Structural and functional brain correlates of suicidal ideation and behaviours in depression: A scoping review of MRI studies

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Abstract

Identifying and integrating the neural correlates of suicidal ideation and behaviors is crucial to expand the knowledge and develop targeted strategies to prevent suicide. This review aimed to describe the neural correlates of suicidal ideation, behavior and the transition between them, using different magnetic resonance imaging (MRI) modalities, providing an up-to-date overview of the literature. To be included, the observational, experimental, or quasi-experimental studies must include adult patients currently diagnosed with major depressive disorder and investigate the neural correlates of suicidal ideation, behavior and/or the transition using MRI. The searches were conducted on PubMed, ISI Web of Knowledge and Scopus. Fifty articles were included in this review: 22 on suicidal ideation, 26 on suicide behaviors and two on the transition between them. The qualitative analysis of the included studies suggested alterations in the frontal, limbic and temporal lobes in suicidal ideation associated with deficits in emotional processing and regulation, and in the frontal, limbic, parietal lobes, and basal ganglia in suicide behaviors associated with impairments in decision-making. Gaps in the literature and methodological concerns were identified and might be addressed in future studies.

Keywords: depression, suicide behaviors, suicidal ideation, magnetic resonance imaging, scoping review.

1. Introduction

Suicide is a major public health concern, accounting for more than 700,000 deaths every year (World Health Organization, 2021). At time of death by suicide, major depressive disorder (MDD) is one of the most frequent diagnoses (Moitra et al., 2021; Nock et al., 2009). In fact, death by suicide is 20-fold higher in MDD patients than in the general population (Ösby et al., 2001). For each death, there are an even higher number of suicide attempts. In depression, compared to patients without depression, the odds ratio for lifetime and past-year prevalence of suicide attempts were 3.45 and 7.34, respectively (Cai et al., 2021).

The suicide pathway is a complex process that ranges from suicidal ideation, communicated (or not) verbally or non-verbally, suicide attempts and death by suicide (Wasserman et al., 2012). This process is influenced by multiple interacting biological, psychological, environmental, and situational factors (Wasserman et al., 2012). Suicidal ideation is considered a major risk factor for suicide (Franklin et al., 2017), and its presence in MDD is associated with worse treatment response (Lopez-Castroman et al., 2016).

In the past decades, multiple non-invasive neuroimaging tools, such as magnetic resonance imaging (MRI), have been used to investigate the suicidal brain *in vivo* in multiple psychiatric disorders (Bani-Fatemi et al., 2018; Cox Lippard et al., 2014; Desmyter et al., 2011; Schmaal et al., 2020). Although suicidal symptoms might be identified in multiple psychiatric disorders, previous reviews on their neuroimaging correlates reported inconsistent findings across disorders (Dominguéz-Baléon et al. 2018; Schmaal el et al., 2020), which might be partially explained by the specific characteristics of the different diagnoses. In fact, there is evidence of different clinical characteristics of suicide behavior across psychiatric disorders (Nakagawa et al., 2011). To date, only one review (Zhang et al., 2014) focused on MDD alone, reporting abnormalities in the frontal-striatal circuits associated with suicide behavior. Two meta-analyses reported no morphometric abnormalities (Jollant et al., 2018; Rentería et al., 2017),

while alterations in the activation of the insula and fusiform gyrus during different tasks were associated with suicide behaviors in depression (Li et al., 2020). Nevertheless, the amount of literature available at the time of publication was small, with 14 studies included in the review, and 16 and 7 in the brain structure and function meta-analyses, respectively. Contrary to the findings of previous meta-analyses, a recent pooled mega-analysis from the Enhancing NeuroImaging Genetics through Meta Analysis (ENIGMA) MDD Consortium revealed a decreased volume in the bilateral thalamus and the right pallidum and lower cortical surface area in the left inferior parietal lobe in patients with previous suicide attempts in MDD (Campos et al., 2021). Moreover, no previous review or meta-analysis, to our knowledge, has focused on the neural correlates of suicidal ideation in adult patients with MDD only.

Suicidal ideation is a red flag for clinical concern and an important part of suicide risk assessment, given that it is the first step of the suicidal pathway (Wasserman et al., 2012). It is highly dependent on the patient collaboration and clinician expertise, given it is usually assessed through clinical interviews and self-report instruments (Lotito & Cook, 2015). Even though active suicidal ideation constitutes one of the best predictors of suicide attempts (Franklin et al., 2017), only one third of patients with suicidal ideation will act on their thoughts (Kessler et al., 1999), which suggest different profiles between suicide ideators and attempters. Taking that into consideration, Klonsky, and May (2014) proposed that suicide research and theory should follow an ideation-to-action framework, suggesting that the development of suicidal ideation and the transition from ideation to behaviors may be distinct processes, with distinct explanations, and consequently different predictors. Given the ethical issues associated with the study of this transition within the same person, comparing suicide attempters and ideators (suicide attempters vs. suicide ideators) may bring new insights on specific processes of suicidal thoughts and behaviors. Neuroimaging techniques, such as MRI, might be crucial to identify neural signatures of suicidal ideation and behaviors, and consequently help developing models

to identify the individuals with higher risk for suicide as well as targeted treatments and prevention strategies for future attempts. Even though, the number of neuroimaging studies following this approach is small and no previous review compiled the neural correlates of the transition from suicide ideation to attempt.

Finally, literature reviews and meta-analyses are essential to synthetise and integrate the findings available in the literature, which is particularly useful when there is high heterogeneity in the published studies as in the field of neuroimaging and suicidology. This type of scientific approach allows the field to move forward by developing new theories and identifying gaps in the literature. The present review aimed to describe the neural correlates of suicidal ideation, behaviors and transition between them in MDD, using MRI, to provide an up-to-date and comprehensive overview of the literature. Compared to the most recent literature reviews on the field (e.g., Schmaal et al., 2020), this review focuses on MDD alone, given that different psychiatric disorders might have unique neurobiological characteristics underlying suicide as stated above. Moreover, we explored for the first time the neural correlates of the transition between suicidal ideation and attempt. Given the broad focus of this review on the neural correlates of different steps on the suicide pathway, MRI modalities and analyses, as well as the complexity and heterogeneity of our research questions and the literature available, a scoping review may be the most beneficial approach to provide an up-to-date overview (Munn et al., 2018).

2. Methods

The present scoping review follows the Preferred Reporting Items for Systematic Reviews and Meta-analyses extension for Scoping Reviews (PRISMA-ScR). The PRISMA-ScR checklist is available in the Supplementary Material (Table S1). The protocol of this review was registered with the Open Science Framework (https://osf.io/6z3cx/).

2.1 Literature search

The literature search was conducted on PubMed, ISI Web of Knowledge and Scopus from February 1st to September 28th 2022 using the following terms: (depress* or major depressive disorder) and (suicide* or suicidal thoughts or death thoughts or suicidal ideation or suicide ideators or suicide attempt or suicide behavior or parasuicide) and (neuroimaging or brain image or magnetic resonance imaging or MRI or functional magnetic resonance imaging or functional MRI or fMRI or resting-state fMRI or functional connectivity or diffusion MRI or DTI or white matter or structural connectivity or structural MRI or gray matter or cortical thickness or volume). See detailed search strategy for each database in the Supplementary Material (Table S2). To complement our searches, the reference lists of included studies and relevant reviews and meta-analyses on this topic were manually checked.

2.2 Eligibility criteria

The eligibility criteria are summarized in Table 1. To be included in this review, the studies must report brain structural and functional correlates of suicidal ideation, attempt and transition between them in adult patients currently diagnosed with MDD. The data must be acquired with MRI in at least one of the following modalities: structural, diffusion, resting-state, and task-related functional MRI (fMRI). Studies were excluded when including patients diagnosed with other psychiatric, neurologic disorders or comorbidities, did not clearly define suicidal ideation, attempt, or used the broad term "suicidality" without any detailed definition. Suicidality is a broader term including suicide ideation, attempt and death, which lacks specificity and confounds the findings of the studies (Meyer et al., 2010).

2.3 Article selection and data extraction

After the primary searches, the results were uploaded to Rayyan (Ouzzani et al., 2016) to remove duplicates. Then, a two-step screening process was implemented. First, titles and

abstracts of all publications were screened against the eligibility criteria by 3 independent reviewers (RV, ARF, DR). If a decision could not be made based on the title and abstract, the article was retained for full text screening. Full text of all publications included at first screening were then examined in detail to determine eligibility. Any disagreement between reviewers was solved through discussion and consulting a fourth reviewer (MPP). The authors of the publications were contacted by the reviewers, when necessary. Neither one of the reviewers were blind to the journal's title, authors' names, or institutions.

A standardized data extraction form was created using Google Forms (see Figure S1), and the three independent reviewers (RV, ARF, DR) extracted the relevant data of the included manuscripts.

3. Results

3.1 Main findings

Through the literature search detailed above 2375 articles were identified. From these, 816 duplicated papers were excluded using Rayyan (Ouzzani et al., 2016). Then, the titles and abstracts of the 1559 were examined. From these, 87 articles were kept for full text screening, from which 50 articles met the eligibility criteria to be included in this review. These studies were categorized according to the suicide pathway (ideation, attempt or transition) and MRI modality (structural, diffusion, and fMRI). Regarding the suicide pathway, studies were categorized according to the main comparisons of the statistical analysis performed: patients with suicidal ideation vs. controls with or without MDD or direct correlations with suicidal ideation scale score were classified as suicide ideation; patients with history of suicide attempt vs. controls with and without MDD were classified as suicide attempt; and patients with suicide ideation vs. patients with history of previous suicide attempt were classified as transition between suicidal ideation and attempt. Thus, there were 22 studies on suicidal ideation, 26

studies focused on suicide attempts, and two on the transition from ideation to action. Regarding MRI modality, the different studies used the following analysis: gray and white matter volumes using voxel-based morphormetry or Freesurfer, magnetization transfer ratio, cortical thickness, and structural covariance network for structural MRI; tract-based spatial statistics, deterministic and probabilistic tractography, graph theory and network-based statistics (NBS) for diffusion MRI; seed-based analysis, independent component analysis, regional homogeneity (ReHo), amplitude of low frequency fluctuation (ALFF), NBS, and graph theory for resting-state fMRI; and brain activation and connectivity (psychophysiological interactions analysis) for task-based fMRI. Figure 1 displays the PRISMA flow diagram of the study selection process, providing information on the reasons of exclusion.

3.2 Studies' characteristics

The studies included in this review were published between 2005 and 2022 (see Figure 2). Most of the studies (80%) were conducted in Asia, whereas the remaining studies were conducted in North America and Europe. Patients' samples were recruited in Psychiatric Departments of Hospitals, mostly in outpatient wards. Healthy control samples were commonly recruited from the community. From 39 studies indicating medication status, 22 (~56%) included medication free patients (drug-naïve or washout) and 17 (~44%) included patients under any pharmacotherapy. The characterization of the samples is detailed in Tables S3, S4 and S5 for the included studies focusing on suicide attempts, ideation, and transition between them, respectively.

3.3 Suicide ideation

From the 22 studies focusing on the neural correlates of suicide ideation, two used structural MRI, three diffusion MRI, and 13 fMRI (only resting state). Four studies combined more than

one MRI modality, specifically two combined structural and resting-state fMRI, one structural and diffusion MRI, and one diffusion and resting-state fMRI. The results of the qualitative synthesis are summarized in Table 2.

3.3.1. Structural MRI

Taylor and collaborators (2015) found a decrease in the cortical thickness of the insula, caudal middle frontal gyrus, superior parietal, and temporal gyri in suicide ideators compared to depressed controls. Abnormalities in gray matter volume were also described in suicide ideators, particularly in the lingual gyrus (Wang et al., 2021). Moreover, a study considering the severity of suicidal ideation reported not only a decrease in the gray matter volume of frontal areas, but also an increased structural connectivity between them in severe and mild suicide ideators when compared to controls (He et al., 2022). Nevertheless, two studies reported no differences in gray matter volume in cortical and subcortical regions (Kim et al., 2019; Taylor et al., 2015).

3.3.2 Diffusion MRI

Despite the different diffusion metrics used in the included studies, in general suicide ideators exhibited decreased fractional anisotropy, being the corpus callosum, the anterior thalamic radiation and the corona radiata the most reported (Chen, et al., 2021a; Reis et al., 2022; Taylor et al., 2015). Moreover, two studies using NBS identified subnetworks disrupted in suicide ideators, comprising frontal and occipital regions, as well as the basal ganglia in the left hemisphere (Chen et al., 2021a; Myung et al., 2016). Myung and collaborators (2016) described decreased structural connectivity in suicide ideators compared with both depressed and non-depressed controls, whereas Chen and collaborators (2021a) only found this difference among suicidal ideators and non-depressed controls. Finally, mixed findings were reported regarding the brain topological organization. Specifically one study reported no differences in the graph

theory metrics between suicide ideators and controls (with and without MDD) (Chen et al., 2021a), whereas the other reported decreased small worldness, global efficiency and modularity only between suicide ideators and controls without MDD (Liu et al., 2021).

3.3.3 Functional MRI

3.3.3.1 Resting-state

Abnormalities in the functional connectivity of different brain regions were reported in suicide ideators (Du et al., 2017; Fan et al., 2022; Li et al., 2022a; Li et al., 2022b; Qiao et al., 2020; Wei et al., 2018; Yang et al., 2022a). At the cortico-cortical level, there was a decreased functional connectivity between the right anterior cingulate cortex (ACC) and the medial orbitofrontal cortex (OFC) and right middle temporal gyrus (Du et al., 2017), as well as an increased dynamic functional connectivity (i.e., increased switch between two regions) between the left posterior cingulate cortex (PCC) and the left inferior frontal gyrus in suicide ideators (Li et al., 2022a). At the subcortico-cortical level, a decreased functional connectivity was described not only between the right amygdala and the left postcentral gyrus, left precentral gyrus, left superior and right middle temporal gyrus, and right angular gyrus, but also between the left amygdala and the right precentral gyrus and left inferior parietal lobule in suicide ideators (Li et al., 2022b; Yang et al., 2022b). Also, an increased functional connectivity was found between the bilateral amygdala and the bilateral precuneus, as well as between the left amygdala, the left frontal gyrus, and bilateral caudate nuclei for suicidal ideators (Wei et al., 2018; Yang et al., 2022b). Interestingly, different subnetworks associated with suicidal ideation were identified using NBS, consistently including regions as the OFC, PCC, middle temporal gyrus, and postcentral gyrus (Chen et al., 2022b; Kim et al., 2017; Reis et al., 2022). These studies described a decrease in the functional connectivity in the identified subnetworks in patients with depression and suicidal ideation. Abnormalities in the functional connectivity of

resting-state visual networks (Reis et al., 2022) as well as in the stability and temporal variability of the default-mode network (DMN) were also reported in suicidal ideators (Ouyang et al., 2022). Two studies did not find any differences between groups in the ALFF (Li et al., 2018a; Wang et al., 2021), whereas one study reported increased ALFF in the left cuneus and decreased ALFF in the right cuneus (Chen, et al., 2021). Moreover, a decrease in the ReHo of the right cuneus and right OFC and an increase in the ReHo of the left middle temporal gyrus and right middle frontal gyrus was associated with suicidal ideation (Chen et al., 2021b; He et al., 2022). Regarding the brain topological organization, mixed findings were described (Chen, et al., 2021b; Yang et al., 2022b). On one hand, Chen and collaborators (2021b) reported decreased global efficiency in suicide ideators compared to controls with MDD, whereas compared to controls without MDD, suicide ideators showed increased global efficiency and decreased assortativity and transitivity. No differences between the groups were found for other graph theory metrics (e.g., small wordlness, normalized characteristic path length). On the other hand, Yang and colleagues (2022b) described a decreased global connectivity and small worldness, but an increased normalized characteristic path in suicide ideators compared to controls without MDD.

3.4 Suicide attempt

From the 26 studies focusing on the neural correlates of suicide attempt, 9 used structural MRI, 4 diffusion MRI, and 11 fMRI (9 resting-state and two task-based). Two studies combined more than one MRI modality, specifically one combined structural and diffusion MRI, and the other structural and resting-state fMRI. The results of the qualitative synthesis are summarized in Table 3.

3.4.1 Structural MRI

Most of the studies reported decreased gray matter volumes in suicide attempters compared with depressed and non-depressed controls in both cortical and subcortical structures (Jollant et al., 2018; Lee et al., 2016; Lee et al., 2018; Peng et al., 2014; Yang et al., 2020). In accordance, suicide attempters showed a decreased magnetization transfer ratio and cortical surface in parietal and frontal cortices, respectively (Chen et al., 2015; Kang et al., 2020a). At the subcortical level, Kang and collaborators (2020b) found that suicide attempters had a decreased volume in the putamen, hippocampus, amygdala, pallidum and thalamus compared to controls with MDD. Nevertheless, two studies found an increased gray matter volume in the calcarine fissure (Yang et al., 2020), postcentral gyrus and OFC (Kang et al., 2020a) in suicide attempters when compared to depressed controls. Additionally, Kang and collaborators (2020b) also reported an increased cortical surface in the postcentral gyrus and occipital regions. Only one study explored the role of white matter hyperintensities in suicide attempts in depression, reporting no statistically significant differences between groups in the deep white matter hyperintensities, but increased periventricular hyperintensities in suicide attempters (Ehrlich et al., 2005). Two studies did not find statistically significant differences in gray and white matter volume, or cortical thickness, between suicide attempters and controls (Jia et al., 2010; Jollant et al., 2018).

3.4.2 Diffusion MRI

Diffusion MRI studies consistently showed decreased fractional anisotropy in suicide attempters compared to depressed and non-depressed controls (Chen, et al., 2021c; Jia et al., 2010, 2014; Olvet et al., 2014; Zhang et al., 2021). Additionally, the studies also reported decreased axial diffusivity (Jia et al., 2010), and increased mean and radial diffusivity (Jia et al., 2010; Zhang et al., 2021) associated with suicide attempts. The anterior limb of the internal

capsule (Jia et al., 2010, 2014), the corpus callosum (Chen et al., 2021c), the forceps minor and major, the inferior fronto-occipital fasciculus and the cingulum bundle (Zhang et al., 2021) were described as disrupted in patients with history of suicide attempts. Recently, Chen and colleagues (2021c) identified a subnetwork, comprising mainly frontal and parietal regions, with increased structural connectivity in suicide attempters compared with healthy controls. Moreover, these authors did not find differences in the topological parameters of the brain structure, such as global efficiency, modularity, and small worldness (Chen et al., 2021c).

3.4.3 Functional MRI

3.4.3.1 Resting-state

Several authors reported alterations in the functional connectivity of the OFC, ACC, and amygdala at rest (Chen et al.,2021d; Kim et al., 2017; Qiu et al., 2020; Shu et al., 2022) in suicide attempters versus controls with and without depression. On the one hand, there was a decreased functional connectivity between the right OFC and the left rectus, left inferior parietal lobule, left ACC, and left calcarine sulcus (Chen et al., 2021d; Yang et al., 2020), as well as between the subgenual ACC and the right caudate nucleus, the pregenual ACC, the left insula, and the left superior medial frontal gyrus (Qiu et al., 2020). On the other hand, increased functional connectivity was reported between the left amygdala and the right insula, the left OFC, the right amygdala, and the left middle temporal gyrus (Kim et al., 2017), as well as between the subgenual ACC and frontal brain regions in suicide attempters (Qiu et al., 2020). Increased functional connectivity was also found between the dorsomedial prefrontal cortex (PFC) and the left frontal and the right temporal regions in suicide attempters (Chen et al., 2021d). Interestingly, two studies employing NBS approaches identified subnetworks showing a decreased functional connectivity only when suicide attempters were compared with healthy controls (Wagner et al., 2019; Weng et al., 2019). Both subnetworks included motor and

somatosensory regions. Moreover, Weng and collaborators (2019) reported an increase in suicide attempters in the ALFF and ReHo in the left superior parietal gyrus and the right putamen, respectively. Compared to patient's controls, suicide attempters also showed a decrease in the ALFF in the right angular gyrus and in the ReHo of the right superior temporal gyrus and right OFC (Weng et al., 2019). Other authors (Yang et al., 2022b) described a decrease as well in the ReHo of the PCC.

3.4.3.2 Task-based

Richard-Devantoy and collaborators (2016) used a Go/No Go task to explore brain function during response inhibition in suicide attempters, reporting decreased activation in the precuneus and PCC during the Go/No-Go contrast in suicide attempters compared to healthy controls. No differences were reported among the patients' groups. Another study investigated the neural correlates of risk and loss aversion in suicide attempters, focusing on the activation of the following brain regions: OFC, ventromedial PFC, ACC, insula, midbrain, striatum, and amygdala (Baek et al., 2017). Compared to controls with depression, suicide attempters showed a decreased activation in the ACC during loss aversion (Baek et al., 2017). Moreover, a decreased activation in the ACC and amygdala during loss aversion, as well as decreased activation in the insula during risk aversion were described only when suicide attempters were compared with controls without depression (Baek et al., 2017).

3.5 Transition from ideation to action

Two studies focused on the transition of suicidal ideation to action in patients with depression. Both used fMRI (one resting-state and one task-based). The results of the qualitative synthesis are summarized in Table 4.

3.5.1 Functional MRI

3.5.1.1 Resting-state

Compared with suicide ideators, suicide attempters showed a decreased ALFF, particularly in bilateral parietal regions, and an increased ALFF in limbic regions, such as the left hippocampus and parahippocampal gyrus (Wagner et al., 2021). Interestingly, similar findings were described for suicide attempters when compared with controls with and without depression, and no differences between suicide ideators and controls were reported (Wagner et al., 2021).

3.5.1.2 Task-based

Ai and colleagues (2018) used the tower of London and the faces tasks to investigate the neural correlates of executive function and emotional processing, respectively, in patients with and without suicide attempts and ideation. Compared with suicide ideators and controls, suicide attempters showed an increased activation in the insula (under a very liberal threshold) and a decrease in the activation of the bilateral fusiform gyri during executive planning and processing of emotional faces, respectively (Ai et al., 2018). No differences between suicide ideators and controls were described (Ai et al., 2018).

3.6 Summary findings

Figure 3 integrates the findings of all the included studies in this review organized by the following lobes: frontal, temporal, parietal, occipital, insular, limbic (i.e., cingulate, parahippocampal, hippocampus, amygdala, septal area, thalamus, and hypothalamus), basal ganglia (i.e., striatum, globus pallidum, caudate nucleus, putamen, nucleus accumbens, subthalamic nuclei, substantia nigra) and cerebellum. For suicidal ideation studies, alterations in frontal, temporal and limbic lobes were the most reported across studies but were even more evident when using fMRI (75% frontal, 56% temporal, and 50% limbic). For suicide attempt, alterations in frontal and limbic lobes were recurrently reported across studies (frontal lobe:

373 36% structural, 60% diffusion, and 67% fMRI; limbic lobe: 45% structural, 40% diffusion and
374 83% fMRI). Moreover, alterations in the basal ganglia and parietal lobe were also highly
375 reported (basal ganglia: 18% structural, 60% diffusion, and 25% fMRI; parietal lobe: 55%
376 structural, 20% diffusion and 50% fMRI). Only two studies compared suicide attempters and
377 ideators, both used fMRI and reported differences mainly in the occipital lobe.
378

379 **4. Discussion**

380 In the present study, a scoping review of the literature on the neural correlates of suicidal
381 ideation, attempt and the transition between them was performed, aiming to provide an up-to-
382 date and comprehensive overview of the published MRI studies on this topic. A total of 50
383 studies were included in this review. Specifically, 22 studies focused on the neural correlates
384 of suicidal ideation, 26 studies on suicide attempts, and two on the transition from ideation to
385 action, using structural, diffusion and functional MRI. The interest on this topic has increased
386 throughout the years, with half of the studies included in this review published in the last 3
387 years.

388 Overall, the studies included in this review pointed to the involvement of different brain lobes,
389 for instance, frontal, temporal, parietal, and limbic lobes, and basal ganglia. Both suicide
390 attempters and ideators displayed alterations in frontal and limbic lobes, mainly in the OFC, the
391 ACC and the amygdala (Baek et al., 2017; Chen et al., 2021b; Colle et al., 2015; Du et al., 2017;
392 He et al., 2022; Kang et al., 2020a; Kang et al., 2020b; Kim et al., 2017; Li et al., 2018a ; Liao
393 et al., 2018; Qiao et al., 2020; Qiu et al., 2020; Reis et al., 2022; Shu et al., 2022; Taylor et al.,
394 2015; Wagner et al., 2019; Weng et al., 2019; Yang et al., 2022b; Yang et al., 2020). These
395 regions have been previously implicated in decision-making, cognitive control, and emotional
396 processing and regulation (Rolls et al., 2018). Therefore, the abnormalities described in these
397 regions might be more associated with deficits in emotional processing and regulation linked

with suicidal ideation and impairments in decision-making contributing more to suicide attempts.

4.1 Suicidal ideation

To our knowledge, no review nor meta-analysis focused on the neural correlates of suicidal ideation in patients diagnosed with MDD only. Based on the studies included in this review, frontal, temporal and limbic lobes showed structural and functional alterations associated with suicidal ideation. The regions of these lobes are connected and involved in emotional processing and regulation as well as self-referential processing, which are disrupted in MDD (Li et al., 2018b; Mitchell, 2011; Park et al., 2019).

Two resting-state functional MRI studies included in this review reported altered functional connectivity between prefrontal and temporal regions and amygdala in suicidal ideation (Li et al., 2022b; Yang et al., 2022a). These regions integrate bottom-up and top-down brain circuits, and its maladaptive functioning may cause biases in attention, processing, and memory typically associated with MDD (Disner et al., 2011), which in turn would lead to emotional dysregulation. In fact, these biases have been also previously linked to suicidal ideation (Wenzel & Beck, 2008). Accordingly, abnormal patterns of brain activation in the prefrontal cortex have been shown during emotional processing and regulation in a sample of adolescents with suicidal ideation, suggesting deficits in the recruitment of top-down circuits (Miller et al., 2018). Moreover, abnormalities in the white matter microstructure of corpus callosum and anterior thalamic radiation, involved in the emotional response (Coenen te al., 2012; Lungu & Stip, 2012), were also associated with suicidal ideation in MDD (Taylor et al., 2015; Chen et al., 2021a; Reis et al., 2022).

Interestingly, some of the regions included in the lobes identified as altered for suicidal ideation in this review, such as the medial PFC and temporal regions, belong to the DMN. This network

has been consistently described as impaired in MDD (Kaiser et al., 2015; Li et al., 2018b) and its main regions have been correlated with rumination in patients with depression (Zhou et al., 2020). Moreover, rumination has been linked to suicidal ideation (Rogers & Joiner, 2017). Indeed, in the comprehensive review of Schmaal and collaborators (2020), it was suggested that frontal, limbic and temporal lobes were involved in the generation of suicidal ideation by enhancing the negative internal states and rumination.

4.2 Suicide attempts

A previous review suggested that a fronto-striatal circuit, including the OFC, ACC, and striatum, had a key role in suicide for depression (Zhang et al., 2014), whereas meta-analyses reported no morphometric differences and brain activation changes in the insula and fusiform gyrus between suicide attempters and controls during different tasks (Jollant et al., 2018; Li et al., 2020; Rentería et al., 2017). In contrast, a previous ENIGMA MDD Consortium study described structural abnormalities in the thalamus, pallidum and inferior parietal lobule in suicide attempters compared to non-attempters (Campos et al., 2021).

In this scoping review, the studies included suggest alterations mainly in frontal and limbic lobes and basal ganglia, and in a lesser extent in the parietal lobe. The regions of these lobes are included in frontoparietal and frontostriatal networks, both disrupted in MDD (Li et al., 2018b). These networks have been implicated in executive functions and reward processing (Li et al., 2018b; Uddin et al., 2019). Interestingly, inhibition and decision-making are the only neurocognitive abilities that differentiated suicide attempters and ideators (Saffer & Klonsky, 2018). In accordance, suicide behaviours were proposed as a decision-making dysfunction displayed by neglecting decision-relevant information and alterations in delay discounting (Dombrovski & Hallquist, 2017), as well as less inhibitory control (Mann & Risk, 2020). Indeed, decreased cortical surface (Kang et al., 2020a), magnetization transfer ration (Chen et

al., 2015), and functional connectivity at rest (Yang et al., 2020) were described in frontoparietal regions involved in response inhibition (Menon, 2011). Compared to control patients, suicide attempters with MDD have more commission errors in Go/No-Go response inhibition task, but no alterations were found in the brain activity between the groups (Richard-Devantoy et al., 2016). Schmaal and collaborators (2020) also suggested that regions of the frontoparietal network might be facilitators of suicide behaviors due to their role in cognitive control, cognitive flexibility, and decision-making.

Not surprisingly, basal ganglia were also associated with suicide attempts in MDD. The studies included in this review reported abnormal volumes (Kang et al., 2020b), as well as altered white matter microstructure and functional connectivity between frontal cortex and these subcortical structures (Jia et al., 2010, 2014; Qiu et al., 2020). Basal ganglia have an important role not only in motor control, but also in reward-related behavior and emotions (Lanciego et al., 2012; Li et al., 2018b). Elderly suicide attempters with MDD, who had a lower gray matter volume in the putamen, prefer immediate rewards rather than larger delayed ones (Dombrovski et al., 2011). Moreover, suicide attempters have increased loss aversion, suggesting that they might overestimate the likelihood of future negative events and use suicide to avoid them (Baek et al., 2017). Decreased insula activity was associated to their risk aversion and heightened negative valuation of expected loss, whereas decreased ACC was associated with potential gains in the loss aversion task (Baek et al., 2017).

Taken together, the alterations in the brain structure and function present in suicide attempters with MDD seem to be associated with deficits in decision-making probably due to impairments in cognitive control and reward systems. Importantly, other neurobiological mechanisms such as the serotoninergic system and the hypothalamic-pituitary-adrenal (HPA) axis, have been linked to suicidal behaviors (Orsolini et al., 2020). Dysregulations in the serotonergic system

and the HPA axis have been shown in suicide attempters (Pandey, 2013; Pompili et al., 2010), which might also help to explain the reported alterations in brain structure and function.

4.3 Transition from suicidal ideation to attempt

Ninety-six percent (n=48) of the studies included in this review focus on suicidal ideation or attempts alone but including patients with both suicidal ideation and attempt. In fact, only 6 studies focusing on suicidal ideation excluded patients with history of previous suicide attempts, and no study focusing on suicide attempts controlled for suicidal ideation severity. Therefore, it is difficult to be confident about the common and differential brain alterations across suicidal ideation and behaviors. May and Klonsky (2016) showed that the most cited risk factors for suicide were associated with suicidal ideation but did not distinguish suicide ideators from attempters. Nevertheless, not every person with suicidal thoughts will attempt suicide (Nock et al., 2009). Therefore, Klonsky and May (2014) proposed an ideation-to-action framework, aiming to better understand the transition from suicidal ideation to behavior. Two studies followed the ideation-to-action framework reporting differences in the functional brain patterns of suicidal ideators and attempters (Ai et al., 2018; Wagner et al., 2021), suggesting widespread dysfunction in brain activity and connectivity were contributing to the transition from ideation to action. More studies following this framework are required.

4.4 Gaps and methodological concerns

Suicidality related features, such as timeframe between suicide attempt and assessment (i.e., lifetime, past year), amount and lethality of the attempts, family history of suicide, and severity of suicidal ideation, are underexplored and might be moderating the relationship between suicide risk and brain function and structure. Colle and collaborators (2015) described a decrease in the gray matter of hippocampus in suicide attempters, however, these findings only

remained for patients with history of previous suicide attempts in the past month (not for lifetime suicide attempts) compared with non-attempters. Another study exploring the morphological alterations associated with suicide behaviors, reported no differences among suicide attempters and control patients when combining two samples (Jollant et al., 2018). Nevertheless, the same authors reported increased gray matter volume in the caudate nucleus among patients with and without history of previous suicide attempts using violent means and decreased gray matter volume in temporal gyrus, dorsomedial PFC, and putamen in patients with family history of suicide attempts (Jollant et al., 2018). Moreover, patients with mild and severe suicidal ideation showed differences in gray matter volume and structural connectivity (He et al., 2022).

Other gaps and methodological concerns were identified among the included studies. For instance, suicidality measures were highly heterogeneous for ideation and behaviors. Across studies, multiple tools of measurement (e.g., medical records and/or interviews, self-reported questionnaires) were used to assess suicidal ideation and behaviours. Moreover, a recent study revealed that nearly one-third of the participants responded inconsistently across measures of suicide attempt, which may lead to misleading categorizations depending on the tool used (Hom et al., 2019). Similar findings were also described for single-items to assess suicidal ideation and planning (Ammerman et al., 2021). On top of that, van Velzen and collaborators (2022) also showed reduced effect sizes for the comparison between interrupted, aborted, and actual suicide attempts compared to using only actual suicide attempts, highlighting the importance of using specific and consistent definitions for suicide attempts. The heterogeneity of timeframe of these tools, that could vary from past month to lifetime for suicide attempts and from past week to past month for suicidal ideation, is also concerning. Given that suicidal ideation displays a rapid onset and short duration (Kleiman & Nock, 2018), that is not captured by the current available scales (Gratch et al., 2021). Although the current research methods of

measurement bring interesting and valuable findings to the field, introducing new measurement approaches, such as ecological momentary assessment, and pairing it with MRI might shed light on the development of suicidal ideation.

Still, longitudinal studies are missing, and they are crucial to better understand the suicide pathway and to identify individual at risk, as highlighted by several reviews on the suicidal brain (Bani-Fatemi et al., 2018; Desmyter et al., 2011; Schmaal et al., 2020). These studies should include short-term intervals of assessments, and if possible, hour-to-hour assessments to map the suicidal ideation fluctuations in the brain as suggested by Ballard and colleagues (2021). Moreover, more studies investigating alterations in the brain structure and function of pharmacological and non-pharmacological treatments for suicide are needed to expand the knowledge on its therapeutic mechanisms, determine predictors of treatment response and develop new treatments. A few studies emerged showing promising findings. Specifically, alterations in the functional connectivity between DMN and precuneus network after individual target-transcranial magnetic stimulation, and within ACC and frontoparietal network after ketamine treatment in patients diagnosed with depression and suicidal ideation were reported (Chen et al., 2019; Tang et al., 2021).

As highlighted by Campos and collaborators (2021), and confirmed in this review, the current literature available in the field includes studies with small samples sizes, multiple MRI methodologies and analyses, heterogenous measurements, and lack of clinical information wich might be on the basis of the lack of reproducibility across studies and the small effect sizes reported. Hence, well-powered studies accounting for the issues detailed above are needed to avoid reaching biased conclusions, and further enhance their reproducibility.

4.5 Limitations

As a scoping review, there was no formal assessment of the methodological quality of the included studies. This review did not mean to provide a systematic review or meta-analyses of the available literature, but an up-to-date overview of the literature on the brain structural and functional alterations associated with suicidal ideation and behaviors. Nonetheless, there was an effort to reduce the heterogeneity between the samples of the included studies by using the following inclusion criteria: patients currently depressed (not euthymic), adults, and clearly stating how history of suicidal attempts and ideation were defined or measured. The effects of medication of the included studies cannot be discarded, given that only 22 studies reported to use medication-free patients (drug-naïve patients or washout). We also included studies reporting differences between suicide attempters and ideators and controls without depression (i.e., healthy controls). The inclusion of these studies might hamper the final conclusions, given that we cannot guarantee that the differences are due to the presence of ideation/attempt or due to depression itself. Moreover, several studies followed hypothesis driven approaches, either using regions of interest or seed-based analysis which might be biasing the conclusions of this review. It is important to highlight that the heterogeneity of suicidality measures, MRI modalities and its analyses complicated the identification of common and differential brain alterations across suicide behaviors and ideation, preventing the possibility to perform a meta-analysis with this data. This remains an open question for future work when further and more homogeneous studies are available. Overall, caution is needed when interpreting the findings of this review, given that its findings are hampered by the same biases of the included studies, which can lead to misleading conclusions.

5 Conclusion

In sum, this review aimed to offer an overview and up-to-date picture on the MRI studies focusing on suicidal ideation, behavior and the transition between them in depression. Fifty

studies met the eligibility criteria and were included in this review. Their findings were summarized in Figure 3 pointing to alterations in frontal, limbic and temporal lobes in suicidal ideation and alterations in frontal, limbic, parietal lobes, and basal ganglia in suicide behaviors. Gaps in the literature and methodological concerns were identified, which might be important to address in future studies, in order to expand the knowledge on the neurobiological correlates of the suicidal process. Nevertheless, it is important to highlight that the suicidal process is a very complex and heterogenous one, and the information provided by neuroimaging techniques, specifically MRI, is only a small piece of the big puzzle.

6. Conflicts of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

7. Authors' contributions

RV, MPP and JMB contributed to the concept and design the study. RV performed the literature searches and wrote the first draft of the manuscript. RV, ARF and DR screened the studies against the eligibility criteria of this review and extracted its data. MPP solved any disagreement between the reviewers. All the authors contributed for the following and final versions of the manuscript.

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10 Figures captions

Figure 1. PRISMA flow diagram. Retrieved from Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., Shamseer, L., Tetzlaff, J. M., Akl, E. A., Brennan, S. E., Chou, R., Glanville, J., Grimshaw, J. M., Hróbjartsson, A., Lalu, M. M., Li, T., Loder, E. W., Mayo-Wilson, E., McDonald, S., McGuinness, L. A., … Moher, D. (2021). The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. *Systematic reviews*, *10*(1), 1-11. https://doi.org/10.1186/s13643-021-01626-4

Figure 2. Number of MRI studies on suicidal ideation and behaviors published by 3-year periods. This figure only shows the studies included in this review. Abbreviations: MRI, magnetic resonance imaging.

Figure 3. Summary findings of the review. A) Percentage of suicidal ideation studies reporting findings in the frontal, temporal, parietal, insular, limbic, basal ganglia, and cerebellar lobes. B) Percentage of suicidal attempt studies reporting findings in the frontal, temporal, parietal, insular, limbic, basal ganglia, and cerebellar lobes. C) Percentage of transition studies reporting findings in the frontal, temporal, parietal, insular, limbic, basal ganglia, and cerebellar lobes.

11 Tables

Table 1. Eligibility criteria for the review

Inclusion criteria	Exclusion criteria
Published on peer-reviewed journals; English language; Empirical studies; Humans; Adult patients, aged 18-65 years old; Current diagnosis of major depressive disorder, according to DSM or ICD; Brain MRI acquisition; Assessment of suicidal ideation and/or attempt; Group comparison or association between suicidal ideation or attempt and an MRI measure.	Gray literature; Case reports, conference abstracts, protocol papers, letters, editorials, opinion pieces, theoretical papers, reviews, and studies with computational methods or purely qualitative designs; Animal studies; Post-mortem studies; Adolescents (<18) or elderly people (>65); Other psychiatric and/or neurologic disorders diagnoses; Other neuroimaging tools; Focus on non-suicidal self-injury; No assessment of suicidal ideation or attempt, using the broad term suicidality without any specification, not indicating how suicidal ideation or attempt were measured; Not measuring the association between suicidal ideation and/or attempt and the MRI measure.

Abbreviations: DSM, Diagnostic and Statistical Manual of Mental Disorders; ICD, International Classification of Diseases; MRI, magnetic resonance imaging.

1042 **Table 2.** Main findings of the studies on suicidal ideation.

Author (Year)	MRI methods	p-value corrections	Main findings	Secondary findings
STRUCTURAL				
Taylor (2015)	GM volume and cortical thickness Freesurfer	p <.05, FDR corrected	ROI – GM volume: bilateral OFC, cingulate cortex, insula, amygdala, parahippocampi, thalamus, and basal ganglia; Cortical thickness: cortical regions **SI vs DC:** No differences in the GM volume. ↓ cortical thickness in the L insula, L caudal middle frontal gyrus, L superior parietal gyrus, and L superior temporal gyrus. **SI vs HC:** No differences in the GM volume, nor cortical thickness.	
Kim (2019)	LSV Freesurfer	p<.05, FDR corrected	ROI – bilateral amygdala, caudate, hippocampus, pallidum, putamen, and thalamus **SI vs DC/HC**: No differences in the LSV.	
		p<.001, Gaussian Random Field corrected		**SI**: BSSI score was positively correlated with L pallidum LSV.
Wang (2021)	GM volume VBM	p-value corrected with cluster-based statistics [a]	Whole brain **SI vs DC:** ↓ GM volume in the R lingual gyrus.	
He (2022)	GM volume Freesurfer Structural covariance network	p<.05, FDR corrected	ROI - Cingular opercular network regions **Severe SI vs DC:** ↓ GM volume in the L ACC and R inferior OFC. ↑ SC between the R inferior OFC and R ventral PCC; R ventral PCC and R superior frontal gyrus; and R superior frontal gyrus and R postcentral gyrus. **Mild SI vs DC:** ↓ GM volume in the R inferior OFC. ↑ SC between the R inferior OFC and R ventral PCC; and the R ventral PCC and R superior frontal gyrus. **Severe SI vs HC:** ↓ GM volume L ACC, L superior frontal Gyrus, L middle temporal gyrus, bilateral postcentral gyrus, R inferior OFC, and R PCC. ↑ SC between the L ACC and L postcentral gyrus, and L superior frontal gyrus; L superior frontal gyrus and L middle temporal gyrus; R inferior OFC and R ventral	

			PCC; R ventral PCC and R superior frontal gyrus; and R superior frontal gyrus and R postcentral gyrus. **Mild SI vs HC**: ↓ GM volume in the L ACC, L superior frontal gyrus, and R inferior OFC. ↑ SC between the L superior frontal gyrus and L middle temporal gyrus; and L ACC and L superior frontal gyrus. **Severe SI vs Mild SI:** ↓ GM volume in the R inferior OFC. ↑ SC between the R inferior OFC and R ventral PCC.	
Kang (2022)	GM volume CAT	p<.05, uncorrected	<u>ROI - bilateral dmPFC, dlPFC, vmPFC, vlPFC, OFC, and ACC</u> MDD: SSI score was positively correlated with GM volume of the L dlPFC and R dmPFC.	
DIFFUSION				
Taylor (2015)	FA and RD maps TBSS	p<.05, TFCE corrected [a]	<u>Whole brain</u> **SI vs DC:** ↓ FA in the L posterior corona radiata and ↑ RD in the R anterior thalamic radiation. **SI vs HC:** ↓ FA in the splenium of the CC, R corticospinal tract, and R anterior thalamic radiation; and ↑ RD in the L superior longitudinal fasciculus.	
		p<.05, FDR corrected	<u>ROI – CgH, CgC, superior and posterior corona radiata, CC, ALIC, PLIC, anterior and posterior thalamic radiation</u> **SI vs DC/HC:** ↓ FA and ↑ RD in the corona radiata, CgH, and anterior thalamic radiation.	
Myung (2016)	Probabilistic tractography NBS Graph theory: nodal, strength and degree, clustering, and participation coefficients, regional efficiency and betweenness centrality	p<.05, non-parametric correction method [a]	<u>Whole brain</u> **SI vs DC/HC:** ↓ SC in a subnetwork including L frontal and occipital regions, and basal ganglia.	
		p<.05, FDR corrected		**SI:** SSI score was positively correlated with betweenness centrality of the L rostral middle frontal gyrus.
Chen (2021a)	Generalized Q-Sampling: GFA, and NQA maps Graph theory: global efficiency, normalized shortest	p<.05, FDR corrected	<u>Whole brain</u> **SI vs DC:** ↓ GFA and NQA in the CC and ACC. No differences in graph theory measures. **SI vs HC:** ↓ GFA in the CC and ACC. ↓ NQA in the ACC. No differences in graph theory measures.	

	and characteristic path length, and small worldness NBS	p<.05, non-parametric correction method [a]	Whole brain **SI vs DC:** No differences in the SC of any subnetwork. **SI vs HC:** ↓ SC of the frontal subnetwork.	
Liu (2021)	Deterministic tractography Graph theory: normalized shortest path length, normalized clustering coefficient, small worldness, global and local efficiency, rich-club, and modularity NBS	p-value corrected with Bonferroni	Whole brain **SI vs DC:** No differences in the topological parameters. ↓ betweenness centrality in the L fusiform gyrus. **SI vs HC:** ↓ small worldness, global efficiency, and modularity.	
Reis (2022)	FA, AD, MD, and RD maps TBSS	p<.05, TFCE corrected [a]	Whole brain **MDD:** BSSI score was negatively correlated with FA in the genu of the CC and R anterior corona radiata.	
FUNCTIONAL				
Resting-state fMRI				
Du (2017)	Seed-based FC Seed: R rostral ACC	p<.05, Bonferroni corrected	Whole brain **SI vs DC/HC:** ↓ intrinsic FC between the R rostral ACC and the medial OFC and the R middle temporal pole.	
		p<.05, uncorrected		**SI:** SSI score was positively correlated with intrinsic FC between the R rostral ACC and the middle temporal pole.
Kim (2017)	NBS Graph theory: node strength, betweenness centrality, regional efficiency	p<.05, non-parametric correction method [a]	Whole brain **SI vs DC:** ↓ FC in a subnetwork including frontal and temporal regions and basal ganglia.	
		p<.05, FDR corrected		**SI:** SSI score was negatively correlated with FC of the regions of the subnetwork, node strength, clustering coefficients, and regional efficiency in the bilateral thalamus and L OFC.
Li (2018a)	Static and dynamic ALFF	p<.05, Bonferroni corrected	ROI – R dorsal ACC, L inferior temporal gyrus, L hippocampus/parahippocampal gyrus and L OFC **SI vs DC:** No differences in the static ALFF. ↓ dynamic ALFF in the L OFC, L inferior temporal	

			gyrus, L hippocampus/parahippocampus gyrus and R dorsal ACC. **SI vs HC:** ↑ in the static ALFF in the R dorsal ACC and L inferior temporal gyrus; ↓ dynamic ALFF in the R dorsal ACC and L hippocampus/parahippocampal gyrus.	
Liao (2018)	Static and dynamic connectomics Graph theory: network strength and efficiency, nodal efficiency and small worldness	p<.05, Bonferroni corrected	Whole brain **SI vs DC:** No differences in the overall static connectomics. ↓ static nodal efficiency in the R insula. ↑ overall network strength and network efficiency in dynamic connectomics. ↑ dynamic nodal efficiency in the L inferior OFC, R fusiform gyrus, R postcentral gyrus and R superior parietal gyrus. **SI vs HC:** ↓ overall network strength and efficiency in static connectomics; ↓ static nodal efficiency in the R insula. ↑ overall network strength and efficiency in dynamic connectomics. ↑ dynamic nodal efficiency in the L superior frontal medial gyrus.	
Wei (2018)	Seed-based FC Seed: bilateral amygdala	p<.05, Bonferroni corrected	ROI –bilateral precuneus/cuneus **SI vs DC/HC:** ↑ FC between bilateral amygdala and bilateral precuneus/cuneus.	
Qiao (2020)	Seed-based FC (static and dynamic) Seed: bilateral habenula	p<.05, Bonferroni corrected	ROI – static FC: L habenula-L putamen, L cerebellum, R precentral gyrus, R habenula-R precuneus, L IFG; dynamic FC: L habenula-R lingual gyrus, bilateral precuneus, R habenula-L superior temporal gyrus, L angular gyrus and L postcentral gyrus **SI vs DC/HC:** ↓ static FC between R habenula and R precuneus, and L IFG; ↑ static FC between L habenula and L cerebellum. ↓ dynamic FC between L habenula and R lingual gyrus and R habenula and L postcentral gyrus; ↑ dynamic FC between L habenula and L precuneus and R habenula and R superior temporal gyrus.	**SI:** No correlation between BSSI score and static and dynamic FC in the regions with differences between groups.

Chen (2021b)	Seed-based FC Seed: bilateral amygdala, hippocampus, thalamus, visual and motor cortices, ACC, PCC and precuneus ALFF ReHo Graph theory: clustering and normalized clustering coefficient; characteristic and normalized characteristic path length, local and global efficiency, transitivity, assortativity, and small worldness NBS	p<.05, FDR corrected	<u>Whole brain</u> **SI vs DC:** ↓ ALFF in the L cuneus and ↑ ALFF in the R middle temporal pole gyrus. ↓ ReHo in the R cuneus and ↑ ReHo in the L middle temporal gyrus. ↓ global efficiency. **SI vs HC:** ↑ global efficiency, ↓ assortativity and transitivity. <u>ROI - bilateral amygdala, hippocampus, thalamus, visual and motor cortices, ACC, PCC and precuneus</u> **SI vs DC:** ↑ FC in the R and L hippocampus.	
		p<.05, non-parametric correction method [a]	<u>Whole brain</u> **SI vs DC:** ↓ FC in a subnetwork including frontal, parietal, and occipital regions, as well as parahippocampal gyrus. **SI vs HC:** No differences in the FC of any subnetwork.	
Tang (2021)	ICA: inter-network connectivity	p<.05, FDR corrected	<u>DMN, anterior and posterior salience, visual, precuneus, thalamus cerebellum, sensorimotor, motor, language, and L central executive networks</u> **SI vs HC:** ↓ FC between DMN and precuneus networks; ↑ FC between DMN and thalamus cerebellum and sensorimotor networks; between L central executive and sensorimotor networks; and between sensorimotor and precuneus networks.	**SI:** Positive correlation between the changes in the BSSI score and the changes in the FC in DMN-precuneus network (due to IT-TMS therapy).
Wang (2021)	ALFF	p<.001, Gaussian Random Field corrected	<u>Whole brain</u> **SI vs DC:** No differences in the ALFF.	
Fan (2022)	Cerebral blood flow-based FC Seed: Bilateral visual cortices, precuneus, PCC, striatum, L supplementary motor area, L inferior temporal gyrus, L superior temporal gyrus, and L insula	p<.05, Bonferroni corrected	<u>Whole brain</u> **SI vs DC:** ↑ FC between the L precuneus and L middle temporal gyrus; L supplementary motor area and R OFC; R striatum and the bilateral medial PFC. ↓ FC between the L visual cortex and the bilateral sensorimotor cortex. **SI vs HC:** ↓ FC between the L visual cortex and the bilateral sensorimotor cortex.	
He (2022)	ReHo	p<.05, uncorrected	<u>ROI - Cingular opercular network regions</u> **MDD:** MADRS item 10 score was negative correlated with ReHo of the R inferior OFC and positively correlated with ReHo of the R middle frontal gyrus.	

Li (2022a)	Seed-based dynamic FC Seed: Bilateral dorsal and ventral PCC	p<.05, Bonferroni corrected	ROI – L dorsal PCC and L fusiform gyrus, L ventral PCC and L IFG, and R ventral PCC and L IFG **SI vs DC:** ↑ dynamic FC variability between the L ventral PCC and the L IFG. **SI vs HC:** ↑ dynamic FC variability between the L ventral dorsal PCC and the L fusiform gyrus, and the R ventral PCC and the L IFG.	**MDD:** SSI score was positively correlated with the dynamic FC variability between the L ventral PCC and the L IFG. **SI:** No significant correlation between SSI scores and dynamic FC
Li (2022b)	Seed-based FC Seed: Bilateral amygdala	p<.05, Bonferroni corrected	ROI – L amygdala and L middle frontal gyrus, L medial superior frontal gyrus, L inferior and superior parietal lobule, R precentral gyrus; R amygdala and L middle temporal gyrus, L precentral gyrus, R angular gyrus, and L postcentral gyrus **SI vs DC:** ↑ FC between the L amygdala and the L medial superior frontal gyrus and L middle frontal gyrus; and R amygdala and L middle temporal gyrus. ↓ FC between the L amygdala and the L inferior parietal lobule and R precentral gyrus; and the R amygdala and L precentral gyrus, R angular gyrus and L postcentral gyrus.	
Ouyang (2022)	Temporal Correlation Coefficient	p<.05, FDR corrected	Whole brain **MDD:** HDRS item 3 score was negatively correlated with the temporal correlation coefficient of the DMN.	
Reis (2022)	ICA DMN, salience, central executive, precuneus, sensorimotor, basal ganglia, high and primary visual networks NBS	TFCE, p<.05 corrected [a]	Whole brain **MDD:** BSSI score was positively correlated with FC between the high visual network and the R inferior occipital gyrus and negatively correlated with the L precuneus and L cerebellum. BSSI score was positively correlated with FC between the primary visual network and R cuneus, and negatively correlated with the L OFC.	
		p<.05, non-parametric correction method [a]	Whole brain **MDD:** BSSI score was negatively correlated with the FC of a subnetwork including frontal, temporal, occipital and cerebellar regions.	
Yang (2022a)	Seed-based FC Seed: bilateral lateral and medial amygdala Graph theory	p<.05, FDR corrected	Whole brain **SI vs DC:** ↑ FC between the L lateral amygdala and the bilateral caudate; ↓ FC between the R lateral amygdala, the L postcentral gyrus, R superior temporal gyrus and L middle temporal gyrus.	

	Global connectivity, sigma (small worldness), lambda (normalized characteristic path length), and gamma (normalized clustering coefficient)	**SI vs HC:** ↑ FC between the L lateral amygdala and the bilateral caudate nucleus, the R lateral amygdala and the L caudate; ↓ FC between the R lateral amygdala and L superior frontal gyrus, the L medial amygdala and the L parahippocampal gyrus, and the L middle temporal gyrus, and the R medial amygdala and the L superior temporal gyrus. ROI - bilateral superior frontal gyri, parahippocampal gyri, basal ganglia, amygdala, L hippocampus, L OFC, L superior temporal gyrus, R postcentral gyrus **SI vs DC:** ↓ global connectivity. **SI vs HC:** ↓ global connectivity and sigma, and ↑ lambda.	
		P<.05, uncorrected	**SI:** SSI score was negatively correlated with sigma.

Footnotes: a, similar to p<.05 family-wise error rate corrected. *Abbreviations:* ACC, anterior cingulate cortex; AD, axial diffusivity; ALFF, amplitude of low frequency fluctuation; ALIC, anterior limb of the internal capsule; BSSI, Beck Scale for Suicidal Ideation (self-report); CAT, Computational Anatomy Toolbox; CC, corpus callosum; CgC, cingulate portion of the cingulum bundle; CgH, hippocampal portion of the cingulum bundle; DC, patient control group; dlPFC, dorsolateral prefrontal cortex; DMN, default mode network; dmPFC, dorsomedial prefrontal cortex; FA, fractional anisotropy; FC, functional connectivity; FDR, false discovery rate; fMRI, functional magnetic resonance imaging; GFA, generalized fractional anisotropy; HC, healthy control group; HDRS, Hamilton Depression Rating Scale; ICA, independent component analysis; IFG, inferior frontal gyrus; IT-TMS, individual targeted-transcranial magnetic stimulation; GM, gray matter; L, left; LSV, local shape volume; MD, mean diffusivity; MDD, major depressive disorder; NBS, network-based statistics; NQA, normalized quantitative anisotropy; OFC, orbitofrontal cortex; PCC, posterior cingulate cortex; PLIC, posterior limb of the internal capsule; R, right; ReHo, regional homogeneity; RD, radial diffusivity; ROI, region of interest; SI, suicidal ideation group; SC, structural connectivity; BSSI, Scale for Suicidal Ideation (interview); TBSS, tract-based spatial statistics; TFCE, threshold-free cluster enhancement; VBM, voxel-based morphometry; WM, white matter; vlPFC, ventrolateral prefrontal cortex; vmPFC, ventromedial prefrontal cortex.

1055 **Table 3.** Main findings of the studies on suicidal behavior.

Author (Year)	MRI methods	p-value corrections	Main findings	Secondary findings
STRUCTURAL				
Ehrlich (2005)	Deep WMH and periventricular hyperintensities Modified Fazekas 4-point rating scale	p<.05, uncorrected	Whole brain **SA vs DC:** ↑ periventricular hyperintensities. No differences in deep WMH.	**SA:** No correlation between lethality or number of SA and the presence, severity, or number of WMH.
Jia (2010)	WM and GM volume VBM	p <.05, FWE corrected	Whole brain **SA vs DC/ HC:** No differences in GM or WM volume.	
Peng (2014)	GM Volume VBM	p<.05, FDR corrected	Whole brain **SA vs DC:** ↓ GM volume in the L PCC. **SA vs HC:** ↓ GM volume in the R middle temporal gyrus and ↑ GM volume in the R parietal lobe.	
Chen (2015)	MTR maps	Voxel p<.005, AlphaSim corrected p <.05	Whole brain **SA vs DC/HC:** ↓ MTR in the L inferior parietal lobule and R superior parietal lobule. ROI – Bilateral caudate nucleus **SA vs DC/HC:** No MTR differences.	
Colle (2015)	GM Volume SACHA	p<.05, uncorrected	ROI - Bilateral hippocampi **SA** (past month and lifetime) **vs DC:** ↓ GM volume in the hippocampus.	**Past month SA vs DC:** ↓ GM volume in the hippocampus. **Lifetime SA vs DC:** No differences in the GM volume of the hippocampus. **Past month vs Lifetime SA:** No differences in the GM volume of the hippocampus.
Lee (2016)	GM Volume VBM	p<.001, uncorrected	Whole brain **SA vs DC:** ↓ GM volume in the L angular gyrus and R cerebellum.	
Lee (2018)	GM Volume VBM	p<.001, uncorrected	Whole brain **SA vs HC:** ↓GM volume in the L middle frontal gyrus, L IFG, L ACC, R middle temporal gyrus, L cerebellum, R precentral and postcentral gyrus.	
Jollant (2018) **Jena sample**	WM and GM Volume	p<.05, TFCE corrected	Whole brain **SA vs DC:** ↓ GM volume in the R dmPFC cortex.	**SA with violent means vs. SA without:** ↑ GM in the bilateral caudate nuclei.

	VBM		**SA vs HC:** No differences in the GM volume.	**Family history of suicide vs No history:** ↓ GM volume in the bilateral temporal gyri, L temporal gyrus extending to fusiform gyrus, R dmPFC, and L putamen.
Jollant (2018) **Montreal sample**	WM and GM Volume VBM	p<.05, TFCE corrected	Whole brain **SA vs DC/ HC:** No differences in GM or WM volume.	
Kang (2020a)	Cortical thickness, surface area, and cortical volume Freesurfer	p<.05, FDR corrected	ROI – cortical regions **SA vs DC:** ↑ cortical surface areas of the L postcentral and L lateral occipital areas and ↓ cortical surface areas of the L superior frontal area; ↑ cortical volumes of the L postcentral and the L lateral OFC. No differences in cortical thickness.	**SA:** No differences between number of SA and risk-rescue rating score and the surface area/cortical volume of the areas with significant results between groups.
Kang (2020b)	LSV Freesurfer	Non-parametric procedure to estimate the p-value [a]	ROI – bilateral amygdala, caudate nuclei, hippocampi, pallidum, putamen, and thalamus **SA vs DC:** ↓ LSV in the L putamen, L hippocampus, L amygdala and bilateral pallidum and thalamus. **SA vs HC:** ↓ LSV in the bilateral amygdala, pallidum and putamen, and L caudate nucleus and L hippocampus.	**SA:** Negative correlation between BSSI score and LSV of bilateral thalamus.
Yang (2020)	GM volume VBM	Bonferroni corrected p-value	ROI – R inferior OFC, L rectus gyrus, L superior temporal pole, L postcentral gyrus, L calcarine fissure, bilateral amygdala, L insula and L caudate nucleus **SA vs DC:** ↓ GM volume in the R inferior OFC, L caudate nucleus, and ↑ GM volume in the L calcarine fissure. **SA vs HC**: ↓ GM volume in the R inferior OFC, L rectus gyrus, L superior temporal pole, L postcentral gyrus, bilateral amygdala, L insula, L caudate nucleus and ↑ GM volume in the L calcarine fissure.	**SA:** Negative correlation between the GM volume of the R inferior OFC and the Nurses' Global Assessment of Suicide Risk Scale score.
DIFFUSION				
Jia (2010)	FA, AD and RD maps	p <.05, FWE corrected	Whole brain **SA vs DC:** ↓ FA and AD of the L ALIC and the R lentiform nucleus. **SA vs HC:** ↓ FA and AD of the L ALIC and ↓ FA and ↑RD of the R frontal lobe (subgyral WM). ROI - bilateral lentiform nucleus, hippocampus, and thalamus **SA vs DC:** ↓ FA and ↑RD of the R lentiform nucleus.	
Jia (2014)	Deterministic tractography Seed: L ALIC	p<.05, Bonferroni corrected	ROI – L medial frontal cortex, L OFC and L thalamus **SA vs DC:** ↓ mean percentage of projecting fibers from the L ALIC to the L OFC, and the L thalamus; ↓ mean FA in the fibers projecting from L ALIC to the L medial frontal cortex. **SA vs HC:** ↓ mean percentage of projecting fibers from the L ALIC to the L medial frontal cortex, L OFC, and L thalamus; ↓ mean FA	

			in the fibers projecting from L ALIC to the L medial frontal cortex, L OFC, and L thalamus.	
Olvet (2014)	FA and ADC maps TBSS	p<.05, TFCE corrected [a]	Whole brain **SA vs DC/HC:** No differences in FA and ADC.	
		p<.01, uncorrected	Whole brain **SA vs DC:** ↓ FA in the R dmPFC. No differences in ADC.	
		p<.05, uncorrected	ROI - medial OFC, dmPFC, rostral and caudal ACC **SA vs DC:** ↓ FA in the bilateral dmPFC. No differences in ADC.	
Chen (2021c)	Generalized Q-Sampling: GFA, NQA maps Graph theory: global efficiency, normalized shortest and characteristic path length, modularity, normalized clustering coefficient, and small worldness NBS	p<.05, FDR corrected	Whole brain **SA vs DC:** ↓ GFA and NQA in the corpus callosum and precuneus; ↓ GFA in the cuneus. **SA vs HC:** ↓ GFA and NQA in the corpus callosum and the caudate nucleus.	
		p<.05, non-parametric correction method [a]	Whole brain **SA vs DC:** No differences in the topological parameters. No differences in the SC of any subnetwork. **SA vs HC:** ↑ SC in a subnetwork including frontal and parietal regions. No differences in the topological parameters.	
Zhang (2021)	FA, AD, MD, and RD maps Deterministic tractography	p<.05, Bonferroni corrected	ROI – forceps major and minor, bilateral anterior thalamic radiation, arcuate fasciculus, corticospinal tract, CgC, CgH, IFOF, inferior and superior longitudinal fasciculus, uncinate fasciculus **SA vs DC:** ↓ FA forceps major, ↑ MD and RD in the forceps minor, L IFOF, and L CgC. **SA vs HC:** ↓ FA in the forceps major, ↑ MD and RD in the forceps minor and L IFOF.	
FUNCTIONAL				
Resting-state fMRI				
Kang (2017)	Seed-based FC Seed: bilateral amygdala	p<.005, uncorrected	Whole brain **SA vs DC:** ↑ FC between L amygdala and R insula and L OFC, ↑ FC between R amygdala and L middle temporal gyrus.	**SA:** SSI score was positively correlated with FC between R amygdala and R parahippocampal gyrus.
Lee (2019)	Seed-based FC ROI-to-ROI Seed: medial frontal cortex, R supplementary motor cortex, R anterior and L posterior	p<.05, FDR corrected	ROI - regions of the Harvard-Oxford atlases **SA vs HC:** ↑ FC between R anterior parahippocampal gyrus and L posterior parahippocampal gyrus; R temporooccipital part of inferior temporal gyrus and R frontal eye field; ↓ FC between medial frontal cortex and R supplementary motor cortex. Whole brain	**All:** SSI score was negatively correlated with FC between medial prefrontal cortex and R supplementary motor cortex.

	parahippocampal gyri, temporooccipital part of R inferior temporal gyrus, R frontal eye field (significant results ROI-to-ROI analysis)		**SA vs HC:** ↑ FC between L posterior parahippocampal gyrus and R uncus; R frontal eye field of dorsal attention network and R fusiform gyrus.
Wagner (2019) **Jena and Montreal sample**	Graph theory: clustering coefficients, global efficiency, assortativity, rich-club coefficients NBS	p<.05, FDR corrected	Whole brain **SA vs DC:** ↑ rich-club coefficients for higher degree nodes. No differences in the other topological parameters. **SA vs HC:** ↓ assortativity and ↓ rich-club coefficients for lower degree nodes.
		p<.05, FWE corrected	Whole brain **SA vs DC:** No differences in the FC of any subnetwork. **SA vs HC:** ↓ FC in the identified subnetwork, including frontal, parietal, occipital and temporal regions, and parahippocampal gyrus.
Weng (2019)	Seed-based Seed: bilateral visual and motor cortices, PCC, amygdala, hippocampi, thalamus, ALFF ReHo Graph theory: clustering and normalized clustering coefficients, local and global efficiency, characteristic and normalized characteristic path length, small worldness and transitivity NBS	p<.05, FDR corrected	Whole brain **SA vs DC:** ↑ ALFF in the L superior parietal gyrus and ↓ ALFF in the R angular gyrus. ↑ ReHo in the R putamen and ↓ ReHo in the R superior temporal gyrus and R superior and inferior OFC. No differences in the topological parameters. **SA vs HC:** ↓ ALFF in the bilateral thalamus. ↓ ReHo in the bilateral thalamus. ↓ characteristic path length, lambda, assortativity, and transitivity. ROI – bilateral visual and motor cortices, PCC, amygdala, hippocampi, and thalamus. **SA vs DC:** ↑ FC in the L hippocampus and bilateral thalamus. **SA vs HC:** ↓ FC in the bilateral thalamus and motor cortex.
		p<.05, non-parametric correction method [a]	Whole brain **SA vs DC:** No differences in the FC of any subnetwork. **SA vs HC:** ↓ FC in a subnetwork including pre and postcentral gyri and temporal regions.

Qiu (2020)	Seed-based FC Seed: pregenual, anterior and posterior subgenual ACC	Voxel p<.001 with cluster p <.05, Gaussian Random Field corrected	Whole brain **SA vs DC:** ↓ FC between anterior subgenual ACC and R caudate nucleus, ↓ FC between the pregenual ACC and L insula and L superior medial frontal gyrus; ↑ FC between the anterior subgenual ACC and L frontal inferior (tri) frontal and L superior medial frontal gyri, ↑ FC between the posterior subgenual ACC and L superior medial frontal gyrus.	.
		p<.05, uncorrected		**SA:** SSI score was positively correlated with FC between pregenual ACC and L superior frontal gyrus. No correlation between number of SA and FC. **DC:** SSI score was positively correlated with FC between pregenual ACC and L superior frontal gyrus, and negatively correlated with anterior subgenual ACC and superior frontal gyrus.
Shu (2020)	fALFF	p<.01, AlphaSim corrected	Whole brain **SA vs HC:** ↑ fALFF in the L posterior cerebellum, R ACC, L caudate nucleus and L superior frontal cortex.	
		p<.05, uncorrected		**SA:** SSI score was positively correlated with mean fALFF in the L superior frontal gyrus and R ACC.
Yang (2020)	Seed-based FC Seed: R inferior OFC, L caudate nucleus, L calcarine fissure	p<.0019, Bonferroni corrected	ROI – R inferior OFC: L rectus gyrus and left inferior parietal lobule; L caudate nucleus: L middle frontal gyrus **SA vs DC:** ↓ FC between R inferior OFC and L rectus gyrus, and L inferior parietal lobule. **SA vs HC:** ↓ FC between R inferior OFC and L inferior parietal lobule.	
Chen (2021d)	FC strength Seed-based FC Seed: R OFC, and bilateral dmPFC	Voxel p <.001, with a cluster p<.05, FWE corrected	Whole brain **SA vs DC:** ↓ FC strength in the R OFC and bilateral dmPFC; ↓ FC between R OFC and L ACC and L calcarine sulcus; ↑ FC between the R OFC and the R middle frontal gyrus; and ↑ FC between the bilateral dmPFC and the L middle frontal gyrus, and R inferior temporal gyrus. **SA vs HC:** ↓ FC strength in the bilateral hippocampus, R inferior and occipital gyrus.	
Shu (2022)	Seed-based FC Seed: bilateral ACC and precuneus	p<.001, AlphaSim corrected	Whole brain **SA vs HC:** ↓ FC between R subgenual ACC and L posterior cerebellum; ↓ FC between L subgenual ACC and occipital lobe; ↓	

			FC between R precuneus and R middle frontal cortex/precentral gyrus.	
		p<.05, uncorrected		**SA:** SSI score was negatively correlated with FC between R subgenual ACC and L posterior cerebellum.
Yang (2022b)	ReHo	p<.05	Whole brain **SA vs DC:** ↓ ReHo in the R PCC. **SA vs HC:** ↓ ReHo in the L PCC and R PCC/precuneus.	**MDD:** HDRS item 3 score was positively correlated with ReHo in the R PCC.
Task fMRI				
Richard-Devantoy (2016)	Brain activation Task: Go/No-Go Task	Voxel p<.001, uncorrected, with cluster p<.05, FWE corrected	Whole brain **SA vs DC:** No differences in activation during response inhibition. **SA vs HC:** ↓ activation in the precuneus and middle/PCC during Go vs. No-Go contrast (response inhibition).	**SA:** Beck Suicide Intent Scale score was positively correlated with the activation in the medial thalamus during response inhibition.
Baek (2017)	Brain activation Task: Monetary Decision-Making Task (risk and loss aversion)	p<.01 with Tukey's test	ROI - OFC, vmPFC, ventral ACC, insula, midbrain, striatum and amygdala **SA vs DC**: ↓ activation of the subgenual ACC for potential gain contrast (loss aversion). **SA vs HC**: ↓ activation of the subgenual ACC and L amygdala for potential gain and loss contrasts, respectively (loss aversion); ↓ activation of the L insula for subjective value of probabilistic loss contrast (risk aversion).	
		p<.001, uncorrected		**SA:** The L insula activity was negatively correlated with subjective value of probabilistic loss (risk aversion). The R amygdala, bilateral insula, L middle temporal gyrus, and L globus pallidus activity was negatively correlated with the subjective value of probabilistic gain (risk aversion).

Footnotes: a, similar to p<.05 family-wise error rate corrected. *Abbreviations:* ACC, anterior cingulate cortex; AD, axial diffusivity; ADC, apparent diffusion coefficient; ALFF, amplitude of low frequency fluctuation; ALIC, anterior limb of the internal capsule; BSSI, Beck Scale for Suicidal Ideation (self-report); CgC, cingulate portion of the cingulum bundle; CgH, hippocampal portion of the cingulum bundle; DC, patient control group; dmPFC, dorsomedial prefrontal cortex; FA, fractional anisotropy; fALFF, fractional amplitude of low frequency fluctuation; FC, functional connectivity; FDR, false discovery rate; fMRI, functional magnetic resonance imaging; FWE, family-wise error rate; GFA, generalized fractional anisotropy; HC, healthy control group; HDRS, Hamilton Depression Rating Scale; IFG, inferior frontal gyrus; IFOF, inferior fronto-occipital fasciculus; GM, gray matter; L, left; LSV, local shape volume; MD, mean diffusivity; MDD, major depressive disorder; MTR, magnetization transfer ratio; NBS, network-based statistics; NQA, normalized quantitative anisotropy; OFC, orbitofrontal cortex; PCC, posterior cingulate cortex; R, right; ReHo, regional homogeneity; RD, radial diffusivity; ROI, region of interest; SA, suicide attempt group; SI, suicidal ideation group; SC, structural connectivity; BSSI, Scale for Suicidal Ideation (interview); TBSS,

tract-based spatial statistics; TFCE, threshold-free cluster enhancement; VBM, voxel-based morphometry; WM, white matter; WMH, white matter hyperintensities; vmPFC, ventromedial prefrontal cortex.

1068 **Table 4.** Main findings of the studies on the transition between suicidal ideation and behavior.

Author (Year)	MRI methods	p-value corrections	Main findings	Secondary findings
FUNCTIONAL				
Resting-state fMRI				
Wagner (2021)	ALFF Graph theory: degree centrality	p<.05, FWE corrected	ROI – ALFF: R dlPFC, R vlPFC, bilateral inferior and superior parietal lobes, precuneus, angular, supramarginal, postcentral, fusiform, and superior temporal gyri, occipital cortices, hippocampi, and R thalamus; degree centrality: R dlPFC, R vlPFC, R superior parietal cortex, bilateral angular gyrus, and bilateral occipital cortices **SA vs SI:** ↓ ALFF in the bilateral angular gyrus, L inferior parietal cortex, L occipital cortex, R precuneus, R supramarginal, R superior parietal cortex, and R postcentral gyrus; and ↑ ALFF in the L parahippocampal gyrus, L hippocampus, and R fusiform gyrus. ↓ degree centrality in the L occipital cortex, R IFG, and R angular gyrus. **SA vs DC:** ↓ ALFF in the R IFG, R cuneus, bilateral angular and supramarginal gyrus, superior parietal cortex and occipital cortex; and ↑ ALFF in bilateral hippocampus and fusiform gyrus. ↓ degree centrality in the R IFG, R superior parietal cortex, R occipital cortex, and bilateral angular gyrus. **SA vs HC:** ↓ ALFF in the bilateral angular gyrus, temporal cortex, supramarginal gyrus, angular gyrus, R paracentral lobule, L inferior and R superior parietal cortex, R inferior and middle frontal gyri, L occipital cortex, R cuneus; and ↑ ALFF in the bilateral hippocampus, R thalamus and R fusiform gyrus. ↓ degree centrality in the bilateral angular gyrus, occipital cortex, and R IFG. **SI vs DC:** No differences in the ALFF, nor in degree centrality. **SI vs HC**: No differences in the ALFF. ↓ degree centrality in the angular gyrus.	No correlation between the number of SA and ALFF and degree centrality values.
Task fMRI				
Ai (2018)	Brain activation Task: Faces task; Tower of London	p<.05, FWE corrected	ROI – Faces task: bilateral fusiform gyri extending to the lingual gyrus; Tower of London: L insula, L dlPFC, and L postcentral gyrus **SA vs SI/DC/HC:** ↓ activation in the bilateral fusiform gyri extending to lingual gyrus in the processing of emotional faces. No differences between groups in the activation for executive planning. **SI vs DC/HC:** No differences in activation in the processing of emotional faces or executive planning.	
		p<.001, uncorrected	ROI - L insula, L dlPFC, and L postcentral gyrus **SA vs SI/DC/HC:** ↑ activation in the L insula during executive planning.	

Abbreviations: ALFF, amplitude of low frequency fluctuation; DC, patient control group; dlPFC, dorsolateral prefrontal cortex; fMRI, functional magnetic resonance imaging; FWE, family-wise error rate; HC, healthy control group; IFG, inferior frontal gyrus; L, left; R, right; ROI, region of interest; SA, suicide attempt group; SI, suicidal ideation group; vlPFC, ventrolateral prefrontal cortex.