# EEG Correlates of Suicide Ideation and Suicide Attempt

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Previous research suggests that electroencephalography (EEG) can play a key role in the evaluation of suicide risk. We systematically reviewed EEG resting state studies of adults with suicide ideation (SI) or with a history of suicide attempts (SAs). After searching for relevant studies using the PubMed and Web of Science databases, we applied the PRISMA method to exclude duplicates and studies that did not match our inclusion criteria. The selection process yielded seven studies, which suggest that imbalances in frontal and left temporal brain regions might reflect abnormal activation and correlate with psychological distress. Furthermore, asymmetrical activation in frontal and posterior cortical regions was detected in high-risk depressed persons, although the pattern in the frontal region was inverted in non-depressed persons. The literature reviewed suggests that SI and SA may be driven by separate neural circuits and that high-risk persons can be found within non-depressed populations. More research is needed to develop intelligent algorithms for the automated detection of high-risk EEG anomalies in the general population.

Keywords: suicide risk assessment ; resting state ; electroencephalogram ; EEG

## 1. Introduction

Suicide is a global phenomenon that involves individuals from all income groups worldwide and can be prevented if personalized interventions are timely implemented [1,2,3,4]. Unfortunately, assessments based on interviews and questionnaires most often fail to reliably identify high-risk profiles [2,3]. Neuroimaging studies have found that both structural and functional changes in fronto-temporal networks, prefrontal cortex, anterior cingulate cortex, and upper anterior temporal gyrus are associated with greater risk for suicide [**12**]. These findings support the hypothesis that the disruption of executive functions can have a direct impact on emotion regulation in individuals with suicidal behavior, impairing their ability to adaptively cope with stress [**13**]. On the other hand, standard neuroimaging can only detect brain anomalies at the population level and their application on a day-to-day basis still awaits validation [**14**]. Additionally, neuroimaging equipment, its operation, and its management are extremely costly and generally not affordable to small clinical practices and clinics [**15**]. In this context, several decades of research support the use of electroencephalography (EEG) as a diagnostic method in mental health [**16**,**17**]. Through electrodes appropriately placed on the scalp, EEG systems detect and record electrical signals that originate in the brain, converting them into digital form. The rhythmic EEG spectrum is typically subdivided into five main oscillation frequency bands: (1) delta (1–4 Hz), typically recorded during sleep; (2) theta (4–8 Hz), which reflects a state of drowsiness; (3) alpha (8–12 Hz), which accompanies a relaxed state; (4) beta (12–30 Hz), a common index of an engaged or active brain in healthy individuals; and (5) gamma (30–50 Hz or higher), which reflects both perception and synchronization of neural firing rates across separate brain regions [**18**,**19**]. However, while standard EEG in many cases fails to reveal biological anomalies in patients with psychiatric disorders [**20**], hundreds of studies support the use of quantitative EEG (qEEG), a more sophisticated method based on the application of mathematical algorithms and computer processing capabilities that allow for a comparison between the patient's EEG activity and reference values extracted from an age and sex matched healthy population [**21**]. Clinical studies suggest that qEEG can be used to identify patterns of brain activity that may be associated with mental health conditions that increase the risk of suicide. In particular, reduced frontal delta power might reflect poor ability to manage psychological suffering [**22**], which could be in line with the evidence showing that the desire for suicide is modulated by the interaction between psychological pain and frontal delta power [**23**]. In addition, there is evidence indicating that depression is the most common psychiatric disorder in people who die by suicide [**24**]. However, while mental health professionals most often support the hypothesis that depression severity increases the risk for self-harm and suicide [**25**], there is research suggesting that specific electrophysiological imbalances might independently play a role in the general population [**26**,**27**]. For example, although increased theta activity is found in persons with depressive disorder [**28**,**29**,**30**] and has been proposed to reflect brain dysfunction in patients with depression or anxiety disorders [**31**,**32**], increased fronto-central theta power has been found to strongly correlate with behaviorally assessed SI in young healthy persons [**33**]. It is well known that antidepressant treatment may induce suicidal thoughts [**34**] and that these are associated with specific EEG changes. For example, a study investigating qEEG changes during treatment with selective serotonin

reuptake inhibitors (SSRI) in MDD patients showed that left–right asymmetry of combined theta and alpha power correlated with changes in suicidal ideation from baseline [**35**]. Moreover, matching treatment to specific patients is too often attempted through trial and error, which may result in the worsening of their clinical profile [**36**,**37**,**38**] and patients with treatment resistant depression (TRD) are more likely to report hopelessness and SI [**39**,**40**], which may be associated with EEG cordance changes in midline and right frontal brain regions [**41**]. Although most qEEG studies on suicide have focused on the imbalances linked to suicidal thoughts, other research remarks the need to identify those factors that more specifically can lead a person to attempt suicide, questioning once again the hypothesis that suicide risk is typically associated with depression [**25**]. In the attempt to organize information that could be of support to the implementation of more effective suicide prevention protocols, identifying objective markers of suicide risk could be key to complement the interview-based assessments conducted by mental health professionals. In this context, suicidal ideation is more likely to occur when people's thoughts are at rest [**42**]; therefore, gathering qEEG data during a resting state could provide a background on the psychological processes that take place in the mind of a person with suicidal thoughts, including negative thinking [**43**,**44**], ruminative brooding and hopelessness thoughts [**44**]. Our goal was to review and discuss all the resting state qEEG research conducted to date with suicidal persons, in the attempt to identify patterns of high-risk activity that mental health professionals could use to complement and potentially improve multimodal assessments in this clinical population.

## 2. Methods

A search was carried out in the Medline and Web of Science online databases for English language articles containing the terms "(eeg) AND (suicid*) AND (rest*)" without date restrictions in either the abstract, list of keywords, or both. We looked for resting state EEG studies in children, adolescents, and adults at risk for suicide. We excluded reviews, book chapters, meeting and conference abstracts, editorial material, and publications in languages other than English. We also excluded studies in which the word "suicide" was not mentioned. The search was concluded on 30 November 2022. It returned 40 results from Medline and 1 from Web of Science. We then applied the PRISMA method to exclude duplicates and studies not matching our inclusion criteria.

## 3. Results

The emerging high-risk profile is generally characterized by increased slow frequency (delta and theta power) in frontal and central areas, which is in line with evidence suggesting that suicide risk is associated with reduced emotion regulation efficiency [50], and with neuroimaging research showing that altered functional abnormalities in frontal cortical areas can be associated with SA [51].

## 4. Discussion

The papers reviewed indicate that persons at risk for suicide exhibit frequency/region specific EEG anomalies and suggest that EEG-based assessments could play an important role in predicting suicide attempts and/or death by suicide. In this context, the selected literature also suggests that the qEEG method should be regularly employed by mental health professionals to probe for brain function imbalances in patients with psychological suffering, even when depression cannot be diagnosed.

## 5. Limitations

The present review attempted to identify selective EEG imbalances in persons with either SI or with a history of SA. However, the interpretation of results should keep into account the different methods used across studies and the heterogeneity of the populations recruited. Importantly, the evaluation of suicide risk may vary across studies as a result of the administration of different rating instruments [68] and inter-rater variability may temper the results of unstructured assessments [69]. Again, heterogeneity may also derive from the differential effects of medication and recreational drugs on both behaviorally assessed symptoms and EEG waveforms [70,71,72].

## 6. Conclusions

Resting state EEG-based evaluations of suicide risk hold promise in the implementation of more reliable suicide prevention protocols. Imbalances in frontal and left temporal brain regions might reflect abnormal activation at rest and correlate with behaviorally assessed psychological distress. Additionally, asymmetrical activation in frontal and posterior cortical regions could reflect a high-risk profile, although the pattern may be inverted in non-depressed persons. In this context, the literature reviewed supports the hypothesis proposing that SI and SA may be driven by separate neural circuits and that high-risk persons can be found within non-depressed populations, suggesting that the qEEG method could complement standard psychiatric interviews and questionnaires, potentially revealing high risk imbalances in patients displaying psychological distress but not symptoms of depression. More research in a larger population sample should evaluate the role of the EEG anomalies outlined in the present review while also controlling for demographic heterogeneity in the attempt to identify at-risk populations and collaborate with mental health providers in implementing precision-based treatment plans, including suicide preventive strategies.

## 7. Future Directions

While a wide range of EEG methods are available to mental health professionals, the value of EEG-based assessments of suicide risk is still poorly understood. This may have a significant impact on the development and consolidation of protocols for the timely detection of high-risk brain activity. Therefore, more effort is urgently needed to facilitate the collaboration between clinicians and EEG clinics with the joint goal of developing more effective suicide prevention plans. Given the multitude of the factors involved and the complexity of their interaction, future research should also aim at developing intelligent algorithms capable of integrating multimodal data and generating outputs that clinical staff can easily interpret and use to tailor suitable interventions. In this context, machine learning-based research combining EEG methods with the acquisition and interpretation of peripheral physiological changes holds promise [73]. Given the greater vulnerability to stress often exhibited by high-risk individuals [74] and the range of early experiences that are well known to increase suicide risk (e.g., physical, emotional, and sexual abuse) [75,76,77,78,79], resting state assessments should be complemented by ad hoc tests investigating the differential EEG changes occurring during the presentation of adequately targeted emotionally challenging stimuli. Finally, combining EEG-based methods with methods based on the investigation of sympathetic and affect changes occurring during the performance of mood induction tasks [74,80] might contribute to develop more ecological assessments and more reliably identify individuals with lower resilience.