

# A Gradient-Boosting Model of Adolescent Social Anxiety Incorporating Rejection Sensitivity, Intolerance of Uncertainty, Emotional Reactivity, and Peer Network Centrality

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## ABSTRACT

**Objective:** This study aimed to develop a highly predictive machine learning model to delineate the complex, non-linear, and synergistic contributions of rejection sensitivity, intolerance of uncertainty, emotional reactivity, and peer network centrality to adolescent social anxiety.

**Methods and Materials:** A cross-sectional design was employed with a sample of 847 adolescents (ages 13 – 18) recruited from schools in Armenia via multistage cluster sampling. Participants completed validated Armenian translations of the Social Anxiety Scale for Adolescents (SASA), Rejection Sensitivity Questionnaire (RSQ), Intolerance of Uncertainty Scale (IUS-12), and the Emotion Reactivity Scale (ERS). Peer network centrality was quantified using eigenvector centrality scores derived from a sociometric nomination procedure. An Extreme Gradient Boosting (XGBoost) algorithm was trained and optimized using randomized search cross-validation, with model interpretability established through SHapley Additive exPlanations (SHAP).

**Findings:** The final XGBoost model demonstrated robust predictive power on the unseen test set, explaining 64% of the variance in social anxiety scores ( $R^2 = .64$ , RMSE = 7.45, MAE = 5.88). Global feature importance analysis, based on mean absolute SHAP values, identified emotional reactivity as the most dominant predictor (Mean |SHAP| value = 4.85), followed by rejection sensitivity (Mean |SHAP| value = 3.92), intolerance of uncertainty (Mean |SHAP| value = 2.84), and peer network centrality (Mean |SHAP| value = 1.95). SHAP analysis further revealed significant synergistic effects, particularly between high emotional reactivity and high rejection sensitivity, which exponentially increased predicted social anxiety.

**Conclusion:** Emotional reactivity operates as the primary driver of adolescent social anxiety, with its impact significantly amplified by concurrent cognitive and social vulnerabilities, highlighting the necessity of integrated, skills-based clinical interventions.

**Keywords:** Adolescent Social Anxiety, Emotional Reactivity, Rejection Sensitivity, Peer Network Centrality, Intolerance of Uncertainty

## 1. Introduction

Adolescence is a critical developmental period marked by profound biological, cognitive, and social transformations, during which individuals increasingly navigate complex interpersonal landscapes and establish a sense of self independent of their familial origins. Consequently, the peer group becomes a paramount domain of socialization, making adolescents particularly susceptible to the evaluative judgments of others. Within this heightened context of peer observation, social anxiety emerges as one of the most prevalent and debilitating psychological conditions affecting youth worldwide. Social anxiety is fundamentally characterized by an intense, persistent fear of being scrutinized, negatively evaluated, or rejected in social or performance situations. The trajectory of adolescent social anxiety is of significant clinical and educational concern, as it frequently precipitates a cascade of negative psychosocial outcomes, including academic underachievement, depressive symptomatology, and an increased risk for substance abuse (Tamang & Bhandari, 2025). Recent epidemiological shifts have highlighted the pervasive nature of this condition, particularly among secondary school populations where the pressures of social conformity and academic performance intersect (Cao et al., 2025). The multifaceted etiology of social anxiety necessitates a comprehensive examination of the various environmental, interpersonal, and intrapersonal risk factors that coalesce to maintain and exacerbate the disorder during adolescence.

Historically, the familial environment has been identified as a primary crucible for the development of social anxiety. Communication patterns within the family unit and the quality of the parent-child relationship significantly influence an adolescent's developing social schemas. Research indicates that perceived parental communication styles profoundly impact adolescent emotional well-being, with critical or dismissive interactions fostering heightened social apprehension (Sriwenda, 2025). Furthermore, comprehensive meta-analytic findings have robustly demonstrated that specific parenting behaviors, particularly those characterized by low warmth and high psychological control from both mothers and fathers, are intrinsically linked to elevated social anxiety symptoms in youth (Howard et al., 2025). The transmission of these vulnerabilities is often indirect, mediated through cognitive and emotional regulatory mechanisms. For instance, maternal and paternal harsh parenting practices have been shown to precipitate emotional dysregulation and cognitive

reactivity, which in turn function as proximal precursors to adolescent social anxiety (Wang et al., 2022). These early relational templates often generalize to broader social contexts, dictating how adolescents approach and interpret interactions within their peer networks.

In the contemporary developmental landscape, the peer ecosystem extends far beyond the physical confines of the schoolyard, deeply permeating the digital realm. The ubiquitous use of social media and internet technologies has introduced novel platforms for social comparison and peer evaluation, fundamentally altering the parameters of adolescent social anxiety. Extensive engagement with digital platforms has been associated with maladaptive psychological dependencies. Specifically, phenomena such as internet addiction and the pervasive fear of being without a mobile device, commonly termed nomophobia, have been identified as significant correlates of social anxiety and diminished subjective happiness (Yilmaz et al., 2025). The architecture of social media, which often emphasizes curated self-presentation and quantified social approval, can severely exacerbate fears of negative evaluation. Consequently, social media addiction and nomophobia frequently operate in tandem, serving as critical pathways that amplify underlying social anxieties (Ayaz-Alkaya & Kulakçı-Altıntaş, 2025). Furthermore, the digital environment introduces the pervasive threat of cyberostracism. Experiences of being ignored or excluded in virtual spaces significantly elevate social anxiety among young adults, a process often mediated by ruminative thought patterns and an acute sensitivity to interpersonal rejection (Shi et al., 2024).

Beyond the digital sphere, the structural and qualitative aspects of offline peer functioning remain central to the manifestation of social anxiety. Prospective longitudinal studies have unequivocally established that poor peer functioning, encompassing lower peer acceptance and fewer high-quality friendships, is a robust predictor of subsequent social anxiety symptoms in adolescents (Chiu et al., 2021). The quality of peer attachment serves as a vital psychological tether; secure attachments foster resilience, whereas insecure or fraught peer relationships undermine self-concept and precipitate social apprehension (Zhang & Zhang, 2024). Adolescents navigating social transitions, such as the precarious shift to high school, are particularly vulnerable. During these periods, underlying social anxiety can interact with deficits in socio-cognitive skills, such as empathy, to influence peer dynamics and indirect aggression (Tarlow & Greca, 2020). Furthermore, social anxiety is

fundamentally linked to socio-cognitive deficits, including impairments in theory of mind and empathic accuracy, which hinder the adolescent's ability to accurately decode social cues and navigate complex group dynamics (Talha et al., 2020).

The positioning of an adolescent within their broader peer network—often conceptualized mathematically as network centrality—plays a critical, yet highly complex, role in shaping their social experiences. Adolescents suffering from social anxiety are not only at a deficit in terms of popularity but are also at a significantly heightened risk of explicit peer victimization and bullying (Sireli et al., 2024). The relationship between social anxiety and peer victimization is often reciprocal and self-perpetuating; social anxiety invites victimization, and prolonged exposure to peer aggression subsequently deepens social withdrawal and anxiety (Zhou et al., 2024). Moreover, fear of negative evaluation and overt peer rejection operate synergistically to construct a hostile social environment that severely limits an adolescent's capacity for normative social engagement (Muñoz et al., 2024). Given these severe interpersonal consequences, interventions targeting socially anxious youth often necessitate broad-based approaches, such as cognitive-behavioral play therapy, which aim to reduce both internalizing distress and externalizing aggressive behaviors stemming from social frustration (Zolrahim & Azmoudeh, 2020).

A core cognitive-affective vulnerability that bridges these interpersonal experiences with internal distress is rejection sensitivity. Rejection sensitivity is defined as the dispositional tendency to anxiously expect, readily perceive, and intensely overreact to social rejection. Longitudinal evidence spanning across adolescence demonstrates that baseline levels of rejection sensitivity act as a potent catalyst for the developmental exacerbation of social anxiety symptoms (Zimmer-Gembeck et al., 2021). This hypersensitivity distorts social perception, causing adolescents to interpret ambiguous social cues as overt signs of exclusion. Within various demographic cohorts, including college students, a robust and direct relationship between elevated rejection sensitivity and severe social anxiety has been consistently documented (Hussain et al., 2023). The etiology of this trait is deeply intertwined with early relational experiences. For instance, parenting attitudes characterized by rejection or neglect foster high rejection sensitivity, which subsequently mediates the pathway to severe social anxiety (Hyun & Lim, 2022). Similarly, from an attachment theory perspective, early maladaptive

schemas formed in response to insecure attachments operate through the mechanism of rejection sensitivity to produce chronic social anxiety (Bintas-Zorer & Dirik, 2023). This cognitive bias extends to physical self-perception as well; appearance-based rejection sensitivity serves as a crucial link connecting social anxiety symptoms to the development of body dysmorphic concerns, highlighting the pervasive nature of this vulnerability (Brekalo, 2022). Furthermore, structural relationship analyses reveal that insecure adult attachment styles and ambivalence over emotional expression compound rejection sensitivity, locking the individual in a paralyzing cycle of social apprehension (Lee, 2023).

In tandem with rejection sensitivity, emotional reactivity and the intolerance of uncertainty constitute fundamental pillars of the socially anxious phenotype. Emotional reactivity refers to the threshold, intensity, and duration of affective arousal in response to environmental stimuli. Adolescents with subclinical and clinical social anxiety exhibit profound physiological and psychological reactivity to social stressors, characterized by overwhelmingly negative cognitive appraisals and intense subjective emotional distress (Crişan et al., 2016). The inability to effectively down-regulate these intense emotional responses severely impairs social functioning. The experience of perceived rejection, when coupled with deficits in cognitive reappraisal strategies, frequently leads to the internalization of anger and heightened anxiety (Tsekova, 2023). Conversely, adaptive emotional regulatory capacities, such as high emotional granularity—the ability to precisely differentiate between discrete emotional states—and effective cognitive reappraisal, serve as protective factors that buffer against social anxiety and facilitate healthier interpersonal relationships (Lian, 2025). Intolerance of uncertainty further complicates this emotional landscape. Social interactions are inherently unpredictable, and adolescents who possess a profound cognitive aversion to ambiguity find the uncertain nature of peer evaluation intolerable, leading to systemic avoidance behaviors and chronic anticipatory anxiety.

While the individual contributions of rejection sensitivity, intolerance of uncertainty, emotional reactivity, and peer network positioning to adolescent social anxiety are well-documented, the existing literature relies heavily on traditional linear analytical frameworks. These conventional methodologies often fail to capture the highly complex, synergistic, and potentially non-linear interactions among these multifarious variables. The psychological architecture

of an adolescent is not merely an additive sum of isolated traits; rather, it is a dynamic system where vulnerabilities interact in compounding ways. For example, the precise mathematical threshold at which peer network centrality ceases to be protective and becomes a source of evaluative pressure remains poorly understood. Similarly, the synergistic explosive risk posed by the confluence of high emotional reactivity and acute rejection sensitivity requires advanced methodological approaches to properly quantify. Machine learning techniques, particularly gradient-boosting algorithms, offer a robust solution to these analytical limitations by adeptly modeling high-dimensional, non-linear relationships without the restrictive assumptions inherent in traditional parametric statistics. Therefore, utilizing an Extreme Gradient Boosting algorithm complemented by SHapley Additive exPlanations, the primary aim of this study is to predict adolescent social anxiety by delineating the complex, non-linear interplay and relative feature importance of rejection sensitivity, intolerance of uncertainty, emotional reactivity, and sociometric peer network centrality.

## 2. Methods and Materials

### 2.1. Study Design and Participants

The present research utilized a cross-sectional, predictive study design to investigate the complex interplay of psychological and social factors contributing to adolescent social anxiety. The target population comprised middle and high school students residing in the Republic of Armenia. A multistage cluster sampling technique was employed to recruit a precise and diverse sample of 847 adolescents from various public and private educational institutions across Yerevan and three surrounding provincial regions. The participants ranged in age from 13 to 18 years, reflecting the critical developmental window of middle to late adolescence where peer dynamics and psychological vulnerabilities are particularly salient. Prior to the commencement of data collection, official ethical clearance was obtained from the relevant institutional review boards, and site permissions were secured from school administrators. Written informed consent was collected from the parents or legal guardians of all participants, alongside the documented assent of the adolescents themselves. To ensure the integrity of the data, students with a documented history of severe cognitive impairments or those who lacked sufficient proficiency in the Armenian language to comprehend the survey instruments were excluded from the final sample. The

administration of the surveys was conducted in quiet classroom environments during regular school hours, supervised by trained research assistants who were available to clarify any queries without influencing the participants' responses.

### 2.2. Measures

To comprehensively measure the variables of interest, a battery of standardized, self-report psychological questionnaires and sociometric assessments was administered, all of which were rigorously forward- and backward-translated into Armenian to ensure cultural and linguistic validity. Adolescent social anxiety, serving as the primary criterion variable, was assessed using the Social Anxiety Scale for Adolescents, which captures fear of negative evaluation and social avoidance in new and general situations. Rejection sensitivity was measured via the Rejection Sensitivity Questionnaire for children and adolescents, a tool designed to evaluate the precise expectations of rejection and the degree of anxiety associated with potential interpersonal rebuffs. Intolerance of uncertainty, reflecting the cognitive bias toward perceiving ambiguous future events as inherently threatening, was quantified using the short form of the Intolerance of Uncertainty Scale. To evaluate emotional reactivity, the Emotion Reactivity Scale was utilized, capturing the intensity, duration, and threshold of emotional responses. Finally, to construct the peer network centrality metric, a sociometric nomination procedure was implemented within bounded school cohorts. Participants were asked to nominate up to five peers within their grade level with whom they most frequently interact and consider friends. From these sociometric matrices, eigenvector centrality scores were calculated for each adolescent, providing a robust mathematical representation of their social integration and influence within the broader peer network structure, moving beyond simple popularity to capture the quality of their social ties.

### 2.3. Data Analysis

The data analysis phase was heavily anchored in advanced machine learning techniques, specifically employing a gradient-boosting modeling approach to handle the anticipated nonlinear relationships and complex interactions among the psychological and sociometric predictors. Initially, data preprocessing was conducted to address missing values using multiple imputation by chained

equations, ensuring that no valuable participant data was discarded unnecessarily. The dataset was subsequently randomly partitioned into a training set, comprising 80% of the data, and a hold-out testing set containing the remaining 20%. An Extreme Gradient Boosting algorithm was selected due to its superior execution speed and model performance. To optimize the model and prevent overfitting, a rigorous hyperparameter tuning process was executed using randomized search cross-validation with 5folds on the training data. The key hyperparameters adjusted included the learning rate, maximum tree depth, and the number of estimators. The predictive performance of the finalized gradient-boosting model was evaluated on the unseen testing dataset utilizing several standard metrics, primarily the coefficient of determination  $R^2$ , the root mean square error, and the mean absolute error. To interpret the model and understand the relative contribution of rejection sensitivity, intolerance of uncertainty, emotional reactivity, and peer network centrality, SHapley Additive exPlanations values were computed. This advanced game-theoretic approach allowed for the precise quantification of feature importance, revealing not only the magnitude of each predictor’s impact on social anxiety but also the directionality of these complex effects across individual adolescent profiles. All statistical and machine learning analyses were executed using the Python programming language, leveraging the Scikit-learn and XGBoost libraries.

### 3. Findings and Results

The findings of the present study provide a comprehensive understanding of the factors contributing to adolescent social anxiety, analyzed through both traditional statistical methods and advanced gradient-boosting machine learning techniques. Preliminary analyses were conducted to ascertain the demographic characteristics and baseline psychological profiles of the sample. The final sample consisted of  $N = 847$  adolescents, comprising 445 females (52.5%) and 402 males (47.5%), with a mean age of  $M = 15.42$  years ( $SD = 1.35$ ). The descriptive statistics for the primary continuous variables, including the criterion variable of social anxiety and the predictor variables of rejection sensitivity, intolerance of uncertainty, emotional reactivity, and peer network centrality (eigenvector centrality), are presented in Table 1. The data indicates moderate to high levels of variance across all psychological constructs, suggesting a diverse representation of emotional and cognitive profiles within the Armenian adolescent cohort. Skewness and kurtosis values for all measures fell within the acceptable ranges of  $-2$  to  $+2$ , confirming that the distributions were sufficiently normal for the subsequent analytical procedures.

**Table 1**

*Descriptive Statistics for Demographic and Key Study Variables (N=847)*

Variable	<i>M</i>	<i>SD</i>	Minimum	Maximum	Skewness	Kurtosis
Age (years)	15.42	1.35	13.00	18.00	-0.12	-0.85
Social Anxiety	48.65	12.43	18.00	90.00	0.45	-0.21
Rejection Sensitivity	11.34	4.21	2.00	28.00	0.78	0.54
Intolerance of Uncertainty	32.18	8.65	12.00	60.00	0.32	-0.44
Emotional Reactivity	45.22	14.11	21.00	84.00	0.61	0.15
Peer Network Centrality	0.14	0.08	0.00	0.45	1.12	1.25

To explore the initial linear associations between the variables, a bivariate correlation analysis using Pearson’s correlation coefficient was executed. The results, detailed in Table 2, revealed significant relationships among all variables of interest in the expected directions. Social anxiety demonstrated strong positive correlations with emotional reactivity ( $r = .58, p < .001$ ), rejection sensitivity ( $r = .53, p < .001$ ), and intolerance of uncertainty ( $r = .49, p < .001$ ). This indicates that adolescents who reported higher emotional volatility, greater fear of interpersonal rejection, and a stronger aversion to

ambiguous situations also experienced elevated levels of social anxiety. Conversely, peer network centrality exhibited a significant negative correlation with social anxiety ( $r = -.36, p < .001$ ), suggesting that adolescents who are more centrally embedded and influential within their peer networks tend to experience lower social anxiety. The intercorrelations among the predictor variables were moderate, ranging from  $r = -.22$  to  $r = .46$ , indicating that while the constructs are related, they represent distinct phenomena without raising severe concerns of multicollinearity for the predictive modeling phase.

**Table 2**

*Bivariate Correlation Matrix of Key Study Variables*

Variable	1	2	3	4	5
1. Social Anxiety	–				
2. Rejection Sensitivity	.53***	–			
3. Intolerance of Uncertainty	.49***	.38***	–		
4. Emotional Reactivity	.58***	.46***	.41***	–	
5. Peer Network Centrality	–.36***	–.28***	–.22***	–.31***	–

\*\*\* $p < 0.001$

Following the correlational analysis, the Extreme Gradient Boosting model was trained to predict adolescent social anxiety. The dataset was split into an 80% training set ( $n = 677$ ) and a 20% hold-out testing set ( $n = 170$ ). The model’s hyperparameters were optimized using randomized search cross-validation, resulting in a final model with a learning rate of 0.05, a maximum tree depth of 4, and 150 estimators. The performance of the finalized gradient-boosting model was evaluated using the testing dataset to ensure its generalizability to unseen data. The evaluation metrics, presented in Table 3, indicate that the model

possessed a robust predictive capacity. Specifically, the model achieved a coefficient of determination ( $R^2$ ) of .64 on the testing set, meaning that approximately 64% of the variance in adolescent social anxiety could be accurately explained by the nonlinear combination of rejection sensitivity, intolerance of uncertainty, emotional reactivity, and peer network centrality. The Root Mean Square Error and Mean Absolute Error values further confirmed the model’s accuracy, showing minimal deviation between the predicted and actual social anxiety scores.

**Table 3**

*Predictive Performance Metrics of the Gradient-Boosting Model*

Metric	Training Set ( $n = 677$ )	Testing Set ( $n = 170$ )
Coefficient of Determination ( $R^2$ )	.72	.64
Root Mean Square Error (RMSE)	6.54	7.45
Mean Absolute Error (MAE)	5.12	5.88

To unpack the “black box” of the gradient-boosting algorithm and determine the relative importance of each psychological and sociometric predictor, SHapley Additive exPlanations (SHAP) values were calculated. The SHAP analysis assigns an importance value to each feature for every individual prediction, allowing for a highly nuanced understanding of the model’s internal logic. Table 4 presents the mean absolute SHAP values for each predictor, which serves as a global measure of feature importance. Emotional reactivity emerged as the most critical predictor of adolescent social anxiety, possessing the highest mean absolute SHAP value (+4.85). This was closely followed by rejection sensitivity (+3.92). Intolerance of uncertainty also contributed substantially to the model’s predictive power

(+2.84). Finally, peer network centrality emerged as a significant, albeit slightly less dominant, predictor (+1.95). Furthermore, the directional SHAP summary plots (not shown in tables but analyzed in the data) revealed complex nonlinear dynamics. For instance, the protective effect of peer network centrality on social anxiety exhibited diminishing returns; once an adolescent achieved a moderate level of network centrality, further increases in peer status yielded only marginal reductions in social anxiety. Conversely, the compounding interaction between high emotional reactivity and high rejection sensitivity resulted in exponential spikes in predicted social anxiety scores, highlighting the synergistic risk posed by these vulnerabilities.

**Table 4**

*Global Feature Importance Based on Mean Absolute SHAP Values*

Predictor Variable	Mean Absolute SHAP Value	Rank
Emotional Reactivity	4.85	1
Rejection Sensitivity	3.92	2
Intolerance of Uncertainty	2.84	3
Peer Network Centrality	1.95	4

**4. Discussion**

The present study aimed to elucidate the complex, non-linear relationships between adolescent social anxiety and a multidimensional set of predictors, specifically rejection sensitivity, intolerance of uncertainty, emotional reactivity, and peer network centrality, utilizing an advanced gradient-boosting machine learning approach. The finalized Extreme Gradient Boosting model demonstrated robust predictive utility, successfully accounting for 64% of the variance ( $R^2 = .64$ ) in social anxiety scores within the hold-out testing dataset. This high degree of explanatory power underscores the profound interconnectedness of these intrapersonal and interpersonal vulnerabilities during the critical developmental window of adolescence. By leveraging SHapley Additive exPlanations (SHAP) values, the analytical framework moved beyond traditional linear correlations to reveal the hierarchical importance and compounding interactive dynamics of these psychological factors. The global feature importance rankings identified emotional reactivity as the most dominant predictor of adolescent social anxiety, followed sequentially by rejection sensitivity, intolerance of uncertainty, and peer network centrality. The integration of these findings with the existing developmental and clinical literature provides a comprehensive understanding of the mechanisms driving social apprehension among youth.

The emergence of emotional reactivity as the primary predictor of social anxiety in this cohort strongly aligns with prior psychological investigations emphasizing the role of affective dysregulation in psychopathology. Adolescents who exhibit lower thresholds for emotional arousal and experience emotions with overwhelming intensity are inherently more vulnerable to the evaluative pressures of their social environments. Previous studies have similarly demonstrated that individuals with subclinical and clinical social anxiety exhibit profound physiological and psychological reactivity when exposed to social stressors, often accompanied by rigid, negative cognitive appraisals (Crişan et al., 2016). The inability to effectively modulate

this intense emotional arousal severely impairs social functioning. Adaptive emotional regulatory capacities, such as emotional granularity and cognitive reappraisal, typically serve to buffer adolescents against social anxiety (Lian, 2025). However, when emotional reactivity is high and these regulatory skills are deficient, the experience of perceived social threat frequently leads to internalized distress, anger, and heightened anxiety (Tsekova, 2023). The etiology of this emotional volatility is often rooted in early familial environments; for instance, harsh parenting practices have been shown to directly precipitate emotional dysregulation, thereby functioning as a distal precursor to adolescent social anxiety (Wang et al., 2022). These foundational familial dynamics, including poor parental communication (Sriwenda, 2025) and parenting styles characterized by psychological control (Howard et al., 2025), create an environment where the adolescent fails to develop the necessary tools to process intense emotional states, leaving them highly susceptible to social anxiety as they transition into peer-dominated spheres.

Rejection sensitivity emerged as the second most critical predictor in the gradient-boosting model, a finding that corroborates extensive longitudinal evidence highlighting its role as a developmental catalyst for social anxiety (Zimmer-Gembeck et al., 2021). The SHAP summary analyses in the current study revealed a dangerous synergistic effect: the combination of high emotional reactivity and acute rejection sensitivity resulted in exponential spikes in predicted social anxiety. This interaction suggests that it is not merely the expectation of rejection, but the devastating emotional intensity with which that potential rejection is felt, that paralyzes the adolescent socially. This trait is pervasive across various demographics, consistently correlating with severe social apprehension (Hussain et al., 2023; Tamang & Bhandari, 2025). The formation of this hypersensitivity is frequently explained through an attachment theory perspective, wherein early maladaptive schemas derived from insecure attachments manifest as a profound fear of interpersonal rebuff, driving chronic social anxiety (Bintas-Zorer & Dirik, 2023). Furthermore, rejecting parenting

attitudes directly foster this sensitivity, creating a mediating pathway to severe social withdrawal (Hyun & Lim, 2022). Insecure adult attachment styles and ambivalence over emotional expression further compound this vulnerability, locking the individual in a cycle of fear (Lee, 2023). The ramifications of rejection sensitivity extend beyond general social interactions into specific domains of self-perception, acting as a crucial link between social anxiety and body dysmorphic concerns, as adolescents become terrified of appearance-based rejection (Brekalo, 2022). In the modern era, this sensitivity is heavily exploited by the digital environment, where experiences of cyber-ostracism trigger ruminative cycles that severely exacerbate social anxiety (Shi et al., 2024). The pervasive nature of social media addiction and nomophobia further amplifies these fears, as adolescents become obsessively tethered to platforms where social approval is quantified and the threat of rejection is ever-present (Ayaz-Alkaya & Kulakçı-Altıntaş, 2025; Yılmaz et al., 2025).

Intolerance of uncertainty, ranking as the third most impactful predictor, highlights the profound cognitive discomfort socially anxious adolescents experience when faced with ambiguous social information. Peer interactions are inherently unpredictable, requiring continuous decoding of subtle verbal and non-verbal cues. Adolescents burdened by social anxiety frequently exhibit deficits in socio-cognitive skills, including impairments in theory of mind and empathic accuracy, which hinder their ability to accurately interpret these ambiguous cues (Talha et al., 2020). Consequently, ambiguous situations are immediately catastrophized as threatening. During precarious developmental transitions, such as the shift to high school, this intolerance of uncertainty interacts with empathy deficits to influence peer dynamics, sometimes resulting in indirect aggression as a maladaptive coping mechanism (Tarlow & Greca, 2020). The fear of negative evaluation, coupled with the unpredictable nature of peer group acceptance, constructs a hostile psychological environment that limits normative social engagement (Muñoz et al., 2024). The pervasive rural-urban divide also contextualizes this uncertainty, as varying levels of social support and social comparison heavily mediate the relationship between social anxiety and broader depressive symptoms across different secondary school populations (Cao et al., 2025).

Finally, peer network centrality, derived from sociometric data, emerged as a significant predictor, validating the vital role of actual social integration. However, the non-linear capabilities of the gradient-

boosting algorithm revealed a phenomenon of diminishing returns: while moving from marginalization to moderate centrality significantly reduced social anxiety, achieving highly central “popular” status offered little additional protective benefit, and may even introduce new evaluative pressures. This nuanced finding adds depth to the well-established consensus that poor peer functioning and low peer acceptance are robust prospective predictors of subsequent social anxiety (Chiu et al., 2021). Adolescents lacking secure peer attachments are left without a vital psychological tether, undermining their self-concept and precipitating social apprehension (Zhang & Zhang, 2024). Furthermore, those situated on the periphery of the social network are not only isolated but are at a significantly heightened risk of explicit peer victimization and bullying (Sireli et al., 2024). This relationship is dangerously reciprocal; social anxiety invites victimization, and prolonged exposure to peer aggression further deepens social withdrawal, cementing the adolescent’s marginalized status within the network (Zhou et al., 2024). Addressing these severe interpersonal consequences often necessitates broad-based, systemic interventions, such as cognitive-behavioral play therapy in younger cohorts, designed to alleviate both internalizing distress and the externalizing aggressive behaviors that stem from chronic social frustration (Zolrahim & Azmoudeh, 2020).

## 5. Conclusion

The present study successfully developed a sophisticated gradient-boosting machine learning model (achieving an explanatory power of  $R^2 = .64$ ) that substantially advances our understanding of adolescent social anxiety by quantifying the complex, non-linear interactions between key psychological and social factors. The findings robustly underscore emotional reactivity as the most potent driver of social anxiety within this demographic, with its deleterious impact dramatically amplified by concurrent cognitive vulnerabilities such as rejection sensitivity and an intolerance of uncertainty—a synergistic dynamic uniquely elucidated by SHAP value analysis. Furthermore, while peer network centrality offers a demonstrable degree of protection against social apprehension, its benefits exhibit diminishing returns at higher echelons of peer status, highlighting the critical importance of secure, high-quality interpersonal functioning rather than mere social embeddedness. Ultimately, these results collectively reinforce the paradigm that adolescent social anxiety is a

multifaceted construct best decoded through advanced analytical techniques that capture interactive risks, thereby providing a crucial evidence base for designing more targeted, comprehensive clinical interventions that simultaneously address emotional dysregulation, cognitive biases, and sociometric marginalization.

## 6. Limitations & Suggestions

Despite the methodological strengths of this study, several limitations must be acknowledged when interpreting the findings. First, the cross-sectional nature of the research design precludes the establishment of definitive causal relationships among rejection sensitivity, intolerance of uncertainty, emotional reactivity, peer network centrality, and social anxiety. While the machine learning model demonstrates high predictive accuracy, it captures a snapshot of these variables at a single point in time, unable to account for the dynamic, bidirectional developmental trajectories that likely exist. Second, the reliance on self-report questionnaires for the psychological constructs introduces the potential for common method bias and socially desirable responding. Adolescents experiencing severe social anxiety may underreport or overreport their symptoms due to heightened self-consciousness. Third, while the sociometric peer nomination process provides a robust measure of network centrality within the bounded school environment, it does not account for the quality of friendships outside of the school setting or the rapidly expanding influence of digital and online peer networks, which represent a significant proportion of contemporary adolescent socialization. Finally, the sample was restricted to adolescents within specific geographic and cultural confines in Armenia, limiting the generalizability of the findings to youth in vastly different cultural, socioeconomic, or educational contexts where peer dynamics and the expression of psychological distress may significantly vary.

Future research endeavors should prioritize longitudinal study designs to map the developmental cascades and directional influences among these psychological and sociometric variables over the course of adolescence. Tracking these factors from early middle school through late high school would allow researchers to identify critical developmental windows where emotional reactivity or rejection sensitivity most acutely translates into chronic social anxiety. Additionally, future investigations must integrate multidimensional assessments that move beyond self-report, incorporating physiological indices of emotional

reactivity, such as heart rate variability or galvanic skin response, to provide a more objective measure of affective arousal during social stressors. It is also imperative for future sociometric research to map both offline and online peer networks simultaneously. As digital socialization becomes ubiquitous, understanding an adolescent's network centrality and experiences of ostracism across both physical and virtual domains is essential for capturing the complete landscape of peer influence. Expanding the application of machine learning algorithms to culturally diverse, cross-national datasets will also be crucial for determining the universal applicability versus cultural specificity of the predictive models developed in this study.

The findings of this study translate into several critical suggestions for clinical and educational practice. Mental health professionals and school counselors should prioritize the assessment and targeted treatment of emotional reactivity and rejection sensitivity as primary clinical interventions for socially anxious youth. Traditional cognitive-behavioral therapies that focus solely on exposure to feared social situations may be insufficient if the adolescent lacks the fundamental emotional regulatory skills to tolerate the associated distress. Therefore, incorporating dialectical behavior therapy skills or mindfulness-based emotion regulation training could prove highly beneficial in raising the adolescent's threshold for emotional arousal. Furthermore, schools must recognize the profound impact of peer network structures on psychological well-being. Educational initiatives should move beyond individual-level interventions to include systemic, classroom-based sociometric restructuring. By identifying marginalized students who lack peer network centrality, educators can proactively facilitate inclusive group activities, peer mentoring programs, and structured cooperative learning environments that foster genuine social integration and disrupt the reciprocal cycle of social withdrawal and peer victimization. Finally, psychoeducational programs targeting parents should be implemented to emphasize the role of warm, validating familial environments in building the adolescent's resilience against the inevitable uncertainties and rejections inherent in peer relationships.

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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.

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