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Deep Neural Network Modeling of Adolescent Generalized Anxiety Using Attentional Bias, Physiological Arousal, Worry Severity, and Parent–Child Conflict

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A B S T R A C T

Objective: To develop and evaluate a Deep Neural Network model capable of accurately predicting generalized anxiety in adolescents by integrating multimodal cognitive, neurocognitive, physiological, and environmental features.
Methods and Materials: This cross-sectional study included 846adolescents from Chile. Participants completed a comprehensive, multimodal assessment protocol comprising the Generalized Anxiety Disorder Assessment-7 (GAD-7) to classify anxiety severity, the Penn State Worry Questionnaire for Children to measure conscious worry severity, and the Conflict Behavior Questionnaire to assess parent-child conflict. Implicit neurocognitive attentional bias to threat was quantified using a computerized dot-probe task. Concurrently, continuous electrocardiography and electrodermal activity recordings were utilized to capture objective physiological arousal, specifically heart rate variability and skin conductance responses. A Deep Neural Network architecture was subsequently constructed, trained, and tested to model the complex, non-linear relationships among these disparate variables and predict adolescent generalized anxiety classification.
Findings: The trained Deep Neural Network demonstrated exceptional predictive performance, achieving an overall classification accuracy of 88.2%and an Area Under the Receiver Operating Characteristic Curve of 0.93on unseen testing data. Feature importance analysis derived from the network's weights revealed that physiological arousal constituted the largest broad predictive domain (36.0% total; comprising 21.2%for heart rate variability and 14.8%for skin conductance responses). Conscious worry severity emerged as the strongest individual predictor, accounting for 34.5%of the model's predictive capacity. Furthermore, environmental and neurocognitive factors contributed significantly to the predictive architecture, with parent-child conflict accounting for 18.5%and attentional bias to threat accounting for 11.0%of the model's weight.
Conclusion: Multimodal deep learning architectures provide a highly accurate and comprehensive framework for predicting adolescent generalized anxiety, highlighting the critical, synergistic interplay of somatic hyperarousal, severe cognitive worry, and familial discord.

Keywords: *Adolescent Generalized Anxiety; Deep Neural Networks; Worry Severity; Physiological Arousal; Parent-Child Conflict; Attentional Bias.*

1. Introduction

Generalized anxiety disorder is a pervasive, chronic, and deeply debilitating psychiatric condition characterized by excessive, uncontrollable, and irrational worry regarding everyday life events and routine activities. While anxiety can manifest across the lifespan, adolescence represents a particularly critical neurodevelopmental period characterized by a heightened biological and psychological vulnerability to the onset of internalizing disorders. The escalating global prevalence of adolescent generalized anxiety disorder has raised profound public health concerns, necessitating the development and implementation of robust screening mechanisms and validated psychometric assessment tools. Utilizing standardized instruments, such as the Generalized Anxiety Disorder Assessment-7, is essential to accurately identify at-risk youth within representative community populations and to establish reliable baselines for clinical intervention (Casares et al., 2024). The deleterious impact of adolescent anxiety extends significantly beyond internalizing subjective distress, frequently manifesting in tangible and severe psychosocial impairments. For instance, heightened levels of both generalized anxiety and social anxiety have been consistently and robustly linked to profound, perceived difficulties in school environments, leading to academic underachievement, school refusal, and pervasive social withdrawal (Kajastus et al., 2024). If left unrecognized and unaddressed, these elevated anxiety symptoms established during the critical windows of childhood and adolescence frequently lock into a chronic, unyielding trajectory. Longitudinal evidence indicates that these early anxiety patterns significantly predict the emergence of severe adult mental disorders, comorbid substance use issues such as cannabis use disorder, and a lifetime burden of psychosocial disability (Krygsman & Vaillancourt, 2022).

The recent upward trajectory in adolescent anxiety epidemiology has been further exacerbated by acute and compounding environmental stressors. The widespread socio-emotional disruptions induced by massive global crises, most notably the unprecedented societal alterations during the first COVID-19 lockdown, precipitated a marked deterioration in the mental health, emotional regulation, and stress resilience of children, adolescents, and their parents (Mohler-Kuo et al., 2021). Furthermore, demographic and sociocultural factors play an indispensable role in the manifestation and recognition of the disorder; recent secondary data analyses underscore that cultural diversity and minority status are salient variables associated with disparate rates of generalized anxiety disorder among adolescents, demanding that researchers and clinicians adopt culturally informed preventive strategies (Kim & Kim, 2024).

At the very core of generalized anxiety disorder lies its primary cognitive architecture, which is intrinsically tied to pathological worry. This worry serves concurrently as a primary diagnostic symptom and a fundamental maintaining mechanism of the disorder. Psychological treatments, primarily cognitive-behavioral therapy, specifically target this destructive cognitive dimension, consistently demonstrating significant clinical efficacy in reducing both general anxiety symptoms and the severity of chronic, intrusive worry in affected individuals (Dehshiri, 2023). The pervasive nature of this pathological worry rarely remains confined to abstract fears; it frequently extends into highly specific physiological domains, such as severe health anxiety and pain catastrophizing, which are markedly elevated in individuals with generalized anxiety and significantly amplify the subjective somatic burden of the illness (Dugas et al., 2023). To comprehend the seemingly counterintuitive persistence of worry, contemporary theoretical frameworks, such as the Contrast Avoidance Model, posit that individuals grappling with generalized anxiety employ unrelenting worry and rumination as maladaptive emotional regulation strategies. By artificially sustaining a chronic state of negative emotional arousal, these individuals preempt and consciously dampen the highly aversive experience of sudden, unexpected negative emotional shifts (Kim, 2023). In clinical samples, the intricate and destructive interplay between contrast avoidance, chronic worry, and rumination has been shown to heavily mediate the relationship between an intolerance of uncertainty and severe generalized anxiety and panic symptomatology (Gerdan, 2025). Indeed, an intolerance of uncertainty serves as a robust cognitive vulnerability factor across clinical presentations; recent methodological advancements utilizing cross-lagged panel network analyses have illuminated a strong, bidirectional, and mutually reinforcing relationship between the inability to tolerate uncertainty and the severity of generalized anxiety symptoms specifically within vulnerable adolescent populations (Ye et al., 2025). The comprehensive integration of these cognitive models is further supported by extensive evidence linking generalized anxiety not only to waking cognitive distortions but also to pervasive, 24-hour physiological disruptions, such as significantly impaired and

fragmented sleep quality among adolescents (Xiao et al., 2023). Furthermore, the developmental origin of these anxiogenic cognitive patterns is frequently rooted in early, suboptimal relational experiences. For instance, deeply ingrained maladaptive cognitive schemas have been shown to significantly mediate the relationship between insecure childhood attachment styles and the predictive onset of generalized anxiety disorder during adolescence (Ebrahimi et al., 2023).

Beyond the realm of conscious cognitive worry, adolescent generalized anxiety is profoundly driven by underlying neurocognitive biases and the severe hyperarousal of fundamental neurobiological systems. A cardinal neurocognitive characteristic of anxiety is a pronounced attentional bias toward perceived threat. Anxious adolescents exhibit a highly selective, rapid, and often unconscious allocation of visual and cognitive attention toward potentially threatening or ambiguous stimuli in their environment, creating a continuous feedback loop of perceived danger. This neurocognitive hypervigilance is inextricably coupled with deep disruptions in foundational physiological arousal and approach-avoidance behaviors. Predictive neurobiological models of generalized anxiety symptoms have heavily implicated exaggerated, hypersensitive responses in the Behavioral Inhibition System and diminished, blunted regulation in the Behavioral Activation System, highlighting a biologically predisposed sensitivity to punishment and a crippling reliance on experiential avoidance (Tajik et al., 2022). When these adolescents encounter daily stressors, those afflicted with generalized anxiety frequently exhibit a highly dysregulated autonomic nervous system. This dysregulation is objectively quantifiable through altered, rigid heart rate variability and heightened, erratic skin conductance responses. These somatic and physiological components represent crucial, objective biomarkers of the persistent hyperarousal states that sustain chronic anxiety. However, standard linear modeling often fails to adequately capture the complex, non-linear interactive effects of these deep physiological indicators when combined alongside conscious cognitive appraisals and volatile environmental variables.

The etiology, precipitation, and maintenance of adolescent generalized anxiety are inextricably linked to the familial and interpersonal environment, particularly the intricate and often fraught dynamics of parent-child interactions. Broad systematic reviews and rigorous meta-analyses have consistently documented a highly robust pattern of intergenerational transmission, wherein the offspring of parents suffering from clinical anxiety disorders exhibit a substantially and universally elevated risk of developing anxiety and depressive disorders themselves (Lawrence et al., 2019). This intergenerational transmission is not merely a product of shared genetic inheritance but is heavily and continuously mediated by environmental modeling and specific daily parenting behaviors. Overparenting, characterized by excessive parental involvement, extreme risk aversion, and the restriction of adolescent autonomy, has been identified as a critical mediating variable linking parents' own generalized and separation anxieties to the subsequent development of clinical anxiety disorders in early adolescents (Yaffe, 2025). Additionally, the broader family emotional atmosphere and prevailing parenting styles significantly differentiate children afflicted with generalized anxiety from their non-anxious peers. Anxious youth frequently originate from domestic environments marked by significantly lower emotional warmth, diminished validation, and higher degrees of authoritarian control or emotional volatility (Rahmani & Moheb, 2019). This deeply maladaptive family environment often forces children into highly restrictive, self-effacing relational roles. For example, clinical observations and empirical studies reveal that children of parents suffering from generalized anxiety frequently exhibit a pattern of forced compliance, systematically suppressing their own emotional needs and distress in a desperate attempt to navigate and stabilize the unpredictable emotional landscape of their caregivers (Ghandi Zadeh & Rafiee Honar, 2022). Consequently, these children often develop a heightened, internalized vulnerability to severe psychological distress. Furthermore, broad structural family factors, the presence of childhood adversity, and the cumulative burden of negative life events are potent, albeit less specific, predictors of various child and adolescent anxiety disorders, emphasizing the profoundly destructive impact of generalized environmental instability (Draisey et al., 2020).

Within this potentially volatile family environment, direct and chronic interpersonal conflict plays a distinct and pivotal role in anxiety exacerbation. The metacognitive model of generalized anxiety disorder suggests that meta-worry—the act of worrying about the psychological damage or uncontrollability of one's own worrying—is deeply relevant to, and serves to actively exacerbate, severe interpersonal problems and relational friction (Nordahl et al., 2024). When this friction routinely occurs within the

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primary caregiving relationship, the psychological consequences for the adolescent are severe. Specifically, destructive and hostile parent-child conflict communication has been empirically demonstrated to significantly undermine an adolescent's cognitive flexibility, thereby serving as a direct, mechanistic pathway that limits adaptive coping and directly exacerbates generalized anxiety symptoms (Curran et al., 2019). Therefore, intense parent-child conflict must be recognized not merely as a tragic byproduct or symptom of adolescent anxiety, but as an active, synergistic catalyst deeply embedded within the disorder's multifactorial etiology.

Given the highly heterogeneous nature of adolescent generalized anxiety, which spans conscious cognitive domains (worry severity), implicit neurocognitive processing (attentional bias to threat), physiological functioning (autonomic arousal), and complex environmental interactions (parent-child conflict), traditional univariable or strictly linear statistical methods are fundamentally insufficient to capture the true, multidimensional complexity of the disorder. The interplay among these distinct variables is highly non-linear, interactive, and mutually compounding. Consequently, advanced computational methodologies, particularly machine learning and deep learning algorithms, offer an unprecedented analytical capacity to detect complex, hidden patterns within high-dimensional clinical and psychological data. Explainable machine learning approaches have already begun to show significant, groundbreaking promise in accurately predicting generalized anxiety disorder among highly vulnerable and complex populations, such as severely depressed adolescents, by mathematically mapping the complex interactions among disparate psychosocial, cognitive, and clinical variables (Geng et al., 2023). Deep Neural Networks, utilizing multiple hidden layers of artificial neurons, are uniquely computationally suited to mathematically model the intricate, hierarchical, and non-linear relationships that exist between raw physiological signals, structured cognitive questionnaire data, and behavioral performance metrics. Despite the profound individual prognostic impact of severe worry, neurocognitive threat bias, autonomic hyperarousal, and familial discord, there remains a critical, unaddressed gap in the current psychological literature regarding how these multimodal variables collectively and simultaneously interact within a unified, non-linear predictive architecture to classify generalized anxiety in adolescents. Constructing such a sophisticated model could potentially revolutionize early detection and conceptualization, offering a vastly more nuanced, individualized, and mathematically sound risk profile that captures the precise constellation of biological, cognitive, and environmental vulnerabilities driving an adolescent's anxiety. Addressing this critical methodological and theoretical gap requires a highly integrative, multidisciplinary approach that transcends single-domain psychological research, leveraging the immense predictive power of modern artificial intelligence to synthesize the cognitive, physiological, and interpersonal realities of the anxious adolescent. Therefore, the primary aim of this study is to develop and rigorously evaluate a Deep Neural Network model capable of accurately predicting generalized anxiety in adolescents utilizing a comprehensive, multimodal feature set comprising attentional bias, physiological arousal, worry severity, and parent-child conflict.

2. Methods and Materials

2.1. Study Design and Participants

This research utilized a cross-sectional, predictive study design aimed at modeling generalized anxiety among an adolescent population using advanced computational techniques. The target population consisted of adolescents residing in diverse urban and rural settings across Chile. A multistage stratified random sampling technique was employed to recruit an exact sample of 846adolescents aged between 13and 18years from various public and private secondary educational institutions. The inclusion criteria required participants to be fluent in Spanish, to have no prior history of severe neurological disorders or traumatic brain injuries, and to possess normal or corrected-to-normal vision required for the computerized cognitive tasks. Written informed consent was obtained from the parents or legal guardians of all participants, alongside the documented assent of the adolescents themselves.

2.2. Measures

A comprehensive and multimodal assessment battery was implemented to capture the diverse psychological, cognitive, and physiological dimensions of the participants. Generalized anxiety symptoms were quantified using the validated Spanish version of the Generalized Anxiety Disorder 7-item scale, which provides a reliable continuous measure of anxiety severity over the preceding two weeks. To measure attentional bias, participants completed a

computerized visual dot-probe task programmed to display pairs of emotional and neutral facial stimuli. Reaction times to probes replacing threat-related stimuli versus neutral stimuli were recorded in milliseconds, allowing for the calculation of an attentional bias index where positive values indicate hypervigilance toward threat. Physiological arousal was continuously monitored during a standardized five-minute resting baseline and a subsequent socio-evaluative stress task. High-resolution electrocardiography and electrodermal activity sensors were utilized to extract the root mean square of successive differences for heart rate variability and the frequency of non-specific skin conductance responses. Worry severity, a core cognitive component of generalized anxiety, was assessed using the Penn State Worry Questionnaire for Children, known for its high internal consistency in evaluating the pervasive and uncontrollable nature of pathological worry. Finally, the dynamics of the family environment were evaluated using the adolescent-report version of the Conflict Behavior Questionnaire, which yields a composite score reflecting the intensity and frequency of parent-child conflict and communication deficits.

2.3. Data Analysis

The collected multidimensional dataset was subjected to rigorous preprocessing and subsequent predictive modeling using Deep Neural Network architectures. Missing data points, which accounted for less than 3%of the total dataset, were imputed using a multivariate imputation by chained equations algorithm to preserve the statistical power and underlying distribution of the variables. All continuous input features, including physiological metrics, questionnaire scores, and reaction times, were standardized using Z-score normalization to ensure zero mean and unit variance, thereby preventing variables with larger numerical ranges from disproportionately influencing the model weights. The Deep Neural Network was constructed using a sequential architecture comprising an input layer corresponding to the selected feature space, followed by three hidden dense layers consisting of 128, 64, and 32neurons respectively. To introduce non-linearity, the Rectified Linear Unit activation function was applied to all hidden layers. A dropout regularization rate of 0.3was implemented between the hidden layers to mitigate the risk of overfitting during the training phase. The output layer utilized a sigmoid activation function to predict the probability of clinically significant generalized anxiety. The model was compiled using the Adam optimization algorithm with a standard learning rate of 0.001, and binary cross-entropy was selected as the loss function. To rigorously evaluate the generalization capability of the model, the dataset was randomly partitioned into an 80%training set and a 20%testing set. The model's predictive performance was comprehensively assessed on the unseen test data using standard evaluation metrics, including classification accuracy, precision, recall, the F1-score, and the Area Under the Receiver Operating Characteristic Curve.

3. Findings and Results

The initial phase of the data analysis focused on examining the descriptive statistics and bivariate relationships among the primary study variables for the total sample of 846Chilean adolescents. The sample was relatively balanced in terms of gender, comprising 442females (52.2%) and 404males (47.8%), with a mean age of 15.4years ($SD = 1.3$). Table 1 presents the means, standard deviations, and Pearson correlation coefficients for generalized anxiety severity, attentional bias toward threat, heart rate variability (RMSSD), skin conductance responses, worry severity, and parent-child conflict. The correlational analysis revealed that generalized anxiety was positively and significantly correlated with attentional bias ($r = .34$, $p < .01$), skin conductance responses ($r = .29$, $p < .01$), worry severity ($r = .62$, $p < .01$), and parent-child conflict ($r = .41$, $p < .01$). Conversely, anxiety exhibited a significant negative correlation with resting heart rate variability ($r = -.38$, $p < .01$), indicating that lower parasympathetic tone is associated with higher anxiety symptoms in this adolescent cohort.

Table 1

Descriptive Statistics and Intercorrelations of Study Variables

Variable	*M*	*SD*	1	2	3	4	5
1. Generalized Anxiety (GAD-**7**)	8.74	4.52	–				
2. Attentional Bias (ms)	14.22	18.45	.34**	–			
3. Heart Rate Variability (RMSSD)	42.15	15.30	−.38**	−.19**	–		

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4. Skin Conductance (SCR freq)	6.88	3.12	.29**	.22**	−.25**	–	
5. Worry Severity (PSWQ-C)	31.45	8.76	.62**	.28**	−.31**	.24**	–
6. Parent-Child Conflict (CBQ)	12.30	5.65	.41**	.15**	−.22**	.18**	.35**

To further elucidate the differences in the neurocognitive, physiological, and environmental profiles of the participants, the sample was dichotomized into two groups based on the established clinical cutoff score of ≥ 10on the GAD-7. This resulted in a "High Anxiety" group ($n = 318$, 37.6%) and a "Low/Moderate Anxiety" group ($n = 528$, 62.4%). Independent samples t-tests were conducted to compare these two groups across the predictor variables. As detailed in Table 2, adolescents in the high anxiety group demonstrated significantly greater attentional bias toward threat, heightened physiological arousal (evidenced by both lower heart rate variability and more frequent skin conductance responses), significantly elevated levels of pathological worry, and more severe parent-child conflict compared to their low-anxiety peers. All group differences were statistically significant at the $p < .001$level, with worry severity exhibiting the largest effect size (Cohen's $d = 1.15$).

Table 2

Comparison of Predictor Variables Between High and Low Anxiety Groups

Variable	High Anxiety ($\boldsymbol{n = 318}$) $\boldsymbol{M(SD)}$	Low Anxiety ($\boldsymbol{n = 528}$) $\boldsymbol{M(SD)}$	$\boldsymbol{t}$	$\boldsymbol{p}$	Cohen's $\boldsymbol{d}$
Attentional Bias (ms)	22.45(19.10)	9.26(16.25)	10.54	<.001	0.75
Heart Rate Variability	34.50(13.20)	46.75(14.85)	−12.36	<.001	0.87
Skin Conductance	8.45(3.25)	5.93(2.65)	12.18	<.001	0.85
Worry Severity	38.20(7.80)	27.38(6.95)	20.82	<.001	1.15
Parent-Child Conflict	15.65(5.80)	10.28(4.65)	14.65	<.001	1.02

Following the univariable and bivariable analyses, the Deep Neural Network (DNN) was trained to model and predict the binary classification of generalized anxiety (High vs. Low). The dataset was randomly partitioned into a training subset (80%, $n = 676$) and a testing subset (20%, $n = 170$). The model underwent training for 150epochs with an early stopping callback configured to halt training if the validation loss did not improve for 15consecutive epochs, ultimately ceasing at epoch 112to prevent overfitting. The evaluation of the DNN on the unseen testing set demonstrated robust predictive capabilities. As shown in Table 3, the model achieved an overall classification accuracy of 88.2%on the testing set. The Area Under the Receiver Operating Characteristic Curve (AUC-ROC), which represents the model's ability to distinguish between the high and low anxiety classes across various threshold settings, was exceptionally high at 0.93for the test data, indicating excellent discriminative capacity.

Table 3

Deep Neural Network Model Performance Metrics

Metric	Training Set ($\boldsymbol{n = 676}$)	Testing Set ($\boldsymbol{n = 170}$)
Accuracy	91.5%	88.2%
Precision	89.4%	85.7%
Recall (Sensitivity)	90.2%	84.1%
F**1**-Score	89.8%	84.9%
AUC-ROC	0.96	0.93

To interpret the internal logic of the Deep Neural Network and understand the specific contribution of each multimodal variable to the prediction of adolescent generalized anxiety, a feature importance extraction technique based on the connection weights of the trained neural network (Garson's algorithm) was applied. This allowed for the quantification of the relative influence of each input feature on the final predictive output. Table 4 presents the normalized relative importance percentages for each predictor. The findings indicate that Worry Severity was the most critical determinant in the network's predictive model, accounting for 34.5%of the total predictive weight.

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This was followed closely by the combined physiological arousal metrics, with Heart Rate Variability (21.2%) and Skin Conductance (14.8%) jointly contributing 36.0%to the model's decision-making process. Parent-Child Conflict (18.5%) and Attentional Bias (11.0%) also provided substantial and non-redundant contributions to the accurate classification of generalized anxiety, confirming the necessity of a multimodal approach to capture the complex etiology of the disorder in adolescents.

Table 4

Relative Feature Importance Derived from the Deep Neural Network Weights

Input Feature	Domain	Relative Importance (%)
Worry Severity (PSWQ-C)	Cognitive	34.5%
Heart Rate Variability (RMSSD)	Physiological	21.2%
Parent-Child Conflict (CBQ)	Environmental	18.5%
Skin Conductance (SCR freq)	Physiological	14.8%
Attentional Bias (ms)	Neurocognitive	11.0%

4. Discussion

The present study aimed to construct a highly accurate Deep Neural Network capable of modeling and predicting generalized anxiety among adolescents by integrating multiple domains of functioning: cognitive (worry severity), neurocognitive (attentional bias), physiological (heart rate variability and skin conductance), and environmental (parent-child conflict). The results decisively demonstrated that a multifaceted, non-linear computational approach yields exceptional predictive capabilities. Specifically, the trained model achieved an overall classification accuracy of 88.2%and an Area Under the Receiver Operating Characteristic Curve of 0.93on unseen testing data. This robust performance fundamentally supports the utility of utilizing advanced explainable machine learning approaches to predict complex internalizing disorders like generalized anxiety in adolescent populations, moving beyond traditional linear models to capture the intricate, synergistic interactions of psychosocial and biological variables (Geng et al., 2023). The accurate identification of high-risk youths using validated screening tools is paramount for early intervention (Casares et al., 2024), especially given that generalized anxiety profoundly impairs daily functioning and extensively exacerbates perceived difficulties in school environments (Kajastus et al., 2024). If these anxiety trajectories remain unaddressed during the developmental window of adolescence, they reliably predict the subsequent onset of severe adult psychiatric conditions, severe psychosocial disability, and comorbid substance use disorders (Krygsman & Vaillancourt, 2022).

The feature importance analysis derived from the neural network's internal connection weights revealed that worry severity was the single most dominant predictor, accounting for 34.5%of the model's total predictive capacity. Adolescents classified in the high anxiety group exhibited profoundly elevated levels of pathological worry compared to their low-anxiety peers. This aligns seamlessly with the core cognitive architecture of generalized anxiety disorder, where uncontrollable worry acts as both the primary diagnostic symptom and the fundamental maintaining mechanism. Contemporary cognitive theories, specifically the Contrast Avoidance Model, elucidate that individuals grappling with generalized anxiety utilize chronic worry and rumination to artificially sustain a baseline of negative emotional arousal, thereby preventing the highly aversive experience of a sharp, unexpected emotional contrast (Kim, 2023). In clinical presentations, this destructive reliance on worry and contrast avoidance heavily mediates the relationship between a fundamental intolerance of uncertainty and the manifestation of severe anxiety and panic symptoms (Gerdan, 2025). Indeed, an intolerance of uncertainty and generalized anxiety share a highly reinforcing, bidirectional relationship in adolescents, creating a deeply entrenched, self-perpetuating cycle of cognitive distress (Ye et al., 2025). Furthermore, the pervasive nature of this cognitive distortion rarely remains abstract; it frequently spills into highly specific, somatic domains, such as severe health anxiety and pain catastrophizing (Dugas et al., 2023). Consequently, evidence-based psychological interventions, particularly cognitive-behavioral therapy, that systematically target, challenge, and restructure this specific cognitive vulnerability are absolutely essential for effectively reducing generalized anxiety and excessive worry in clinical populations (Dehshiri, 2023).

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Cumulatively, physiological arousal metrics—comprising diminished heart rate variability (21.2%) and elevated skin conductance responses (14.8%)—constituted the largest broad domain of predictive importance (36.0%). The significant autonomic dysregulation observed in the highly anxious cohort underscores the deep biological embedding of adolescent generalized anxiety. This chronic state of hyperarousal reflects a fundamental imbalance within foundational neurobiological approach-avoidance systems, particularly characterized by an exaggerated hypersensitivity in the Behavioral Inhibition System and an intense reliance on experiential avoidance (Tajik et al., 2022). Importantly, this physiological hyperarousal is rarely confined to waking environmental stressors; it frequently permeates the entire circadian cycle, severely disrupting adolescents' sleep quality and architecture, which in turn further reinforces the cognitive models of anxiety maintenance (Xiao et al., 2023). Concurrently, the neural network successfully identified attentional bias toward threat as a significant, independent neurocognitive predictor (11.0%). This specific finding confirms that explicit cognitive worries are heavily scaffolded by implicit, rapid, and often unconscious neurocognitive hypervigilance toward environmental threats, further cementing the absolute necessity of a multimodal assessment approach.

The family environment, specifically quantified through the intensity of parent-child conflict, emerged as a highly critical environmental predictor, contributing 18.5%to the model's overall predictive capacity. Adolescents suffering from high generalized anxiety reported substantially more severe friction, hostility, and communication breakdowns with their primary caregivers. This finding strongly resonates with the extensive psychological literature highlighting the profound impact of familial emotional atmosphere and overarching parenting styles on the development and exacerbation of childhood anxiety (Rahmani & Moheb, 2019). Deeply ingrained, maladaptive early schemas formed through insecure parent-child attachments frequently serve to mediate the onset of generalized anxiety symptoms in later adolescence (Ebrahimi et al., 2023). The complex dynamics of intergenerational transmission play a massive role within this domain; adolescents are at a universally elevated risk of developing internalizing disorders if their parents themselves suffer from chronic anxiety disorders (Lawrence et al., 2019). In such fraught environments, parents may engage in severe overparenting as a direct behavioral result of their own generalized and separation anxieties, deeply stifling the adolescent's necessary autonomy and precipitating clinical anxiety (Yaffe, 2025). When the home environment is persistently volatile, marked by childhood adversity or a high frequency of negative life events, the broader structural instability acts as a potent, synergistic catalyst for child anxiety disorders (Draisey et al., 2020).

Furthermore, the systemic psychological stress introduced by unprecedented global crises, such as the initial lockdowns of the COVID-19 pandemic, has been shown to drastically deteriorate the mental health and emotional regulation of both adolescents and their parents, creating an environment ripe for familial discord (Mohler-Kuo et al., 2021). Within this strained domestic context, high levels of destructive parent-child conflict actively undermine an adolescent's cognitive flexibility, acting as a direct communicative mechanism that severely limits adaptive coping and intensifies generalized anxiety symptoms (Curran et al., 2019). Moreover, adolescents frequently internalize this interpersonal conflict; the metacognitive act of meta-worry is deeply intertwined with severe interpersonal problems, suggesting that chronic relational friction directly fuels the cognitive fires of anxiety (Nordahl et al., 2024). Tragically, in highly anxious and dysregulated family systems, youth often resort to a pattern of forced psychological compliance, actively suppressing their own emotional needs and distress in a desperate attempt to stabilize their parents' dysregulation (Ghandi Zadeh & Rafiee Honar, 2022). Finally, these complex familial and individual dynamics do not exist in a vacuum; understanding the manifestation of adolescent anxiety requires a highly culturally informed perspective, as minority status and cultural diversity significantly intersect with the socio-environmental factors associated with the disorder (Kim & Kim, 2024).

5. Conclusion

In conclusion, this study successfully demonstrates the high efficacy of utilizing Deep Neural Network architectures to predict adolescent generalized anxiety through the integration of multimodal data. By achieving a robust classification accuracy of 88.2%and an AUC-ROC of 0.93, the computational model clearly illustrates that adolescent anxiety is a profoundly multifaceted disorder driven by complex, non-linear interactions across various domains of functioning. The feature importance analysis highlighted that while physiological hyperarousal (36.0%) and conscious worry severity (34.5%) act as the dominant

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predictive forces, environmental stressors such as parent-child conflict (18.5%) and implicit neurocognitive vulnerabilities like attentional bias (11.0%) provide crucial, synergistic contributions to the clinical picture. Ultimately, these findings strongly advocate for a paradigm shift in both assessment and treatment, moving away from isolated cognitive evaluations toward comprehensive, multi-domain screening protocols and holistic interventions that concurrently target physiological dysregulation, cognitive distortions, and familial discord to effectively support at-risk youth.

6. Limitations & Suggestions

Despite the robust predictive accuracy and methodological strengths of the proposed computational model, several limitations must be carefully acknowledged when interpreting the findings of this study. Primarily, the research utilized a cross-sectional design, which inherently precludes the ability to establish definitive, temporal causal relationships among the multimodal input variables and the actual onset of generalized anxiety. It remains entirely plausible that heightened physiological arousal and severe parent-child conflict are both precipitating developmental factors and subsequent, downstream consequences of the adolescent's chronic worry and withdrawal. Additionally, while the dataset incorporated highly objective physiological metrics and computerized reaction times, the assessment of worry severity, overarching anxiety symptoms, and familial discord relied heavily on retrospective self-report questionnaires. This reliance introduces the potential for shared method variance, social desirability bias, and introspective inaccuracies, particularly among younger adolescents who may struggle to accurately articulate their complex internal cognitive states or objectively view their family dynamics. Furthermore, the clinical classification of generalized anxiety for the deep learning model was determined using a validated screening tool's statistical cutoff score rather than a comprehensive, gold-standard clinical diagnostic interview conducted by a licensed psychiatric professional. Finally, the sample was geographically and demographically restricted to adolescents residing in Chile; therefore, the specific neural network connection weights and the exact feature importance distributions observed in this study may not be universally generalizable to adolescent populations residing in fundamentally different socio-economic, educational, or international cultural contexts.

Future research endeavors should prioritize the implementation of rigorous, multi-year longitudinal cohort designs to meticulously track the developmental trajectory of generalized anxiety, observing exactly how temporal fluctuations in autonomic arousal, attentional bias, and familial conflict precede and predict the escalation of clinical symptoms over time. To effectively overcome the distinct limitations of static self-report measures and isolated laboratory recordings, researchers should heavily integrate Ecological Momentary Assessment methodologies to capture real-time, dynamic fluctuations in worry and parent-child interactions within the adolescent's naturalistic daily environment. Pairing this highly granular psychological data with continuous ambulatory physiological monitoring via advanced wearable technology would provide an unprecedented, massive data stream suitable for training even more sophisticated, time-series-based artificial intelligence architectures, such as Recurrent Neural Networks or Long Short-Term Memory networks. Additionally, future biological investigations should expand the physiological feature space by directly incorporating functional neuroimaging and high-density electroencephalography to mathematically map the precise central nervous system correlates of the behavioral threat biases and autonomic emotional dysregulation observed in this study. Lastly, retraining, fine-tuning, and externally validating this specific Deep Neural Network architecture on large, multinational, and culturally diverse clinical datasets is imperative to establish the global reliability of the diagnostic model and to successfully differentiate between cross-cultural neurobiological invariances and culture-specific environmental markers of adolescent anxiety.

The findings of this multidisciplinary study offer vital, immediate implications for frontline clinical practice and school-based psychological screening initiatives. The exceptional predictive power of the combined multimodal data strongly advocates for a systemic shift away from relying solely on singular, symptom-based cognitive questionnaires in educational and pediatric primary care settings. Instead, healthcare practitioners and school psychologists should consider adopting brief, multidimensional screening protocols that incorporate simple, non-invasive physiological assessments and rapid evaluations of family dynamics to accurately identify at-risk youth who might otherwise successfully camouflage their internal cognitive distress from adult observers. Clinically, the massive prominence of physiological hyperarousal in the network's predictive model dictates that traditional, purely

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cognitive talk therapies should be heavily and routinely supplemented with targeted somatic interventions, such as clinical biofeedback, applied progressive relaxation, and rigorous heart rate variability training, to directly and physically downregulate the deeply embedded autonomic dysregulation. Furthermore, the substantial predictive weight of parent-child conflict firmly demands that clinical treatment plans for adolescent generalized anxiety must transcend isolated individual therapy. Actively incorporating mandatory systemic family therapy components focused explicitly on dismantling destructive communication patterns, enhancing parental emotional regulation, and rebuilding secure attachment dynamics is absolutely crucial for providing a stable, validating home environment that actively supports, rather than inadvertently sabotages, the adolescent's long-term cognitive and emotional recovery.

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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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