect of modeling acute stress responses in suicide research laboratories, given that stress is one of the most consequential precipitants for STBs. Broadly, the review underscores the many challenges associated with risk assessment and invites future studies to implement new approaches that center around objective assessments of risk. In keeping with the Action Alliance mission, such strategies will help to characterize suicide risk, allowing for improved risk mitigation and prevention efforts.

Nuances in suicide-related terminology exist across the research field and in different parts of the world. For the purposes of this review, we delineate between suicidal ideation (i.e., thoughts about killing oneself with or without intent) and behaviors (i.e., intentional self-harm with suicidal intent). Unless otherwise stated, suicide attempts are characterized by any non-fatal suicidal behavior, distinct from nonsuicidal self-injury (NSSI) (i.e., intentional self-harm without suicidal intent). For a review on the distinction between suicide attempts and NSSI, see (Kapur et al., 2013).

2.0 Characterizing suicide risk: Who is most vulnerable and when?

The current state of suicide research methodology should be contemplated within a theoretical context that characterizes those at highest risk for STBs. Across several decades, theories have emerged to explain suicide risk in various contexts. Early theories of suicide implicated dysfunctional social cohesion (i.e., the strength of connectedness and solidarity among social groups) and social integration (i.e., a reliance on others to achieve fulfillment) as the predominant risk factors for STBs or death by suicide, with little consideration given to individual factors (Durkheim, 1897). According to Durkheim (1987), suicide can emerge from *excessive* social integration, whereby self-sacrifice preserves a greater societal good (i.e., the “altruistic suicide hypothesis”). Evolutionary accounts of suicide expand these ideas, viewing suicide as an adaptation under certain conditions that ensures the survival of larger communities and, ultimately, the species as a whole (e.g., self-sacrificial behavior in ants or bees to ensure survival of the colony) (De Catanzaro, 1986). More recent theories suggest that suicide in modern humans is a “derangement” of this evolutionary adaptation, representing a fundamental miscalculation that one’s death is of greater worth to others than their own life (e.g., a perception of emotional or financial burden) (Joiner et al., 2016). Other early theories defined suicide risk based on *internally* directed experiences, describing the suicidal state as a “psychache” (Shneidman, 1976, 1993), an “aversive self-awareness” (Baumeister, 1990), and a “symptom of hopelessness depression” (Abramson et al., 1989).

More recent, prevailing theories of suicide adopt a multifactorial approach that accounts for complex interactions between various risk factors proposed by these classic theories. These also include interactions with neurobiological correlates of suicide. As an example, social disconnection can initiate downstream biological consequences, like activation of inflammatory pathways (Slavich & Irwin, 2014), which has been linked to suicidal ideation and behavior (for a systematic review, see Serafini et al., 2020). Dysfunctional neurotransmitter systems are also associated with suicide risk, such as abnormalities in serotonin, norepinephrine, glutamate, and opioid receptor function (for a review, see Mann & Rizk, 2020). These factors are particularly relevant in the diathesis-stress model of suicide, which posits that suicidal behavior is a product of an interaction between proximal risk factors (e.g., acute stress exposure) and distal factors (e.g., neurobiological correlates of suicide-related traits). Recent conceptualizations of suicide risk delineate these complex dynamics along a continuum of risk that aims to characterize the transition from ideation to behavior.

In line with early theories, recent studies found that social and cultural factors can contribute to suicide risk (perhaps to a lesser extent compared to the presence of any mental disorder, see Favril et al., 2022), particularly in the way that individuals perceive themselves within broader contexts. Cultural risk factors account for wide demographic variability in suicide rates; these include gender role expectations, societal discrimination against race, access to lethal means, suicide-related stigmatization, and income inequality (Stack, 2000). These factors strongly influence the types of stressors that precede suicide attempts, as well as one's likelihood of expressing STBs (Chu et al., 2010). Suicide risk is heightened among ethnic or sexual minority groups that experience acculturative stressors (e.g., discrimination, victimization, stereotyping), with even higher risk conferred among those who identify as sexual *and* ethnic minorities (Meyer et al., 2008; Walls et al., 2008). Social support can buffer these stressors, particularly an increased sense of belonging and connectedness with cultures of origin (Chu et al., 2010). According to the Interpersonal Theory of Suicide (Joiner, 2005; Van Orden et al., 2010), high suicide risk is defined by the co-occurrence of thwarted belongingness (i.e., an unmet need for social connectedness) and perceived burdensomeness (i.e., an unmet need for social competence, driven by the perception that one is a burden on others) in conjunction with both a desire and capability for suicide. In this model, *capability* can develop along a continuum from habituation to provocative experiences, self-injury, or pain, each of which can be invoked by repeated exposure to suicide, including family history or one's own prior attempts, or by chronic stress exposure (e.g., military combat or childhood maltreatment). This theory is supported by several empirical studies linking thwarted belongingness and perceived burdensomeness to greater suicide risk (for a systematic review and meta-analysis, see Chu et al., 2017). Notably, however, these studies yielded small-to-moderate effects (Chu et al., 2017; Joiner et al., 2009).

Ideation-to-action frameworks center around multidimensional influences that increase an individual's risk for suicide. These models attribute the propensity to act on suicidal thoughts to a variety of factors, including dispositional (e.g., genetics, low pain sensitivity), acquired (e.g., habituation to pain, fear, or death), and practical (e.g., access to lethal means) (Klonsky & May, 2015). A biopsychosocial model of suicide similarly integrates genetic,

psychological, clinical, cultural/sociological, and environmental factors to determine risk (Lutz et al., 2017; Turecki et al., 2014, 2016, 2019). In particular, distal factors such as genetics or early life adversity are thought to predispose individuals to STBs, whereas proximal factors such as acute stress and substance use are thought to precipitate suicide attempts (Turecki et al., 2019). Critically, distal factors appear to be indirectly linked to suicide risk via intermediate phenotypes, like personality traits, negative affect, impulsive-aggression, or cognitive deficits (Turecki et al., 2014, 2016, 2019). The relative degree of suicide risk can also depend on interactions between demographic variables and the presence of specific endophenotypes related to suicide risk. As an example, impulsivity, aggression, and novelty-seeking are linked to a greater risk for suicide among younger individuals, but these factors become less important in determining risk with increasing age (McGirr et al., 2008). Notably, acute stress exposure interacts with existing diatheses (i.e., genetic or biological vulnerabilities) to increase one's propensity to shift from suicide ideation to suicide attempt (O'Connor, 2011; O'Connor & Kirtley, 2018). In the Integrated Motivational-Volitional model of suicide, social and cultural factors can act like diatheses (O'Connor & Kirtley, 2018). For instance, socially prescribed perfectionism—a perception of unrealistically high expectations—is a vulnerability factor that might interact with acute social stressors, such as interpersonal conflicts, to increase suicide risk through a sense of defeat and heightened sensitivity to negative stimuli (O'Connor & Kirtley, 2018; Smith et al., 2018).

Interpersonal and multidimensional theories of suicide appear to yield large inter-individual risk variabilities. That is, the contribution of any combination of risk factors varies widely between individuals, impeding the ability to characterize individual risk. Furthermore, these models offer insight into *which* individuals are prone to STBs but less about *when* suicide is likely to occur or the likelihood that any individual will experience suicidal thoughts or attempt suicide at all. Suicide-specific diagnostic categories have recently been proposed to characterize the temporal dynamics of suicide risk, including: 1) Suicide Crisis Syndrome, which includes cognitive and affective responses to real or perceived threats, and 2) Acute Suicidal Affective Disturbance, which reflects interactions between acute psychological states (e.g., overarousal) and theory-driven predictors of suicide (e.g., social alienation) (Rogers et al., 2017). These diagnoses aim to identify those at high risk for imminent suicide crises by identifying the acute and rapidly increasing symptoms that precede STBs.

Alternatively, the fluid vulnerability theory of suicide (Rudd, 2006) characterizes temporal dynamics along a *continuum* of risk, positing that suicide follows a nonlinear time course along two dimensions: 1) chronic or stable properties that persist over time, like genetics or trauma exposure (i.e., a baseline dimension), and 2) dynamic properties, like cognition, emotion, behavior, and physiology that fluctuate in response to external forces (i.e., an acute dimension). Related to the aforementioned theories of suicide, stress plays a significant role in this model. Acute stress exposure is thought to unlock predisposing suicide-specific vulnerabilities (i.e., diatheses), with lower stress tolerance in those with a greater number of predispositions (Bryan et al., 2020). Because stress promotes deviation from a set point—one's homeostatic point of equilibrium—stress-induced alterations within the acute dimension could lead to an imminent shift toward a high-risk state (Bryan et al., 2020). Indeed, several studies have reported temporal associations between the onset of an

acute stress experience and suicide attempts or death by suicide (Feskanich et al., 2002; Gradus et al., 2010). This can be attributed to a failure of biological responses to acute stressors, increasing proximal risk for STBs (for a comprehensive review, see Miller & Prinstein, 2019). Typically, self-regulatory mechanisms and coping strategies will counteract emotional distress caused by acute stress exposure, thereby promoting homeostatic balance. In contrast, dysfunctional self-regulatory processes invite maladaptive responses to acute stressors (e.g., substance use) that can interact with various dynamic factors (e.g., low mood, social isolation) to induce an imminent suicide crisis (Bryan et al., 2020; Rudd, 2006).

Relatedly, the Cognitive Model of Suicidal Behavior proposes that stress activates suicide schemas such as hopelessness and perceptions of unbearability, leading to maladaptive cognitive processing (e.g., attentional fixation on suicide-related cues) that could immediately precede a suicide crisis (Wenzel & Beck, 2008). In this context, suicide attempts emerge when such cognitive-emotional dysregulation exceeds one's threshold of tolerance (Wenzel & Beck, 2008). Although stressful life events across the lifespan can heighten suicide risk (McLaughlin et al., 2012; Serafini et al., 2015), various protective factors—for instance, connectedness (Klonsky & May, 2015) and social support (Turecki et al., 2019)—have been shown to mitigate risk.

Each of these theories offers important insights into the characteristics of suicide risk, but many of these constructs are not thoroughly captured by current research methods. In some cases, suicide risk factors are difficult or impossible to measure objectively. Nevertheless, objective measures have long been used to evaluate many risk factors described in contemporary theories of suicide, including cognitive or behavioral disposition. Subjective measures of suicide risk continue to be the gold standard in research, but many challenges with this approach have recently been discussed.

3.0 Current challenges with risk assessment

Accurate patient reporting is fundamental to our ability to identify which individuals are at highest risk for suicide. Unfortunately, self-reported and clinician-rated data can be unreliable for several reasons. Indeed, multiple intra- and inter-personal factors have been identified as significant barriers to the disclosure of STBs (Maple et al., 2020); as a key example, fear of involuntary hospitalization is among the most cited reasons for concealing or minimizing STBs (Blanchard & Farber, 2020; Hom et al., 2017; Ganzini et al., 2013). One study found that almost half of patients who conceal STBs in therapy would have responded more honestly without the threat of hospitalization (Blanchard & Farber, 2020). People with prior suicide attempts have also been subjected to stereotyping, prejudice, and discrimination (Sheehan et al., 2016), discouraging the accurate reporting of suicidal states and deterring opportunities for therapeutic intervention. The internalization of these negative public perceptions, or self-stigma, could also prevent accurate disclosure of STBs (Ganzini et al., 2013).

Relying on self-reported experiences with suicide also invites concerns about the *validity* of participant accounts, even when participants respond truthfully. Explicit self-judgments are often not congruent with unconscious internal states, including affective or cognitive

processes (Wilson, 2009), thus markedly diminishing the value of subjective measures of suicide risk[1]. Relatedly, participants might accurately report current suicidal states, but the fact that these can fluctuate rapidly over time may further complicate these efforts. For example, suicidal thoughts and intent might be absent during clinical assessment but become acutely activated during subsequent stress exposure (Nock et al., 2009). This requires rapid, in-the-moment assessments of transient changes in suicide risk, which current self-report inventories are not designed to address. Although ecological momentary assessments offer insights into important temporal dynamics associated with suicidal states, these measures do not resolve the aforementioned concerns about the reliability or validity of patient reporting; for further exploration of this issue, see (Ballard et al., 2021). Finally, limitations associated with risk assessment strategies and clinician training can impede the ability to adequately evaluate suicide risk, posing concerns about the validity of clinician-rated data (for a review of these challenges, see (Fowler, 2012)).

Patient and clinician reports continue to offer the best avenue for suicide *prediction* efforts. Despite several decades of research, however, very little progress has been made to predict suicide with clinically relevant accuracy (Franklin et al., 2017). Suicide prediction models rely heavily— and often exclusively—on explicit self-report measures that have relatively poor predictive value; for a systematic review of risk assessment scales and their predictive power, see (Chan et al., 2016). A logical conclusion emerging from these challenges is that suicide simply cannot be predicted with clinically meaningful accuracy (e.g., Mulder et al., 2016). This begs the question of whether this notion is valid or whether improved methodology might enhance predictive power within existing models. Recent findings suggest that using a composite approach that combines various sources of patient self-report and electronic health record data (Nock et al., 2022) may show promise. In one assessment of such models, the positive predictive value, while still relatively low (above 20%-30%), far exceeded that of any modality alone (Nock et al., 2022), suggesting that future efforts should focus on a multi-modal assessment of suicide risk for prediction. Currently, there is a dearth of robust evidence supporting the notion that objective measures, such as laboratory-based tasks, could enhance the predictive capacity of these models. Thus, it remains unknown whether a composite approach that includes task-based outcomes has the potential for clinical utility beyond a research setting.

4.0 Objective task-based measures to characterize and identify suicide risk

Self-insight, particularly self-knowledge about internal states, rarely converges with objective criteria such as behavioral patterns or prospective outcomes. Studies have found that the average correspondence between self-perception and laboratory behavior is low to moderate (Vazire & Carlson, 2010). Literature from social psychology suggests that self-evaluations of internal states must be corroborated with independent measures, namely

[1]As a caveat, some have argued that inaccurate explicit measures of internal states do not reflect unconscious or inaccessible processes but, instead, reflect peoples' tendency to over- or under-present themselves explicitly (Olson et al., 2007). In support of this notion, implicit and explicit self-evaluations converge when people make rapid explicit responses, thus restricting the influence of conscious self-reflection (Koole et al., 2001). While this may explain the discrepancy between explicit and implicit measures, it does not rectify issues surrounding the reliability of self-reported data during risk assessment – that is, the accurate reporting of internal states.

implicit measures or nonverbal behavior (Wilson, 2004, 2009). In this context, behavioral tasks that examine suicide risk are imperative for assessing real-time objective responses in light of concerns associated with self-report. Towards this goal, laboratory-based tasks could easily be incorporated into clinical trials to characterize the continuum of suicide risk (Ballard et al., 2021). Below, we review suicide-specific laboratory tasks as well as tasks that assess suicide indirectly through relevant endophenotypes (for a summary, see Table 1).

4.1 Implicit cognitions about death or suicide

Mounting evidence supports a role for suicide or life-death implicit association tasks (hereafter, S/LD-IAT) in characterizing suicidal states beyond patient or clinician reports and well-known risk factors such as prior attempts or depression (Nock et al., 2010). Derived from social psychology (Greenwald et al., 1998), the S/LD-IAT assesses the degree to which individuals self-associate with death- or suicide-related semantic stimuli as a measure of implicit cognition about suicide or death (Nock et al., 2010). Specifically, the computer task evaluates differences in response latencies between the pairing of the self with life-related words (e.g., breathing, survive, alive) versus death-related words (e.g., lifeless, deceased, suicide) (Nock et al., 2010). Faster reaction times for self-death associations reflect a stronger implicit bias toward death/suicide (Nock et al., 2010).

Original findings by Nock and colleagues (2010) showed a significantly stronger self-death/suicide association among those with a prior suicide attempt compared with psychiatrically distressed individuals with no prior attempts. These findings have since been replicated in various samples (Barnes et al., 2017; Glenn et al., 2017). Self-associations with death/suicide have been found to prospectively predict a future suicide attempt (Barnes et al., 2017; Ellis et al., 2016; Glenn et al., 2017; Nock & Banaji, 2007; Nock et al., 2010; Tello et al., 2020). However, contrary findings suggest that the S/LD-IAT has limited long-term predictive capacity (Harrison et al., 2018; Rath et al., 2021). Nevertheless, in some studies, the predictive power of the S/LD-IAT exceeded that of traditional measures (Nock et al., 2010; Tello et al., 2020), suggesting it might be implemented alongside existing batteries in both research and clinical settings.

Recent studies have also examined the neural underpinnings associated with implicit associations with death or suicide in healthy volunteers. In a functional magnetic resonance imaging (fMRI) version of the task, greater activation was observed in the bilateral insula for self-death as compared with self-life associations (Ballard et al., 2019). This suggests that the salience network might be implicated in dissociating self-referential associations with death versus life. Relatedly, enhanced gamma oscillations were observed in the amygdala and anterior insula for self-death compared with self-life associations (Ballard, Gilbert et al., 2020). Gamma connectivity estimates among these regions also differentiated healthy volunteers from a small group of individuals (N=4) experiencing a suicide crisis, defined as attempt or ideation with intent over the prior two weeks. Future studies are needed to evaluate these differential activation patterns along the continuum of suicide risk with larger samples, thereby elucidating contrasts between healthy volunteers and at-risk groups.

Related paradigms such as the Implicit Relational Assessment Procedure (D-IRAP) (Barnes-Holmes et al., 2010; Hussey et al., 2016) and the Suicide Affect Misattribution Procedure

(S-AMP) (Tucker et al., 2018) have demonstrated similar patterns of implicit death-related cognitions in those with a history of STBs (Hussey et al., 2016; Wells et al., 2020). However, these tasks have neither been widely implemented nor studied extensively in the context of suicide. In the S-AMP, participants with a history of suicide ideation (but no recent ideation) showed an implicit bias for suicide, suggesting that automatic associations with suicide possess trait-like characteristics that persist beyond resolution of suicide ideation (Wells et al., 2020). Major concerns surrounding the validity of AMP tasks have recently been raised (Cummins et al., 2020), suggesting that findings drawn from the S-AMP should be interpreted with caution.

4.2 Suicide-related attentional biases

As described previously, maladaptive cognitive processing could trigger a suicide crisis through attentional fixation on suicide-relevant information, as, for instance, in the Cognitive Model of Suicidal Behavior (Wenzel & Beck, 2008). Various cognitive tasks have been developed to characterize processing biases along the continuum of suicide risk. One prominent example is the Suicide Stroop Task, which measures participants' response latencies when naming the font color of words that represent suicide (e.g., funeral, death) compared to negatively valanced (e.g., stupid, alone) or neutral (e.g., paper, pencil) words. Greater response latencies (i.e., slower reaction times) reflect a diminished ability to disengage from emotionally relevant stimuli (i.e., suicide-relevant information), which is thought to be driven by impaired top-down attentional control (Feng et al., 2018). Individuals with prior suicide attempts show greater response latencies to suicide-related words (Becker et al., 1999; Stewart et al., 2017; Tavakoli et al., 2021; Williams & Broadbent, 1986), particularly those with recent attempts (Cha et al., 2010). Other studies do not show this behavioral effect, reporting that the Stroop effect does not outperform traditional self-report measures that differentiate those with prior STBs from those with none (Chung & Jeglic, 2016). Of note, a recent meta-analysis compared 233 suicide attempters and 768 non-attempters and found a significant attentional bias to suicide-related —but not negatively valanced—words in suicide attempters, but effect sizes were small (Richard-Devantoy et al., 2016a). This is likely a consequence of the task's low internal consistency, low concurrent validity, and poor classification accuracy (Wilson et al., 2019). Nevertheless, the Suicide Stroop Task performs close to chance in differentiating attempters from non-attempters (Wilson et al., 2019). Collectively, these findings suggest that the Suicide Stroop Task's ability to characterize suicide risk, while promising, is somewhat mixed. More studies are needed to systematically analyze the value of this task beyond traditional subjective measures.

To a lesser extent, attentional biases toward emotional faces have also been studied in the context of suicide. Dot probe tasks are widely used to study emotional attentional biases in depression and accurately discriminate depressed from non-depressed samples (for a meta-analysis, see Peckham et al., 2010). In this task, response latencies to words, images, or faces are measured as indices of attentional allocation to either neutral, negative, or positive emotionally valanced stimuli (MacLeod et al., 1986). Faster response times for congruent trials—that is, when the probe and emotional stimulus are paired—indicate an attentional bias toward emotional as opposed to neutral stimuli. Although this task

has rarely been implemented in the context of suicide, interesting neural patterns have emerged in recent studies. For instance, one fMRI study found that neural responses to angry faces differentiated suicide attempters from non-suicidal controls in several regions of the prefrontal cortex, reflecting reduced attention allocation to positively valanced stimuli (Jollant et al., 2008). An electrophysiology study found no behavioral differences between suicide attempters and non-attempters on dot probe reaction times, but groups showed differing patterns of neural responses to negative stimuli (Gilbert et al., 2022). Among attempters, an increase in the positive association between theta power and suicide ideation was observed for angry versus happy faces in the extended amygdala-hippocampal region; the opposite pattern was found in non-attempters (Gilbert et al., 2022). In another study, those with suicide ideation were found to be more sensitive to negatively valanced stimuli than to positively valanced stimuli, as indexed by larger N1 amplitudes to fearful and sad faces (Lin et al., 2022). Thus, the dot probe task might differentially characterize suicide risk on the basis of neural responses to negative emotional stimuli. Future studies should use functional imaging to validate this effect in larger samples. However, it should be noted that concerns have been raised about the reliability of dot probe tasks (Chapman et al., 2019; Price et al., 2015; Schmukle, 2005). For recent suggestions on how researchers might improve the reliability of the task—which may vary based on data analytic methods or sample characteristics (e.g., patients compared to healthy participants)—we refer the reader to a recent review by Price and colleagues (Price et al, 2015).

4.3 Response inhibition and impulsive decision-making

Deficits in impulse control are thought to underlie the transition from suicide ideation to suicide attempt, particularly impaired response inhibition (Klonsky & May, 2015). Several behavioral tasks have been used to characterize impulsivity along the continuum of suicide risk. The Go/No-Go task measures participants' ability to respond to a designated target on a screen (Go trials) and to inhibit responding to an intermittent non-target (No-Go trials) (Gordon & Caramazza, 1982; Keilp et al., 2005). The stop signal task is similar, but participants must inhibit responding on Go trials when a "stop" signal emerges on the screen (Logan & Cowan, 1984). Both tasks measure inhibition of prepotent responses and have successfully differentiated suicide attempters from non-attempters. Specifically, attempters show higher false alarm rates (i.e., failure to inhibit responding to a No-Go target) (Richard-Devantoy et al., 2012, 2016b; Westheide et al., 2008). Furthermore, stop-signal reaction times differentiated impulsive attempters from both non-impulsive attempters and non-attempters (Wojnar et al., 2009). Self-reported trait impulsivity (Barratt Impulsiveness Scale; Barratt, 1959) did not differentiate these groups (Wojnar et al., 2009). This implies that these cognitive tasks are more sensitive to *state* impulsivity than self-report measures, which generally capture *trait* impulsivity. Furthermore, increased Go/No-Go miss rates—that is, failure to respond to a Go target—predicted subsequent suicide attempts among those with severe suicide ideation and past year attempts (Myers et al., 2022). In that study, computational modeling revealed no general slowing of stimulus encoding or motor responses, nor a response bias towards No-Go trials (Myers et al., 2022). This suggests that those who would soon attempt suicide had reduced decisional efficiency (Myers et al., 2022), which is a neurocognitive deficit linked to several clinical disorders (Weigard & Sripada, 2021). Thus, Go/No-Go miss rate might be an important indicator of proximal

suicide risk. Corroborating this sentiment, past-week attempts were associated with greater commission errors on the Go/No-Go task compared to more distal attempts (>1 year prior) (Interian et al., 2020). Notably, these groups were not differentiated by traditional clinical assessments (e.g., prior attempts, suicide ideation, mood disturbances) (Interian et al., 2020), underscoring an added benefit to the objective measurement.

Impulsive decision-making is also associated with STBs, particularly suicide attempts. Delay Discounting tasks measure the propensity to devalue temporally distant rewards, even when long-term benefits outweigh immediate ones (Rachlin et al., 1991). In these tasks, impulsive decision-making is indexed by greater discounting as a reflection of immediate versus delayed gratification. High delay discounting has been associated with prior suicide attempts in several studies (Bryan & Bryan, 2021; Dombrovski et al., 2011; Liu et al., 2012; Mathias et al., 2011), with some exceptions (e.g., Bridge et al., 2015). In these contexts, delay discounting is thought to represent a decision to forgo all future rewards (e.g., prospective goals, prosperity, self-preservation) in favor of immediate relief (e.g., to eliminate severe distress). By this logic, delay discounting should characterize abrupt suicide attempts that involve minimal planning or forethought. In support of this notion, high delay discounting—defined as preference for immediate rewards—is associated with low-lethality attempts whereas low delay discounting (i.e., willingness to delay future rewards) is associated with high-lethality and planned suicide attempts (Dombrovski et al., 2011). As a screening tool, these tasks might identify those at highest risk for imminent suicide attempts, allowing for swift intervention during periods of ambivalence or acute crisis, such as experiencing major life stressors. Related tasks that evaluate risky decision-making, such as the Iowa Gambling Task (IGT), have reported similar results, with suicide attempters demonstrating impaired decision-making compared to both clinical samples and healthy volunteers (Gorlyn et al., 2013; Jollant et al., 2005). As a caveat, IGT performance rarely correlates with cognitive abilities in other domains (Toplak et al., 2010). In fact, IGT decision-making was not correlated with self-reported impulsivity (Jollant et al., 2007) or performance on response inhibition tasks (Richard-Devantoy et al., 2013), suggesting these may be distinct processes. Instead, decision-making impairments in suicide attempters might reflect dysfunctional valuation of risk under conditions of uncertainty (Jollant et al., 2010). Nevertheless, performance on these tasks offers insight into decision-making characteristics that could identify at-risk subgroups, such as suicide attempters that used violent versus non-violent methods.

4.4 Interpersonal difficulties and physiological sensitivity: Desire and acquired capacity

As described above, the Interpersonal Theory of Suicide posits that social difficulties such as perceived burdensomeness and thwarted belongingness suffice to activate a *desire* for suicide (Joiner, 2005; Van Orden et al., 2010). Social exclusion can be measured objectively using the Cyberball game (Williams et al., 2000), which adapts a face-to-face paradigm of ostracism (Williams & Sommer, 1997). In this task, participants play a computerized ball-toss game with two confederate or simulated players where they experience either inclusion (i.e., the ball is equally distributed between the participant and other players) or exclusion (i.e., the ball is predominantly distributed between the other players, but not the participant). Ostracized participants subsequently report lower levels of belonging, self-esteem, and

meaningful existence, as well as a reduced sense of need (Williams, Cheung, & Choi, 2000; Zadro et al., 2004). This effect is amplified in those with chronic depression (Seidl et al., 2020), but few studies have objectively manipulated social belonging in people at risk for suicide. Some studies using the Cyberball game have highlighted dissociable biological patterns depending on suicide risk. Compared with non-suicidal clinical samples and healthy volunteers, suicide attempters showed decreased oxytocin levels during exclusion phases (Chu et al., 2020), perhaps denoting maladaptive neurobiological responses to social rejection. Indeed, unlike control groups, attempters reported no desire for emotional support following exclusion (Chu et al., 2020), further implicating indifference to subsequent social connectedness. Interestingly, attempters also showed reduced posterior insular activity during exclusion relative to non-attempters and healthy volunteers (Olié et al., 2017). Given that this region is implicated in the neural basis for the “acquired capability” for suicide (Deshpande et al., 2016), future studies should evaluate its relevance to prospective suicide risk.

According to the Interpersonal Theory of Suicide, the desire for death only translates to suicidal behavior in the presence of “acquired capability” for suicide, particularly a heightened degree of pain insensitivity and fearlessness. Based on this notion, a lack of fear or aversion toward physical harm (e.g., elevated pain tolerance) increases risk for suicide attempts. Although interoceptive processing is extremely subjective, physiological pain sensitivity tasks offer objective insights into pain tolerance. In these tasks, cold water or mild electrical shocks are administered to participants’ hands or fingers, with endurance time as the index for pain tolerance. Relative to psychiatric controls and healthy volunteers, individuals with prior suicide attempts showed elevated pain tolerance (Orbach et al., 1996a,b, 1997) (for an exception, see Rabasco & Andover, 2020). Elevated pain thresholds have also been observed in individuals with borderline personality disorder, which is commonly associated with STBs (Ludäscher et al., 2007). One study found that, compared to individuals hospitalized for accident-related injuries, those hospitalized for suicide attempts had significantly higher pain tolerance to electric shocks (Orbach et al., 1996a). Furthermore, in that study, perceived negative life stress was positively associated with pain tolerance in the suicide attempt group, but the opposite pattern was found in the accident victim and control groups (Orbach et al., 1996a). These findings suggest that stress might interact with pain tolerance to determine suicide risk, but this has yet to be investigated prospectively. These findings might also reflect dissociative processes that alter pain perception in suicide attempters (Orbach et al., 1996b). This small body of literature offers an important empirical basis for acquired capability theories of suicide, but further replication in independent research groups is necessary.

Dysregulated fear responses are also implicated in the acquired capability for suicide. The affectively modulated startle reflex task is an objective measure of aversion that examines participants’ electromyographic eye blink responses to a startle probe while they view emotionally valanced images (Lang et al., 1990). Potentiated eye-blink response is a proxy measure of increased aversion to these stimuli. Although very few studies have used this paradigm to test suicide directly, emerging findings are worth considering. Compared to suicide ideators and those who attempted suicide only once, individuals with multiple attempts showed greater startle potentiation to unpleasant images (Hazlett et al., 2016).

These individuals did not show higher startle reflex to equally arousing *pleasant* images, implicating potentiated arousal to negatively valanced stimuli rather than generalized heightened arousal (Hazlett et al., 2016). Critically, suicide ideators and attempters did not differ on self-reported picture valance (Hazlett et al., 2016), suggesting that this task evaluates emotional processing beyond subjective assessment. Others have found that attempters did not differ from suicide ideators or healthy volunteers in psychophysiological reactivity to *suicide-specific* images; however, self-reported fearlessness was highest among attempters (Smith et al., 2010). In other words, subjective accounts are more consistent with the acquired capability of suicide, specifically to reduced fear aversion and/or increased habituation to fearful stimuli with prior attempts. Thus, it is possible that introspective self-insights surrounding fear more accurately reflect the principles of Interpersonal Theory than psychophysiological responses. Furthermore, similar tasks have measured startle potentiation to both uncertain and predictable threats (NPU-threat task; Schmitz & Grillon, 2012). Depressed inpatients with a prior suicide attempt showed elevated startle potentiation to predictable, but not unpredictable, threats relative to depressed inpatients with no history of suicide attempt (Ballard et al., 2014). This suggests that distinct mechanisms might underlie suicide ideation, given that current and lifetime ideation is positively associated with startle potentiation to *uncertain* threats (Lieberman et al., 2020). Future studies should examine the precise neural underpinnings associated with these diverging response patterns in suicide risk.

5.0 Modeling suicide precipitants in a laboratory setting: Stress manipulations in suicide research as a future direction

Stress is ubiquitous in various theories of suicide, often mediating the effect of well-known risk factors on STBs (Cohen et al., 2022). As outlined above, contemporary theories differ in how they describe stress as a risk factor for suicide, as well as the types of stressors that increase risk (e.g., interpersonal, psychosocial, physical). Across theories, however, stress emerges as a major precipitant in the development of suicide ideation and impacts the relationship between ideation and action. Specifically, stress is thought to interact with temporal dynamics along the continuum of suicide risk, governing the likelihood and imminence of a suicide crisis. In this context, stress, as well as individual coping mechanisms in response to stressors (see Okechukwu et al., 2022), can powerfully influence one's *capability* for suicide and shape the progression from suicide ideation to attempt. Numerous studies have reported associations between life stress and suicide ideation or attempts (e.g., Coope et al., 2015; Feskanich et al., 2002; Gradus et al., 2010; Liu et al., 2019; Stewart et al., 2019; Wang et al., 2015). This extensive body of literature is beyond the scope of this review; however, several limitations that impede causal inferences about stress can be attributed to concerns raised here. For instance, these studies can be prone to recall bias because they rely on retrospective reports of prior stressful events, which can range from recent to a very distant past. The effects of these subjective accounts are then evaluated using traditional self-reported measures of suicide risk. Recent studies have directly manipulated stress responses in a laboratory setting to characterize associations between stress reactivity, psychological traits, and suicide risk (e.g., Alacreu-Crespo et al., 2022). Few studies, however, have tested whether abnormal stress responses alter objective

suicide risk. Because stress mediates the relationship between common risk factors (e.g., depression) and suicide attempts (Cohen et al., 2022; Merida-Lopez et al., 2018; Moskowitz et al., 2013), information about stress response could improve our understanding of dynamic fluctuations in suicide risk over time.

5.1 Examining stress-related effects on suicide risk using objective tasks: Does acute stress alter implicit or attentional biases toward death- or suicide-related cues?

As described previously, implicit biases toward suicide or death currently offer the most robust objective markers for characterizing suicide risk. Accordingly, future studies could investigate the real-time effects of acute stress induction on various laboratory-based paradigms that evaluate cognitive biases toward suicide-related cues. Although suicide-specific studies are lacking, some evidence exists for acute laboratory-based stress in modulating implicit and attentional biases. Acute psychological stress, for instance, increases the strength of implicit self-associations with anxiety in an implicit association task (Sato & Kawahara, 2012). Of note, this effect might vary depending on the type of stressor, given that a different psychosocial stressor did not elicit the same effect (Schmukle & Egloff, 2004). Relatedly, acute physical stress increased attentional bias to negatively valanced stimuli in a dot probe task, particularly among trauma-exposed individuals (Blekić et al., 2021). Although these methods require replication in suicide research, the study suggests that those with prior traumatic experiences might be more susceptible to stress-induced attentional biases toward negative or threatening stimuli. These findings are also in line with longitudinal studies showing associations between war exposure and attentional biases toward threat stimuli (Wald et al., 2013). Physical stress was also found to differentially affect men and women's attentional biases in a non-clinical sample, with greater post-stress biases toward threatening faces in women than men (Carr et al., 2016). Other forms of stress have produced opposing patterns, whereby attentional biases to threatening faces were suppressed after acute *psychosocial* stress (Jiang et al., 2017), in contrast to the aforementioned effects observed after *physical* stress. As described above, those with prior STBs showed altered physical responses such as pain insensitivity (Orbach et al., 1996a, b), as well as interpersonal difficulties such as maladaptive responses to social rejection (Chu et al., 2020). It is therefore possible that stress could increase suicide risk via different mechanisms based on stressor type—for instance, reactivity to physical versus psychosocial stressors.

Evidence also suggests that acute stress increases attentional responses to self-relevant stimuli. In heavy alcohol consumers, for example, a laboratory psychosocial stressor increased attentional bias for alcohol-related cues and enhanced subjective alcohol cravings (Field & Powell, 2007). Interestingly, the effect was specific to those who used alcohol as a coping mechanism (Field & Powell, 2007). Given that STBs are thought to reflect maladaptive coping strategies in the face of distress (Bazrafshan et al., 2014), future studies should examine whether acute stress similarly enhances biases toward suicide-related cues in at-risk individuals. This would help identify which individuals are at greatest risk for a proximal suicide crisis. A similar psychological stressor increased neural responses to smoking cues among smokers, mainly in regions involved with cognitive control (Dagher et al., 2009). This suggests that acute stress enhances the salience of self-relevant cues,

which might translate to those with prior STBs to the extent that they self-identify with suicide-related cues. In these contexts, difficulties disengaging from aversive stimuli might reflect stress-induced perturbations within brain regions that subserve attentional control. Indeed, stress impedes top-down regulation of subcortical structures such as the amygdala, leading to a reactive and reflexive state that could promote maladaptive cognitive processing and irrational behaviors (Datta & Arnsten, 2019).

By elucidating the mechanisms underlying the relationship between stress and implicit or attentional biases, researchers could better understand the characteristics of dynamic suicide risk. Studies could also evaluate how acute stress interacts with existing traits or diatheses to influence maladaptive cognitions linked to suicide risk. For instance, recent studies found that interactions between acute physical stress and trait impulsivity influenced choice behavior in a decision-making task (Raio et al., 2020). Another study found that acute psychosocial stress interacted with state rumination in biasing attention toward emotional information (LeMoult et al., 2013). Future studies might examine the *indirect* effects of acute stress on these objective measures. For instance, stress-induced inflammation is linked to attentional biases toward negative information (for a review, see Maydych, 2019), and both are associated with elevated suicide risk. Negative preconscious attentional biases can also predict cortisol stress reactivity patterns (Fox et al., 2010). As an example, attentional biases toward negative stimuli in a visual probe task predicted cortisol responsivity to subsequent psychosocial stress, but self-reported depression, anxiety, and neuroticism did not (Fox et al., 2010). These findings implicate bidirectional associations between biological stress responses and suicide-related risk factors. Although these research questions are interesting, they have yet to be investigated in the context of suicide and require further consideration in that context.

6.0 Conclusion

Suicide research is evolving alongside novel methods that capture rapid changes in risk (Ballard et al., 2021). Traditional approaches to risk assessment, which largely include self-report scales, have generated few advances over several decades of research (Franklin et al., 2017). In accordance with the research agenda proposed by the Action Alliance (2014), the current review offers promising new directions for suicide research. By objectively evaluating suicide risk, future studies will improve the precision of risk categorization. With this approach, we can better understand how precipitating factors—like stress exposure—interact with well-known risk factors to determine one's likelihood for suicide, as well as the imminence of a future attempt. Collectively, this narrative review highlights a need for a fundamental shift in suicide research methodology. Although it may not *substitute* for traditional research methods such as subjective reports, complementary objective methods are likely to provide more precise risk assessment, ultimately yielding more successful efforts to mitigate suicide risk.

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Highlights

- Suicide research relies primarily on subjective reports, which have been unreliable
- Laboratory tasks can complement self-report to enhance precision of risk assessment
- Existing tasks show promising directions for objective characterizations of risk
- Future studies might use stress paradigms to model suicide precipitants in the lab
- A multimodal approach to risk assessment can improve suicide prevention strategies

Table 1.

Summary of objective task-based measures used to identify and characterize suicide risk.

Task	Description	Outcomes
Implicit Cognitions Suicide or Life-Death Implicit Association Task (S/LD-IAT)	• Assesses the degree to which individuals self-associate with death- or suicide-related semantic stimuli. Faster reaction times for self-death associations reflect a stronger implicit bias toward death/suicide.	• Stronger self-death/suicide association among those with a prior suicide attempt compared to those with no attempt history (Barnes et al., 2017; Glenn et al., 2017; Nock et al., 2010). • Death/suicide self-associations prospectively predict future suicide attempt (Barnes et al., 2017; Ellis et al., 2016; Glenn et al., 2017; Nock & Banaji, 2007; Nock et al., 2010; Tello et al., 2020). • Some studies show limited long-term predictive capacity of the S/LD-IAT (Harrison et al., 2018; Rath et al., 2021). • In healthy volunteers with no suicide history, self-death associations are linked to greater activation of the insula (Ballard et al., 2019) and enhanced gamma oscillations in the amygdala and anterior insula (Ballard, Gilbert et al., 2020).
Attentional Biases Suicide Stroop Task Dot Probe Task	• Measures attentional fixation on suicide-related semantic cues by assessing response latencies when naming the font color of words that represent suicide compared to negatively valanced or neutral words. Greater response latencies (i.e., slower reaction times) reflect a diminished ability to disengage from suicide- relevant stimuli. • Assesses attentional allocation to neutral, negative, or positive emotionally valanced stimuli via response latencies to words, images, or faces. Faster response times for congruent trials (i.e., when the probe and emotional stimulus are paired) indicate an attentional bias toward emotional as opposed to neutral stimuli.	• Greater response latencies to suicide-related words in those with prior suicide attempts (Becker et al., 1999; Stewart et al., 2017; Tavakoli et al., 2021; Williams & Broadbent, 1986), particularly those with recent attempts (Cha et al., 2010). • Some have reported concerns surrounding this task's ability to characterize suicide risk; for instance, the effect sizes are small (Richard-Devantoy et al., 2016a), the task performs close to chance in differentiating attempters from non-attempters (Wilson et al., 2019), and it might not outperform traditional self-report measures in characterizing risk (Chung & Jeglic, 2016). • Neural responses to angry faces differentiated suicide attempters from non-suicidal controls in several regions of the prefrontal cortex (Jollant et al., 2008). • Among attempters, an increase in the positive association between theta power and suicide ideation was observed for angry versus happy faces in the extended amygdala-hippocampal region; the opposite pattern was found in non-attempters (Gilbert et al., 2022). No behavioral effects emerged in this task (Gilbert et al., 2022). • Suicide ideators are more sensitive to negatively valanced stimuli than to positively valanced stimuli, as indexed by larger N1 amplitudes to fearful and sad faces (Lin et al., 2022).
Response Inhibition and Impulsivity Go/No-Go Task Delay Discounting Task	• Measures inhibition of prepotent responses through participants' ability to respond to a designated target on a screen (Go trials) and to inhibit responding to an intermittent non-target (No-Go trials). • Measures the propensity to devalue temporally distant rewards as an index of	• Higher false alarm rates in attempters (i.e., failure to inhibit responding to a No-Go target) (Richard-Devantoy et al., 2012, 2016b; Westheide et al., 2008). • Task performance differentiated impulsive attempters from both non-impulsive attempters and non-attempters (Wojnar et al., 2009). Self-reported impulsiveness did not differentiate these groups (Wojnar et al., 2009). • Increased Go/No-Go miss rates (i.e., a failure to respond to a Go target) predicted subsequent attempts among those

Task	Description	Outcomes
	impulsive decision-making. Greater discounting is a reflection of immediate versus delayed gratification.	with severe ideation and past year attempts (Myers et al., 2022). • Past-week attempts were associated with greater commission errors on the Go/No-Go task compared to more distal attempts (>1 year prior) (Interian et al., 2020). • Prior suicide attempts linked to high delay discounting (Bryan & Bryan, 2021; Dombrovski et al., 2011; Liu et al., 2012; Mathias et al., 2011), with exceptions (e.g., Bridge et al., 2015). • Greater delay discounting is associated with low-lethality suicide attempts whereas low delay discounting is associated with high-lethality and planned suicide attempts (Dombrovski et al., 2011).
Interpersonal Difficulties Cyberball Task	• Social exclusion is manipulated using a computerized ball-toss game. Participants experience either inclusion (i.e., the ball is equally distributed between the participant and other players) or exclusion (i.e., the ball is predominantly distributed between the other players, but not the participant).	• Compared with non-suicidal clinical samples and healthy volunteers, suicide attempters showed decreased oxytocin levels during exclusion phases (Chu et al., 2020). Attempters reported no desire for emotional support following exclusion (Chu et al., 2020). • Attempters showed reduced posterior insular activity during exclusion relative to non-attempters and healthy volunteers (Olié et al., 2017).
Physiological Sensitivity Pain Sensitivity Tasks Affectively Modulated Startle Reflex Task	• Objectively measure pain sensitivity by administering cold water or mild electrical shocks to participants' hands or fingers, with endurance time as the index of pain tolerance. • Measures aversion via electromyographic eye blink responses to a startle probe while viewing emotionally valanced images. Potentiated eye-blink response is a proxy measure of increased aversion to these stimuli.	• Those with prior suicide attempts showed elevated pain tolerance relative to psychiatric controls and healthy volunteers (Orbach et al., 1996a,b, 1997), with exceptions (e.g., Rabasco & Andover, 2020). • Compared to patients hospitalized for accident-related injuries, those hospitalized for suicide attempts had significantly higher pain tolerance to electric shocks (Orbach et al., 1996a). • Perceived negative life stress was positively associated with pain tolerance in attempters, but the opposite pattern was found in accident victim and control groups (Orbach et al., 1996a). • Compared to suicide ideators and those who attempted suicide only once, those with multiple attempts showed greater startle potentiation to unpleasant images (Hazlett et al., 2016). Effects were not observed in response to equally arousing pleasant images or self-reported picture valence (Hazlett et al., 2016). • Attempters did not differ from suicide ideators or healthy volunteers in psychophysiological reactivity to suicide-specific images (Smith et al., 2010). • Elevated startle potentiation to predictable threats found in depressed inpatients with a prior suicide attempt relative to depressed inpatients with no history of suicide attempt (Ballard et al., 2014).