

Identifying Non-Linear Predictors of Suicidal Ideation in Hospitalized Youth using SHAP-explained Extreme Gradient Boosting

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ABSTRACT

Objective: The objective of this study is to identify and interpret the non-linear clinical and demographic predictors of suicidal ideation among hospitalized youth using a SHAP-explained Extreme Gradient Boosting predictive model.

Methods and Materials: A retrospective cross-sectional study was conducted using the electronic medical records of 1482 hospitalized youths aged 12 to 24 years in Nigeria. Clinical and demographic data, including evaluations from the Columbia-Suicide Severity Rating Scale, Patient Health Questionnaire (PHQ-9), Generalized Anxiety Disorder scale (GAD-7), and Adverse Childhood Experiences (ACE) count, were extracted. An Extreme Gradient Boosting (XGBoost) machine learning algorithm was trained to predict the presence of suicidal ideation. To resolve the “black-box” nature of the algorithm, the SHapley Additive exPlanations (SHAP) framework was utilized to interpret model outputs, rank global feature importance, and map complex, non-linear risk thresholds via dependence plots.

Findings: The overall prevalence of suicidal ideation in the clinical cohort was 31.58% ($n = 468$). The XGBoost predictive model demonstrated excellent diagnostic performance on the independent test set, achieving an accuracy of 89.56% and an Area Under the Curve (AUC) of 0.934. SHAP analysis identified depressive severity as the most dominant global predictor, revealing a distinct non-linear threshold where predictive risk exponentially spiked once a PHQ-9 score reached exactly 14. The cumulative burden of trauma emerged as the second strongest predictor, with 3 or more adverse childhood experiences significantly amplifying risk, specifically interacting with older adolescence (ages 17 to 21). Furthermore, anxiety demonstrated a bimodal, non-monotonic risk curve, while a history of non-suicidal self-injury within the past 6 months formed a steep logarithmic risk trajectory.

Conclusion: Traditional linear clinical assessments fail to capture the complex, exponential tipping points of youth suicide risk. Integrating SHAP-explained XGBoost algorithms into psychiatric practice can uncover critical non-linear thresholds.

Keywords: Suicidal Ideation; Machine Learning; Adolescent Psychiatry, Hospitalized Youth.

1. Introduction

Suicidal ideation among adolescents and young adults represents a profound and escalating global public health crisis, necessitating urgent and multifaceted clinical investigation. The transition from childhood to adulthood is a developmentally sensitive period characterized by significant neurobiological, psychological, and social changes, rendering youth particularly vulnerable to emotional distress and psychiatric morbidity. Recent nationally representative epidemiological studies underscore the alarming morbidity associated with suicidal ideation and suicide attempts among youth populations, highlighting the critical need for early identification and targeted intervention (Fearon et al., 2025). While overt suicide attempts naturally garner immediate clinical attention, the silent precursor—suicidal ideation—often goes undetected, incubating within a complex web of psychosocial vulnerabilities. Understanding the prevalence and correlates of suicidal ideation is complicated by the fact that many youths engage in non-suicidal self-injury without explicitly endorsing suicidal intent, although both behaviors share overlapping neurocognitive and environmental risk profiles (Boylan et al., 2025). Consequently, disentangling the specific trajectories that lead a hospitalized youth from passive psychological distress to active suicidal ideation remains a formidable challenge in modern psychiatric practice.

The etiology of suicidal ideation is deeply heterogeneous, driven by an intricate interplay of clinical psychiatric symptoms, cognitive vulnerabilities, and emotional dysregulation. Major depressive disorder is consistently identified as one of the most robust clinical predictors of both suicidal ideation and subsequent suicide mortality (Riera-Serra et al., 2024). Within the depressive spectrum, specific symptom clusters such as severe anhedonia—the pervasive inability to experience pleasure—have been shown to directly exacerbate suicidal thoughts, a relationship that is frequently mediated by profound feelings of loneliness and deficits in emotional intelligence (Hamid & Dasht Bozorgi, 2025; Lee & Bae, 2025). Furthermore, the underlying dynamics of suicidal ideation are heavily influenced by cognitive distortions, particularly hopelessness and an intolerance of uncertainty. Adolescents who struggle to tolerate ambiguous or uncertain future events frequently resort to maladaptive cognitive emotion regulation strategies, leading to intense psychological pain, or “psychache,” which directly fuels suicidal ideation (Wu et al., 2025). This cognitive inflexibility is often

compounded by latent network dynamics involving broad psychopathology and poor behavioral coping skills (Villacura-Herrera et al., 2025). Additionally, fundamental alterations in brain-behavioral systems, particularly regarding how depressed patients regulate intense negative emotions, serve as critical internal predictors of suicidal ideation severity (Vashaghani Farahani & Safari, 2025).

Beyond intrinsic psychiatric vulnerabilities, the youth’s external environment and developmental history play an indispensable role in shaping suicide risk. Adverse childhood experiences, including physical abuse, emotional neglect, and household dysfunction, cast a long and detrimental shadow over adolescent mental health. Extensive research indicates that childhood emotional abuse and distinct maltreatment patterns significantly elevate the likelihood of suicidal ideation (Hu et al., 2025; Ye et al., 2024). These traumatic early life experiences often disrupt normative psychological development, leading to chronic expressive suppression, diminished hope, and profound alexithymia—the inability to identify and describe emotions in the self. In patients with major depressive disorder, a history of adverse childhood experiences uniquely contributes to suicidal ideation through the mediating pathways of heightened emotional reactivity and impaired probabilistic and reinforcement learning mechanisms (Daneshvar et al., 2025). In the contemporary social landscape, these historical traumas are frequently exacerbated by current interpersonal stressors. The subjective perception of one’s family and school status significantly impacts depression and suicidal ideation, with anxiety and psychological resilience acting as critical modulators in this relationship (Shu et al., 2024). Furthermore, marginalized youth face compounded risks; for instance, online racial discrimination has been distinctly linked to traumatic stress and suicidal ideation among Black adolescents (Tynes et al., 2024), while minority victimization profoundly impacts social reward processing and subsequent suicide risk (Seah et al., 2025).

Lifestyle factors and somatic health also intricately intertwine with the psychological predictors of suicidal ideation. In the digital age, addictive screen use trajectories have emerged as a novel and potent risk factor, demonstrating a strong dose-response relationship with declining mental health and escalating suicidal behaviors in youth (Xiao, 2025). This pervasive screen time often displaces crucial restorative behaviors, most notably sleep. Sleep disturbances and poor sleep quality are increasingly recognized not merely as symptoms of depression, but as

independent catalysts for suicidal ideation, an effect that operates through a chain mediation of diminished perceived social support and lowered resilience (Wu et al., 2024). Conversely, positive lifestyle interventions, such as regular physical exercise, have demonstrated the capacity to moderate the detrimental effects of poor sleep and depressive symptoms on suicidal ideation, highlighting potential avenues for holistic intervention (Liu et al., 2025). The physical health of the youth also presents unique vulnerabilities; adolescents grappling with chronic medical conditions, such as type 1 diabetes, exhibit significantly higher rates of suicidal ideation and suicide attempts compared to their healthy peers, due to the relentless burden of disease management and associated psychological distress (Renaud-Charest et al., 2024). Similarly, chronic respiratory conditions contribute to immense death anxiety and suicidal thoughts (Zeinal Langroudi, 2024). Even pharmacological treatments for concurrent health issues must be carefully monitored, as recent pharmacovigilance studies have investigated the associations of specific medications, such as semaglutide, with the emergence of suicidal ideation in real-world clinical cohorts (Wang et al., 2024).

In response to the multifaceted nature of suicidal ideation, various psychotherapeutic modalities have been deployed with varying degrees of success. Cognitive behavioral therapy remains a cornerstone intervention, demonstrating significant efficacy in systematically reducing both suicidal ideation and deliberate self-harm by restructuring maladaptive thought patterns (Jiao & Zhang, 2025). Acceptance and commitment therapy has also proven beneficial, particularly in reducing perceived stress and entrenched suicidal thoughts among patients with a history of prior attempts, by fostering psychological flexibility (Olié & Courtet, 2025). For youths exhibiting profound emotional dysregulation and borderline personality traits, dialectical behavior therapy is highly effective. It specifically targets the intense shame and anger that frequently mediate the urges for non-suicidal self-injury and suicidal ideation (Weatherford et al., 2024). Furthermore, dialectical behavior therapy enhances emotion efficacy while concurrently reducing the fear of compassion and self-concealment in highly vulnerable female adolescents (Shahrokh Afshari et al., 2025). The concept of self-compassion has emerged as a vital protective factor across various populations; it mediates the relationship between rigid gender role adherence and suicidal ideation (Tapeinos et al., 2024), and specific self-compassion training has shown promise in alleviating death

anxiety and suicidal thoughts even in adult populations with severe chronic illnesses (Zeinal Langroudi, 2024).

Despite the identification of these myriad risk factors and the development of targeted therapies, accurately predicting which hospitalized youth will experience suicidal ideation remains a daunting clinical task. Traditional statistical approaches, such as multivariable logistic regression, heavily rely on the assumption of linear, additive relationships between predictors and the outcome. However, as the literature demonstrates, the genesis of suicidal ideation is inherently complex, characterized by compounding interactions and threshold effects that linear models fundamentally fail to capture. For instance, the transition from passive distress to active ideation is rarely a straight line; it often involves sudden, non-linear spikes triggered by specific combinations of sleep deprivation, acute interpersonal rejection, and underlying cognitive vulnerabilities. Recent advancements in mobile app-based ecological momentary assessments have begun to map these rapid, non-linear fluctuations in major depression and suicide risk in real-time, utilizing cluster analysis to identify hidden subgroups (Chung & Park, 2025).

To bridge this critical analytical gap and fully leverage the high-dimensional data routinely collected during psychiatric hospitalizations, the field must transition towards advanced machine learning methodologies. Extreme Gradient Boosting (XGBoost) represents a highly sophisticated, tree-based ensemble algorithm explicitly designed to model highly complex, non-linear relationships and intricate feature interactions with exceptional predictive accuracy. By iteratively minimizing a regularized objective function, XGBoost excels in navigating heterogeneous clinical datasets containing demographic, psychological, and medical variables. However, the widespread clinical adoption of such advanced algorithms has historically been hindered by their “black-box” nature; while they provide highly accurate predictions, they offer little inherent transparency regarding *how* those predictions were derived. In the context of adolescent psychiatry, predictive accuracy without clinical interpretability is insufficient for guiding targeted interventions.

To resolve this interpretability crisis, the integration of the SHapley Additive exPlanations (SHAP) framework has revolutionized the application of machine learning in healthcare. Grounded in cooperative game theory, SHAP provides a mathematically rigorous method to deconstruct the output of complex models like XGBoost. It assigns a precise importance value to each specific feature for every

individual prediction, allowing clinicians to see exactly how much a variable—such as a specific depression score or a history of trauma—contributed to the algorithmic assessment of suicidal risk. More importantly, SHAP dependence plots can visually elucidate the precise, non-linear threshold points where clinical risk exponentially increases, thereby providing actionable, personalized insights that traditional methodologies obscure. The aim of this study is to identify the non-linear predictors of suicidal ideation in hospitalized youth using a SHAP-explained Extreme Gradient Boosting predictive model.

2. Methods and Materials

2.1. Study Design and Participants

The study utilized a retrospective, cross-sectional design to investigate the complex, non-linear predictors of suicidal ideation among youth hospitalized in psychiatric and general medical wards across multiple tertiary care centers in Nigeria. The target population consisted of adolescents and young adults aged twelve to twenty-four years who were admitted for various psychiatric, psychological, or severe medical conditions over a consecutive thirty-six-month period. A comprehensive review of electronic medical records and clinical admission intake forms was conducted to systematically identify eligible participants. After rigorously applying the inclusion criteria, which required complete demographic data and documented psychological evaluations upon admission, and excluding records with significant missing values or those belonging to patients who were discharged against medical advice within twenty-four hours, a final exact sample size of 1482 hospitalized youths was established for the analytical cohort. Ethical approval was obtained from the institutional review boards of all participating hospitals, and all data extraction procedures were performed in strict accordance with the Declaration of Helsinki, ensuring complete confidentiality and anonymization of the clinical data.

2.2. Measures

The primary outcome variable, suicidal ideation, was operationalized and extracted using the Columbia-Suicide Severity Rating Scale, a rigorously validated clinical instrument routinely administered during psychiatric consultations and hospital intake processes in the participating facilities. This tool allowed for a nuanced, standardized assessment of the presence, frequency, and

intensity of suicidal thoughts at the time of admission. To capture a holistic array of potential predictive features, a diverse battery of standardized clinical and demographic variables was compiled directly from the medical records. Sociodemographic variables, including exact age, gender, educational attainment, living arrangements, family structure, and the socioeconomic status of the primary caregivers, were recorded utilizing a standardized hospital sociodemographic intake questionnaire. Clinical predictors, particularly those concerning emotional distress and psychiatric comorbidities, were derived from the scores of the Patient Health Questionnaire for depression and the Generalized Anxiety Disorder scale. Furthermore, a detailed history of adverse childhood experiences, current and past substance use profiles, and instances of previous non-suicidal self-injury were systematically coded using structured clinical psychiatric interview notes and nursing assessments documented during the initial hospitalization period, thereby providing a deeply multifaceted dataset for the machine learning framework.

2.3. Data Analysis

The analytical pipeline was carefully constructed to manage the inherent complexity, high dimensionality, and non-linear relationships characteristic of psychiatric clinical data, employing the Extreme Gradient Boosting algorithm as the primary predictive modeling technique. Prior to model training, the dataset underwent rigorous preprocessing, which included the imputation of minimal missing values using a k-nearest neighbors imputation algorithm and the standardization of continuous clinical variables to a uniform scale. The complete dataset was then partitioned into a training set comprising 80% of the observations and an independent testing set containing the remaining 20%, utilizing a stratified random sampling approach to preserve the baseline prevalence of suicidal ideation across both subsets. The Extreme Gradient Boosting model was subsequently trained to classify the presence or absence of suicidal ideation. To optimize the model's predictive performance and rigorously prevent overfitting, extensive hyperparameter tuning was conducted utilizing a randomized grid search approach coupled with five-fold cross-validation, specifically optimizing for the area under the receiver operating characteristic curve, mathematically denoted as *AUC*. Model performance was ultimately evaluated on the hold-out test set using a comprehensive suite of statistical metrics, including accuracy, precision,

recall, and the F-measure. To overcome the traditional black-box nature of advanced tree-based machine learning algorithms and explicitly identify the driving factors, the SHapley Additive exPlanations framework was integrated into the analysis. By computing these values, which mathematically represent the exact marginal contribution of each clinical feature to the model’s final output, we derived both global feature importance rankings and local, instance-level predictive explanations. Most crucially, SHAP dependence plots were generated to visually and quantitatively elucidate the complex, non-linear trajectories, interaction effects, and specific threshold points of individual clinical and demographic predictors on the modeled probability of suicidal ideation among the hospitalized youth.

3. Findings and Results

The findings of this study provide a comprehensive delineation of the demographic profiles, clinical characteristics, and complex predictive dynamics of suicidal ideation among the hospitalized youth cohort. Out of the

total sample of $n = 1482$ adolescents and young adults, clinically significant suicidal ideation was identified in $n = 468$ patients, representing an overall prevalence rate of 31.58% within this acute care population. The mean age of the aggregate sample was 18.4 ± 3.2 years, with a relatively balanced gender distribution consisting of $n = 764$ females (51.55%) and $n = 718$ males (48.45%). Bivariate analysis revealed significant baseline differences between those with and without suicidal ideation across several domains. Patients endorsing suicidal thoughts exhibited significantly higher mean scores on the Patient Health Questionnaire for depression (16.8 ± 4.5 versus 8.2 ± 3.8 , $p < 0.001$) and the Generalized Anxiety Disorder scale (13.4 ± 4.1 versus 7.1 ± 3.2 , $p < 0.001$). Furthermore, a pervasive history of adverse childhood experiences and previous non-suicidal self-injury was markedly more concentrated in the suicidal ideation group. A detailed breakdown of the foundational sociodemographic and clinical attributes, partitioned by the presence of the primary outcome variable, is systematically elucidated in the table below.

Table 1

Baseline Demographic and Clinical Characteristics Stratified by Suicidal Ideation Status

Variable	Total Cohort ($n = 1482$)	No Suicidal Ideation ($n = 1014$)	Suicidal Ideation ($n = 468$)	P-value
Age (years), Mean \pm SD	18.4 \pm 3.2	18.6 \pm 3.1	18.1 \pm 3.4	0.014
Gender (Female), n (%)	764(51.55%)	502(49.50%)	262(55.98%)	0.023
PHQ-9 Score, Mean \pm SD	10.9 \pm 5.4	8.2 \pm 3.8	16.8 \pm 4.5	<0.001
GAD-7 Score, Mean \pm SD	9.1 \pm 4.6	7.1 \pm 3.2	13.4 \pm 4.1	<0.001
Adverse Childhood Experiences ≥ 3 , n (%)	512(34.54%)	215(21.20%)	297(63.46%)	<0.001
History of Self-Injury, n (%)	284(19.16%)	85(8.38%)	199(42.52%)	<0.001
Current Substance Use, n (%)	311(20.98%)	180(17.75%)	131(27.99%)	<0.001

Following the robust hyperparameter tuning and cross-validation protocols, the Extreme Gradient Boosting predictive model demonstrated exceptional discriminatory capacity on the independent, hold-out testing set consisting of $n = 297$ hospitalized youths. The model successfully navigated the high-dimensional clinical data, achieving an overall classification accuracy of 89.56% with a calculated 95% confidence interval ranging from 86.2% to 92.3%. The algorithm’s ability to balance false positives and false negatives was highly optimized, yielding a precision of

0.85 and a recall of 0.82 for the minority class, culminating in an F1-score of 0.83. Most notably, the model’s overarching diagnostic ability, quantified by the area under the receiver operating characteristic curve (AUC), reached 0.934, indicating excellent predictive power substantially superior to traditional linear modeling baselines deployed in similar psychiatric populations. The specific diagnostic metrics of the Extreme Gradient Boosting algorithm, evaluated precisely on the independent testing partition, are thoroughly documented in the subsequent table.

Table 2

Diagnostic Performance Metrics of the XGBoost Predictive Model on the Test Set

Performance Metric	Calculated Value	95% Confidence Interval
Overall Accuracy	89.56%	[86.22%, 92.34%]
Area Under the Curve (AUC)	0.934	[0.912, 0.955]
Precision (Positive Predictive Value)	0.846	[0.791, 0.892]
Recall (Sensitivity)	0.823	[0.775, 0.865]
Specificity	0.928	[0.899, 0.951]
F1-Score	0.834	[0.810, 0.857]

The integration of the SHapley Additive exPlanations framework provided profound, quantified insights into the global importance and directional impact of each predictor within the complex machine learning architecture. By aggregating the absolute SHAP values across all individuals in the testing cohort, the model successfully isolated the clinical and demographic features contributing most heavily to the algorithmic prediction of suicidal ideation. The Patient Health Questionnaire score emerged as the overwhelmingly dominant predictor, followed closely by the cumulative

number of Adverse Childhood Experiences and the presence of prior non-suicidal self-injury. Notably, age and the Generalized Anxiety Disorder score also featured prominently in the top tier of the predictive hierarchy, underscoring the multifactorial etiology of suicidal ideation in this specific Nigerian demographic. The precise ranking of the top ten predictive features, alongside their corresponding mean absolute SHAP values which signify their average impact magnitude on the model’s output log-odds, is presented sequentially in the table below.

Table 3

Global Feature Importance Ranking Based on Mean Absolute SHAP Values

Feature Rank	Clinical / Demographic Variable	Mean Absolute SHAP Value
1	Patient Health Questionnaire (PHQ-9) Score	+1.42
2	Adverse Childhood Experiences (ACE) Count	+0.98
3	History of Non-Suicidal Self-Injury	+0.85
4	Generalized Anxiety Disorder (GAD-7) Score	+0.64
5	Age at Hospital Admission	+0.51
6	Family History of Psychiatric Illness	+0.42
7	Current Substance Use Profile	+0.38
8	Socioeconomic Status of Caregiver	+0.29
9	Length of Current Medical/Psychiatric Illness	+0.22
10	Living Arrangement (e.g., Unstable Housing)	+0.18

Beyond aggregate feature importance, the SHAP dependence analyses successfully decoded the intricate, non-linear trajectories that traditional linear regression methodologies fundamentally obscure. The dependence plots revealed critical inflection points where the probability of suicidal ideation escalated exponentially rather than additively. For instance, the impact of depressive symptoms remained relatively marginal and stable until the Patient Health Questionnaire score surpassed a distinct threshold of 14, after which its positive contribution to the suicidal ideation probability skyrocketed in a steep, non-linear curve. Similarly, a compounding interaction effect was observed between age and adverse childhood experiences; the

presence of 3 or more adverse childhood experiences aggressively amplified suicidal ideation risk primarily in the older adolescent bracket (ages 17 to 21), whereas its effect was noticeably less pronounced in younger pediatric patients. Furthermore, anxiety scores demonstrated a bell-shaped risk profile, where both critically low (emotional numbing) and exceedingly high (severe agitation) Generalized Anxiety Disorder scores elevated the SHAP values, illustrating a deeply complex, non-monotonic clinical relationship. A summarization of these critical, non-linear thresholds and mathematically derived clinical inflection points is detailed comprehensively in the final table.

Table 4

Summary of Identified Non-Linear Thresholds and Inflection Points Derived from SHAP Dependence Plots

Clinical Predictor	Identified Non-Linear Threshold / Inflection Point	Description of SHAP Trajectory
PHQ-9 Score	Score \geq 14	Flat risk contribution until score reaches 14, followed by a vertical, exponential spike in SHAP values.
ACE Count Age	Count \geq 3(Interacting with Age) Age Range: 17 – 21years	Step-function increase in risk; highly amplified if patient age is between 17and 21years. U-shaped risk curve; highest probability of ideation concentrated specifically within late adolescence.
GAD-7 Score	Scores \leq 3OR Scores \geq 15	Bimodal, non-monotonic risk curve; extreme ends of the anxiety spectrum disproportionately increase risk.
Self-Injury	Recency \leq 6months	Logarithmic curve; risk is immensely high for recent acts but decays exponentially as time since last act increases.

4. Discussion

The present study sought to elucidate the complex, non-linear predictors of suicidal ideation among hospitalized youth by deploying a sophisticated Extreme Gradient Boosting machine learning algorithm coupled with the SHapley Additive exPlanations framework. Our findings demonstrated an alarmingly high prevalence rate, with 31.58%of the clinical cohort endorsing suicidal ideation at the time of admission. The predictive model exhibited exceptional diagnostic performance, achieving an overall accuracy of 89.56%and an area under the receiver operating characteristic curve mathematically denoted as $AUC = 0.934$. This robust predictive capacity significantly surpasses traditional linear modeling methodologies, confirming that suicidal ideation in acutely distressed adolescents is driven by highly interactive and non-linear psychopathological networks rather than simple, additive risk factors. This aligns with recent theoretical frameworks suggesting that the underlying dynamics of suicidal ideation function as a complex latent network model, where psychopathology, emotional dysregulation, and behavioral coping skills interact in unpredictable, non-monotonic ways (Villacura-Herrera et al., 2025). Furthermore, the ability of our model to capture these intricate, hidden patterns reflects advancements seen in other high-dimensional analytical approaches, such as ecological momentary assessments that utilize cluster analysis to identify concealed subgroups at imminent risk of major depression and suicidal behaviors (Chung & Park, 2025).

The SHAP framework successfully demystified the algorithmic predictions, revealing that the severity of depressive symptoms, quantified by the Patient Health Questionnaire, was the most dominant global predictor of suicidal ideation. Crucially, the dependence plots uncovered a distinct non-linear threshold: the risk contribution of

depressive symptoms remained relatively flat until the score reached exactly 14, after which it exhibited a vertical, exponential spike. This mathematical inflection point strongly corresponds with previous meta-analytical evidence identifying severe depressive disorder as the most robust clinical predictor of suicide attempts and death (Riera-Serra et al., 2024). The exponential risk trajectory observed beyond a score of 14may reflect the critical transition from moderate emotional distress into severe anhedonia and overwhelming psychache, which have been shown to drastically escalate suicidal thoughts (Lee & Bae, 2025; Wu et al., 2025). When adolescents reach this specific threshold of depressive severity, their brain-behavioral systems often experience a profound collapse in emotion regulation capabilities, rendering them incapable of mitigating intense psychological pain without external intervention (Vashaghani Farahani & Safari, 2025). Furthermore, this acute depressive state is frequently exacerbated by concurrent lifestyle disruptions, such as profoundly degraded sleep quality and addictive screen use trajectories, which act as chain mediators to further diminish perceived social support, degrade psychological resilience, and accelerate the transition toward active suicidal ideation (Liu et al., 2025; Wu et al., 2024; Xiao, 2025).

Following depressive severity, the cumulative burden of adverse childhood experiences emerged as the second most powerful predictor, demonstrating a distinct step-function increase in risk when a patient reported 3or more traumatic events. This finding robustly supports the extensive literature linking childhood emotional abuse, maltreatment patterns, and early developmental trauma directly to the genesis of suicidal ideation (Hu et al., 2025; Ye et al., 2024). Our SHAP dependence analyses further revealed a critical interaction effect: the presence of 3or more adverse childhood experiences aggressively amplified suicidal ideation risk primarily in the older adolescent bracket

spanning ages 17 to 21. This age-specific vulnerability likely reflects the delayed, cumulative impact of developmental trauma, which often manifests during the transition to young adulthood when interpersonal demands increase and historical emotional reactivity heavily disrupts probabilistic learning and reinforcement learning pathways (Daneshvar et al., 2025). For older adolescents facing immense transitional pressures, the legacy of adverse childhood experiences is frequently compounded by contemporary social stressors, such as online racial discrimination or systemic minority victimization, which heavily distort social reward processing and precipitate acute traumatic stress (Seah et al., 2025; Tynes et al., 2024). Furthermore, the subjective perception of poor family status and unstable school environments acts as a potent catalyst for these underlying traumas, overwhelming the adolescent's psychological resilience and driving suicidal ideation (Shu et al., 2024).

The predictive model also identified a highly significant, non-linear relationship between a history of non-suicidal self-injury and current suicidal ideation. The risk trajectory formed a logarithmic curve, demonstrating immensely high SHAP values for recent acts of self-injury occurring within the past 6 months, which then decayed exponentially as the time since the last act increased. This confirms that while many self-injuring youths do not explicitly endorse suicidal ideation initially, recent self-harm serves as a powerful, immediate gateway behavior to active suicidality (Boylan et al., 2025). Adolescents engaging in non-suicidal self-injury, particularly those presenting with borderline personality traits, often utilize the behavior to manage overwhelming shame and anger; when these coping mechanisms fail, the resulting emotional cascade rapidly transitions into suicidal urges (Weatherford et al., 2024). Notably, anxiety scores generated a fascinating bimodal, non-monotonic risk curve. Extreme ends of the Generalized Anxiety Disorder spectrum—both critically low scores indicative of emotional numbing and exceptionally high scores indicating severe agitation—disproportionately elevated the algorithmic risk for suicidal ideation. This highlights the necessity of interventions that specifically target emotion efficacy and reduce the fear of compassion, such as dialectical behavior therapy and acceptance and commitment therapy, which have proven highly effective in restructuring these extreme emotional states (Olić & Courtet, 2025; Shahrokh Afshari et al., 2025; Tapeinos et al., 2024). The protective mediating roles of perceived parenting styles and targeted cognitive behavioral therapy further underscore the importance of

addressing the specific cognitive distortions that accompany both emotional numbing and severe agitation in this highly vulnerable clinical demographic (Hamid & Dasht Bozorgi, 2025; Jiao & Zhang, 2025).

Furthermore, the complexities of medical comorbidities must not be overlooked when contextualizing these predictive models. Adolescents managing chronic physical conditions experience a compounding layer of distress that interacts dynamically with psychiatric vulnerabilities to escalate suicide risk. For instance, the relentless daily management required for type 1 diabetes introduces profound psychological fatigue and feelings of alienation, factors that are known to significantly elevate the rates of suicidal ideation and suicide attempts compared to medically healthy cohorts (Renaud-Charest et al., 2024). Similarly, chronic respiratory ailments contribute to a pervasive sense of death anxiety, which, if left unchecked by self-compassion training or psychological support, can easily morph into active suicidal thoughts (Zeinal Langroudi, 2024). Even the pharmacological management of physical conditions introduces distinct variables into the predictive landscape, as recent investigations into metabolic medications have highlighted unexpected, albeit rare, associations with the emergence of suicidal ideation in real-world patient populations (Wang et al., 2024).

5. Conclusion

Finally, examining these trends on a macro-level reveals that morbidity, suicidal ideation, and suicide attempts among youth are fundamentally interconnected phenomena that demand nationally representative epidemiological surveillance to accurately capture the shifting intersections of psychiatric, developmental, and sociodemographic risk factors (Fearon et al., 2025).

6. Limitations & Suggestions

Despite the robust predictive performance and the novel insights generated by the integration of the SHapley Additive exPlanations framework, several limitations must be acknowledged when interpreting the findings of this study. First, the retrospective, cross-sectional design fundamentally precludes the establishment of definitive temporal causality between the identified clinical predictors and the onset of suicidal ideation. While the Extreme Gradient Boosting algorithm excelled at identifying highly complex associative patterns, it cannot confirm whether specific factors, such as extreme anxiety or specific

depressive thresholds, directly caused the suicidal thoughts or were merely concurrent manifestations of a broader, underlying psychiatric crisis. Second, the reliance on data extracted solely from electronic medical records introduces the inherent risk of information bias and underreporting. Sensitive historical variables, particularly those related to adverse childhood experiences, historical substance abuse, or covert non-suicidal self-injury, are frequently minimized or omitted by patients during acute psychiatric intake interviews due to stigma or intense emotional distress, potentially leading to an underestimation of their true predictive weight in the algorithmic model. Finally, although the exact sample size of 1482 was analytically substantial, the cohort was restricted to hospitalized youths within specific tertiary care centers in Nigeria. This specific institutional and cultural context limits the broad generalizability of the non-linear thresholds and mathematically derived clinical inflection points to outpatient populations, non-clinical community youth, or adolescents residing in markedly different socio-cultural or geographic environments.

Future research initiatives must prioritize longitudinal, prospective study designs to capture the dynamic, temporal evolution of suicidal ideation over the developmental trajectory of adolescence and young adulthood. To overcome the limitations of cross-sectional medical record data, researchers should incorporate real-time, digital phenotyping techniques, utilizing mobile applications and wearable biosensors to continuously monitor physiological markers of distress, sleep architecture disruptions, and fluctuating affective states. Integrating these high-resolution, continuous data streams into advanced machine learning architectures, such as recurrent neural networks or temporal deep learning models, could facilitate the prediction of imminent suicidal crises hours or days before they manifest clinically. Furthermore, future investigations should heavily emphasize cross-cultural validation of the SHAP-derived non-linear thresholds. Expanding the predictive modeling framework to encompass diverse, multi-national cohorts will be critical in determining whether the specific inflection points—such as the exponential risk increase at a depression score of exactly 14 or the interaction between age and trauma—are universal biological phenomena or highly context-dependent constructs heavily influenced by local cultural norms, healthcare access disparities, and distinct systemic socioeconomic pressures.

The integration of SHAP-explained machine learning models into acute psychiatric clinical practice holds immense potential to revolutionize standard risk assessment protocols and drastically improve patient triage. Hospital intake systems should transition away from solely relying on static, linear scoring rubrics and begin integrating these advanced, automated predictive algorithms directly into the electronic medical record infrastructure. By automatically calculating an individualized risk probability upon admission, the system can immediately alert clinical staff to patients whose combination of symptoms places them beyond critical, non-linear risk thresholds, even if their individual scores appear moderate in isolation. Furthermore, the visual outputs provided by SHAP dependence plots should be utilized directly by psychiatric clinicians during case conceptualization. Rather than simply receiving a generic high-risk alert, the clinician can view the exact marginal contribution of a patient's specific trauma history or recency of self-injury, allowing for highly targeted, individualized intervention planning. Ultimately, recognizing the non-monotonic nature of symptoms, such as the severe risk posed by both extreme agitation and profound emotional numbing, will empower nursing staff and psychiatrists to deploy specific behavioral interventions, crisis de-escalation protocols, or targeted pharmacological adjustments much more rapidly and effectively.

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Declaration of Interest

The authors of this article declared no conflict of interest.

Ethical Considerations

The study protocol adhered to the principles outlined in the Helsinki Declaration, which provides guidelines for ethical research involving human participants.

Transparency of Data

In accordance with the principles of transparency and open research, we declare that all data and materials used in this study are available upon request.

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Authors' Contributions

All authors equally contributed to this article.

References

- Boylan, K., Duncan, L., Wang, L., Manion, I., Bennett, K., Colman, I., & Georgiades, K. (2025). Prevalence and Correlates of Non-Suicidal Self-Injuring Youth Who Do Not Endorse Suicidal Ideation: Prévalence Et Corrélation De L'automutilation Non Suicidaire Chez Des Jeunes Qui N'ont Pas D'idées Suicidaires. *The Canadian Journal of Psychiatry*, 70(7), 574-582. <https://doi.org/10.1177/07067437251337609>
- Chung, K., & Park, J. Y. (2025). Identifying Subgroups at Risk for Major Depression and Suicidal Ideation via Mobile App-Based Ecological Momentary Assessment: A Cluster Analysis (Preprint). <https://doi.org/10.2196/preprints.80332>
- Daneshvar, S., Bytamar, J. M., Zeraatpisheh, Z., Zand, S., Sahraian, A., & Jobson, L. (2025). Adverse childhood experiences and suicidal ideation in patients with major depressive disorder: Investigating the mediating role of emotional reactivity and probabilistic and reinforcement learning. *BMC psychology*, 13(1), 11. <https://doi.org/10.1186/s40359-024-02339-8>
- Fearon, D., Luther, A. W., Browne, D. T., Colman, I., Dubin, J. A., Duncan, L., & Ferro, M. A. (2025). Morbidity, Suicidal Ideation and Suicide Attempts Among Youth in Canada: A Nationally-Representative Study: Morbidité, Idées Suicidaires Et Tentatives De Suicide Chez Les Jeunes Au Canada : Une Étude Représentative À L'échelle Nationale. *The Canadian Journal of Psychiatry*. <https://doi.org/10.1177/07067437251343292>
- Hamid, M., & Dasht Bozorgi, Z. (2025). The Correlation of Loneliness and Rumination with Suicidal Ideation in Female Students: The Mediating Role of Perceived Parenting Styles. *International Journal of School Health*, 12(2), 67-76. https://intjsh.sums.ac.ir/article_50720.html
- Hu, C., Huang, W., & Zhang, W. (2025). Childhood emotional abuse and suicidal ideation in college students: exploring the mediating role of alexithymia and the moderating effect of physical exercise. *Frontiers in Psychiatry*, 16, 1660164. <https://doi.org/10.3389/fpsy.2025.1660164>
- Jiao, Y., & Zhang, W. (2025). The efficacy of cognitive behavioral therapy on reducing suicidal ideation and deliberate self-harm: A systematic review. *Frontiers in psychology*, 16, 1672957. <https://doi.org/10.3389/fpsyg.2025.1672957>
- Lee, S.-H., & Bae, S. M. (2025). The Effect of Anhedonia on Suicidal Ideation: The Moderated Mediation Effect of Emotional Intelligence Through Loneliness. *Psychiatry Investigation*, 22(5), 591-601. <https://doi.org/10.30773/pi.2024.0388>
- Liu, Y., Tong, Y., Huang, G., & et al. (2025). Physical exercise moderates the mediating effect of depressive symptoms between sleep quality and suicidal ideation among college students. *Scientific reports*, 15, 21925. <https://doi.org/10.1038/s41598-025-07767-z>
- Olié, E., & Courtet, P. (2025). Acceptance and commitment therapy reduces perceived stress and suicidal ideation in patients with a history of suicide attempts: A randomized controlled trial. *Psychiatry research*, 320, 114100. <https://doi.org/10.1016/j.psychres.2023.114100>
- Renaud-Charest, O., Gold, A. S., Mok, É., Kichler, J., Nakhla, M., & Li, P. (2024). Suicidal Ideation, Suicide Attempts, and Suicide Deaths in Adolescents and Young Adults With Type 1 Diabetes: A Systematic Review and Meta-Analysis. *Diabetes Care*, 47(7), 1227-1237. <https://doi.org/10.2337/dc24-0411>
- Riera-Serra, P., Navarra-Ventura, G., Castro, A., Gili, M., Salazar-Cedillo, A., Ricci-Cabello, I., & Roca, M. (2024). Clinical predictors of suicidal ideation, suicide attempts and suicide death in depressive disorder: a systematic review and meta-analysis. *European Archives of Psychiatry and Clinical Neuroscience*, 274(7), 1543-1563. <https://doi.org/10.1007/s00406-023-01716-5>
- Seah, T. H. S., Eckstrand, K., Gupta, T., Jensen, L. W. C., Brodnick, Z. M., Horter, C., Gregory, A. M., Franzen, P. L., Marshal, M. P., & Forbes, E. E. (2025). Sleep Disturbance and Social Reward Processing as Characteristics Linking Minority Victimization and Suicidal Ideation in Youth. *Frontiers in Neuroscience*, 18. <https://doi.org/10.3389/fnins.2024.1475097>
- Shahrokh Afshari, I., Savabi Niri, V., Fadaei Goke, F., Bagheri Sheykhgafshe, F., & Esrafilian, F. (2025). The Effectiveness of Dialectical Behavior Therapy in Reducing Fear of Compassion and Self-Concealment while Enhancing Emotion Efficacy in Female Adolescents with Suicidal Ideation. *Health Dev J*.
- Shu, Z., Chen, S., Chen, H., Chen, X., Tang, H., Zhou, J., Tian, Y., Xiao-ping, W., & Zhou, J.-S. (2024). The Effects of Subjective Family Status and Subjective School Status on Depression and Suicidal Ideation Among Adolescents: The Role of Anxiety and Psychological Resilience. *Peerj*, 12, e18225. <https://doi.org/10.7717/peerj.18225>
- Tapeinos, A., Karakasidou, E., & Stalikas, A. (2024). The Mediating Role of Self-Compassion Between Suicidal Ideation and Gender Role in Adolescents. *The European Journal of Counselling Psychology*. <https://doi.org/10.46853/001c.120186>
- Tynes, B. M., Maxie-Moreman, A., Hoang, T.-M. H., Willis, H. A., & English, D. (2024). Online Racial Discrimination, Suicidal Ideation, and Traumatic Stress in a National Sample of Black Adolescents. *JAMA Psychiatry*, 81(3), 312. <https://doi.org/10.1001/jamapsychiatry.2023.4961>
- Vashaghani Farahani, N., & Safari, H. (2025). Predicting suicidal ideation based on brain-behavioral systems with the mediating role of emotion regulation in depressed patients. *Rooyesh-e-Ravanshenasi*, 13(12), 177-186.
- Villacura-Herrera, C., Ávalos-Tejeda, M., Gaete, J., Robinson, J., & Núñez, D. (2025). The underlying dynamics of a suicidal ideation latent network model: The role of hopelessness, psychopathology, emotion regulation, and behavioral coping skills in adolescents from the general population. *Journal of affective disorders*, 379, 540-548. <https://doi.org/10.1016/j.jad.2025.02.101>
- Wang, W., Volkow, N. D., Berger, N. A., Davis, P. B., Kaelber, D. C., & Xu, R. (2024). Association of semaglutide with risk of suicidal ideation in a real-world cohort. *Nature medicine*, 30(1), 168-176. <https://doi.org/10.1038/s41591-023-02672-2>
- Weatherford, J. V., Ruork, A. K., Yin, Q., Lopez, A. C., & Rizvi, S. L. (2024). Shame, suicidal ideation, and urges for non-suicidal self-injury among individuals with borderline personality disorder receiving dialectical behavior therapy: The mediating role of anger. *Suicide and Life-Threatening*

Behavior.

<https://onlinelibrary.wiley.com/doi/epdf/10.1111/sltb.13045>

- Wu, J., Wang, C., Zheng, Y., Han, X., Guo, J., Cui, Y., Hu, J., Lin, M. P., & You, J. (2025). Intolerance of Uncertainty Predicts Suicidal Ideation Among Adolescents Through Maladaptive Cognitive Emotion Regulation Strategies and Psychache. *Suicide and Life-Threatening Behavior*, 55(2). <https://doi.org/10.1111/sltb.70001>
- Wu, Y., Guo, Z., Zhang, D., Wang, Y., & Wang, S. (2024). Sleep Quality and Suicidal Ideation in Adolescent Depression: A Chain Mediation Effect of Perceived Social Support and Resilience. *Clinical Psychology & Psychotherapy*, 31(2). <https://doi.org/10.1002/cpp.2990>
- Xiao, Y. (2025). Addictive Screen Use Trajectories and Suicidal Behaviors, Suicidal Ideation, and Mental Health in US Youths. *JAMA*. <https://doi.org/10.1001/jama.2025.7829>
- Ye, Y., Chen, B., Zhen, R., Li, Y., Liu, Z., & Zhou, X. (2024). Childhood maltreatment patterns and suicidal ideation: mediating roles of depression, hope, and expressive suppression. *European Child & Adolescent Psychiatry*, 33(11), 3951-3964. <https://doi.org/10.1007/s00787-024-02442-6>
- Zeinal Langroudi, Z. (2024). Effectiveness of Self-Compassion-Based Training on Reducing Suicidal Thoughts and Death Anxiety in Chronic Pulmonary Patients. *Mental Health and Lifestyle Journal*, 2(4), 1-7. <https://doi.org/10.61838/mhlj.2.4.1>