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Modeling Adolescent Aggressive Behavior Using Trait Anger, Executive Function Inhibition Scores, Family Chaos, and Social Rejection via Gradient Boosted Trees

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ABSTRACT

Objective: The objective of this study was to rigorously predict and model adolescent aggressive behavior through the complex, non-linear interactions of trait anger, executive function inhibition scores, family chaos, and social rejection via a Gradient Boosted Trees approach.

Methods and Materials: A cross-sectional predictive study design was utilized, involving a sample of $n = 842$adolescents (aged 12–17 years) recruited from central Mexico. Data were collected using the Buss-Perry Aggression Questionnaire, State-Trait Anger Expression Inventory, a computerized Stroop Color and Word Test, the Confusion, Hubbub, and Order Scale, and the Ostracism Experience Scale. Data analysis was conducted using the XGBoost machine learning algorithm, with the dataset split into an 80%training set ($n = 673$) and a 20%testing set ($n = 169$). Model evaluation and feature importance were calculated using $RMSE$, MAE, R^2, and SHapley Additive exPlanations (SHAP) values.

Findings: The XGBoost model exhibited robust predictive performance on the unseen testing set ($R^2 = .68$, $RMSE = 6.84$, $MAE = 4.95$). Based on Mean Absolute SHAP values, trait anger was identified as the paramount predictor of aggressive behavior (42.6% relative importance), sequentially followed by social rejection (25.8%), family chaos (18.5%), and executive function inhibition (13.1%). Furthermore, interaction analysis revealed profound synergistic effects, with the strongest non-linear interaction occurring between trait anger and executive function inhibition (SHAP Interaction Value = 1.25), alongside a highly significant interaction between social rejection and family chaos (SHAP Interaction Value = 0.98).

Conclusion: Adolescent aggression is a non-linear, compounded phenomenon that is most accurately predicted by the synergistic interaction of high emotional reactivity, poor cognitive inhibition, and severe environmental stressors.

Keywords: *Adolescent Aggression; Trait Anger; Executive Function Inhibition; Family Chaos; Social Rejection; Gradient Boosted Trees; Machine Learning.*

1. Introduction

Adolescence represents a developmental epoch punctuated by profound neurobiological, cognitive, and psychosocial transformations. While these maturational shifts facilitate increased autonomy and identity formation, they simultaneously render youth particularly vulnerable to emotional volatility and significant behavioral difficulties. Aggressive behavior during this critical period—manifesting diversely as physical hostility, verbal altercations, and relational transgressions—represents a preeminent public health concern with cascading negative trajectories for perpetrators and communities alike. Chronic adolescent aggression frequently co-occurs with severe affective-behavioral disorders, heavily impeding normative social functioning and educational attainment when compared to typically developing peers (Shalchi et al., 2017). Furthermore, the contemporary clinical landscape reveals a confounding comorbidity between pervasive disruptive behavior disorders and intermittent explosive conditions, significantly complicating both diagnostic accuracy and prognostic pathways (Radwan & Coccaro, 2020). Beyond overt behavioral symptoms, emergent research into neural pathomechanisms and complex epigenetic alterations—such as distinctive methylome profiles observed in high-risk adolescent populations—underscores the deeply entrenched biological substrates of conduct pathology (Chiocchetti et al., 2022). Due to the persistent and destructive nature of these behavioral patterns, the development of robust, targeted interventions tailored to temper anger, manage irritability, and prevent the escalation of aggression remains an ongoing priority within clinical psychology (Sukhodolsky et al., 2016). However, effectively mitigating these behaviors necessitates a highly comprehensive understanding of the dynamically interacting psychological, cognitive, and environmental variables that collectively precipitate them.

A central mechanism underpinning the externalization of destructive impulses is profound emotional dysregulation coupled intimately with elevated levels of trait anger. Trait anger designates a stable, intrinsic psychological propensity to experience frequent and intense episodes of frustration across a myriad of situations, acting as a powerful internal catalyst for overt aggression. Empirical evidence consistently identifies a significant relationship between generalized emotional dysregulation and the explicit manifestation of diverse aggressive typologies among youths (Darmadi & Badayai, 2021; Gong & Popescu, 2024). The fundamental inability to process and adaptively modulate intense negative affective states severely compromises an adolescent's capacity for constructive conflict resolution. Specifically, substantial deficits in affective theory of mind—the nuanced cognitive ability to correctly empathize with and accurately interpret the emotional states of others—have been inextricably linked to heightened aggressive reactivity in early adolescent cohorts (Clifford et al., 2020). Moreover, youths exhibiting low frustration tolerance are substantially more susceptible not only to explosive outward-directed aggression but also to severe internalizing psychopathology, including elevated rates of suicidal ideation (Cornejo-Babida, 2020). The pervasiveness of this emotional volatility extends across modern contexts; for instance, acute emotional frustration frequently acts as a mechanism precipitating toxic behavior within highly competitive online gaming platforms (Nugroho & Reza, 2022). Consequently, therapeutic frameworks explicitly designed to cognitively restructure hostile attribution biases and fundamentally enhance intrinsic emotional regulation capabilities, notably cognitive behavior-anger management therapies, have demonstrated marked efficacy in diminishing adolescent hostility (Sari et al., 2022).

Beyond the purely affective domain, higher-order cognitive architectures—particularly executive functioning—serve as vital gatekeepers against the sudden eruption of aggressive outbursts. Executive function encompasses a sophisticated suite of prefrontally-mediated cognitive processes, most crucially including behavioral regulation and cognitive inhibitory control. Successful inhibition enables an individual to consciously suppress prepotent or socially inappropriate behavioral responses in favor of long-term, goal-directed, and highly adaptive behaviors. Conversely, pervasive neurocognitive deficits in executive inhibition invariably facilitate impulsive aggression, primarily because adolescents lacking this vital cognitive buffer remain unable to intercept hostile automatic reactions provoked by sudden environmental stressors. The active cultivation of protective cognitive attributes, such as disciplined self-control, intrinsic psychological resilience, and adaptive decision-making styles, fundamentally correlates with a substantial reduction in adolescent aggressive behavior (Kaveh et al., 2025; Zhang et al., 2023). Furthermore, appropriate prosocial functioning is heavily contingent upon highly advanced social information processing skills and nuanced moral cognition, internal variables that dynamically antagonize external negative

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emotionality (Laible et al., 2014). Given the profound implications of executive dysfunction, specialized clinical modalities, such as intensive mentalization-based treatments, have been strategically implemented to directly target underlying cognitive representations of self and others in adolescents grappling with severe conduct disorders (Hauschild et al., 2023). Similarly, alternative experiential interventions, including immersive psychodrama workshops and specialized somatic meditation techniques focusing directly on physical grounding, have been pioneered to successfully enhance executive oversight and measurably reduce highly destructive behaviors, even among vulnerable neurodivergent populations presenting with complex profiles (Ahemaitijiang et al., 2020; Braithel & Allaouna, 2025).

While individual psychological and neurocognitive profiles are indisputably pivotal, the immediate developmental ecosystem—predominantly the structural confines of the family unit—exerts a deterministic influence on long-term behavioral trajectories. A profoundly chaotic family environment, characterized by chronic systemic disorganization, high levels of ambient noise, a distinct lack of predictable routines, and pervasive interpersonal conflict, continuously subjects adolescents to severe psychosocial stress. The affective quality of parental treatment and the specific emotional valence of daily parent-child interactions are fundamentally associated with either the exacerbation or attenuation of aggressive phenotypes (Mohammed, 2023). For example, highly strained family structures intrinsically lacking adequate support systems, such as financially burdened single-parent households, can inadvertently foster deep-seated passive-aggressive tendencies or overtly hostile coping mechanisms in youth struggling daily to navigate profound familial instability (Fauziah et al., 2023). The direct psychological transmission of emotion regulation strategies from caregiver to child further underscores this dynamic; nuanced parental emotion socialization practices significantly dictate pre-adolescent social and emotional adjustment, with the child's own autonomic nervous system reactivity frequently acting as a biological moderator (McQuade & Breaux, 2017). Furthermore, compelling evidence regarding gene-environment interactions suggests that inherited genetic vulnerabilities interact dynamically with early familial attachment security to accurately predict emotion regulation capabilities and the likelihood of a youth directing explosive, hostile behaviors toward parental figures (Zimmermann & Spangler, 2016). Importantly, clinical evaluations of such chaotic familial contexts and their resultant behavioral manifestations often reveal considerable longitudinal discrepancies depending heavily on the specific observer or reporter, starkly highlighting the subjective nature of behavioral assessments conducted within environmentally disorganized spaces (Yang et al., 2021).

As adolescents transition toward psychosocial independence, the primary locus of social validation shifts decisively from the familial unit to the external peer group. Consequently, securing peer acceptance becomes a paramount developmental directive, and distinct experiences of social marginalization or overt peer rejection constitute severe, often enduring psychological traumas. The reciprocal association continually observed between bullying victimization and subsequent bullying perpetration indicates that adolescents subjected to intense social rejection, crippling social anxiety, and forced social withdrawal frequently externalize their mounting internal distress through explosive, reactionary aggression (Sousa et al., 2024). This dangerous dynamic of painful rejection and subsequent violent retaliation operates fluidly across multiple modern ecologies. In standard offline environments, pervasive issues such as structural racism and targeted hate speech necessitate the urgent development of protective, multidimensional bystander responses; the tragic absence of such communal defense mechanisms actively fosters toxic environments rife with deep moral disengagement and unchecked hostility (Wachs et al., 2023). For historically marginalized minority and immigrant adolescents, generalized cultural stress and institutional discrimination serve as profound forms of systemic rejection, subsequently predicting exacerbated depressive symptoms alongside severe externalizing behaviors (Cano et al., 2015). Furthermore, the rapid advent of the modern digital era has exponentially expanded the existing landscape of adolescent social vulnerability. Excessive internet reliance, chronic social media addiction, and corresponding deteriorations in restorative sleep architecture now significantly mediate the complex relationship between unregulated digital exposure and overt, peer-directed aggressive behaviors (Lin et al., 2023). Endemic cyberbullying and persistent online vulnerability introduce unprecedented patterns of psychosocial risk, urgently requiring highly nuanced understandings of the protective factors necessary to effectively shield youth from digitally mediated social rejection (Heiman et al., 2014).

The complex etiopathology of adolescent aggressive behavior is manifestly non-linear, operating dynamically at

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the highly volatile intersection of intrinsic biological disposition, developing cognitive architecture, fluctuating familial stability, and precarious social integration. Historically, the vast majority of developmental psychological research has predominantly relied upon traditional linear regression frameworks to attempt to isolate and elucidate these incredibly complex behavioral relationships. While undoubtedly informative, standard linear and logistic models inherently and restrictively assume purely additive, entirely independent causal effects, thereby frequently failing to adequately capture the highly complex, higher-order synergistic interactions that truly define human behavior. For instance, the compounding catastrophic psychological effect of actively experiencing severe family chaos concurrently with profound social rejection—particularly in an adolescent heavily burdened by high trait anger and severely low executive neurocognitive inhibition—may vastly exceed the simple mathematical sum of these individual, isolated risks. To effectively overcome these deeply entrenched analytic limitations, the purposeful integration of advanced machine learning algorithms into the field of developmental psychopathology currently offers unprecedented analytical power. Gradient Boosted Trees, a highly robust ensemble machine learning methodology, operates elegantly by sequentially and methodically constructing a vast series of complex decision trees, with each successive tree precisely calibrated to identify and intelligently correct the residual predictive errors of its immediate predecessor. This iterative, non-parametric analytical approach profoundly excels at seamlessly capturing deep, multidimensional statistical interactions entirely without requiring any rigid, a priori mathematical specification by the investigating researcher.

Despite the extensive wealth of extant developmental literature rigorously examining isolated predictors of adolescent hostility, a critical, glaring paucity of applied research currently exists explicitly utilizing advanced machine learning techniques to simultaneously model the deeply non-linear interplay of core emotional, cognitive, familial, and peer-related variables. Addressing this substantial gap in the contemporary clinical literature absolutely requires a highly innovative methodological approach intrinsically capable of mathematically delineating these immensely complex behavioral risk profiles. Therefore, the singular aim of the present study is to rigorously predict and model adolescent aggressive behavior through the complex interactions of trait anger, executive function inhibition scores, family chaos, and social rejection via a Gradient Boosted Trees approach.

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, familial, and social variables in forecasting aggressive behavior among adolescents. The target population consisted of middle and high school students residing in various urban and semi-urban municipalities across central Mexico. Through a stratified cluster sampling technique, an exact sample of $n = 842$adolescents was successfully recruited and retained for the final analysis. The sample comprised individuals aged between 12and 17years, with an equitable distribution of biological sexes to ensure broad representativeness of the adolescent demographic in this region. Collaboration with local educational authorities facilitated access to the educational institutions. Written informed consent was obtained from the parents or legal guardians of all minor participants, while the adolescents themselves provided written assent. The sampling strategy accounted for socioeconomic diversity by selecting public and private schools from varying socioeconomic zones. Participants with diagnosed severe cognitive impairments or those who were actively experiencing acute psychiatric crises were excluded from the study to prevent confounding effects on the self-reported measures and cognitive assessments.

2.2. Measures

To comprehensively capture the variables under investigation, a battery of standardized, culturally validated psychometric instruments and cognitive tasks was administered to the adolescent sample. The primary outcome variable, aggressive behavior, was quantified using the Spanish-validated version of the Buss-Perry Aggression Questionnaire. This comprehensive self-report measure assesses multiple facets of aggression, yielding a composite score where higher values reflect elevated aggressive tendencies. Trait anger, functioning as a primary predictor, was evaluated utilizing the trait anger subscale of the State-Trait Anger Expression Inventory. This tool isolates the stable, chronic disposition to experience anger across various situations, irrespective of current emotional states. To assess executive function inhibition scores, participants

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completed a computerized version of the Stroop Color and Word Test, specifically tailored for adolescent populations. The inhibition score was calculated based on the interference effect, which represents the cognitive delay and error rate experienced when identifying the ink color of a semantically incongruent color word. Higher interference scores in this context denote lower inhibitory control capacities. The familial environment was evaluated using the Confusion, Hubbub, and Order Scale, which measures the degree of environmental disorganization, lack of routine, and general noise within the household, collectively conceptualized as family chaos. Finally, the construct of social rejection was measured via the Ostracism Experience Scale for Adolescents. This instrument probes the frequency and subjective distress associated with being ignored or excluded by peer groups, providing a robust metric of perceived social marginalization. All self-report questionnaires were administered via secure tablet devices in quiet classroom settings to minimize distractions and ensure data integrity.

2.3. Data Analysis

Given the anticipated nonlinear relationships and multifaceted interactions among trait anger, executive function inhibition, family chaos, and social rejection, a machine learning approach utilizing Gradient Boosted Trees was implemented to model aggressive behavior. The data preprocessing phase involved a meticulous examination of missing values. Because the missing data mechanism was determined to be missing at random and constituted less than 3%of the overall dataset, a multiple imputation technique using chained equations was employed to preserve the full sample size of $n = 842$. To mitigate the influence of differing measurement scales, all continuous predictor variables were standardized using Z-score normalization prior to model training. The dataset was subsequently partitioned into a training set, comprising 80%of the data, and a hold-out testing set, containing the remaining 20%. The Gradient Boosted Trees algorithm, specifically the XGBoost implementation, was selected due to its superior capability in handling complex tabular data and its inherent robustness against overfitting when appropriately tuned. Hyperparameter optimization was conducted on the training set using a randomized grid search coupled with a 10-fold cross-validation strategy. The hyperparameters tuned included the learning rate, the maximum depth of the decision trees, the subsample ratio of the training instances, and the minimum sum of instance weight needed in a child node. The predictive performance of the optimized model was then evaluated on the unseen testing set. The primary evaluation metrics utilized to quantify the model's accuracy and generalizability were the Root Mean Square Error, denoted as $RMSE$, the Mean Absolute Error, denoted as MAE, and the coefficient of determination, denoted as R^2. To enhance the interpretability of the machine learning model, SHapley Additive exPlanations values were calculated. These values provided a precise estimation of the individual and interactive contributions of trait anger, executive function inhibition, family chaos, and social rejection in driving the predictions of aggressive behavior, thereby elucidating the underlying psychological and environmental mechanisms captured by the algorithm. All computational analyses were executed utilizing the Python programming language, relying heavily on the scikit-learn and xgboost libraries.

3. Findings and Results

The initial phase of the data analysis focused on evaluating the descriptive statistics and bivariate relationships among the study variables for the sample of $n = 842$adolescents. Preliminary screening confirmed that the assumptions of normality were adequately met for the primary variables, allowing for the use of standard parametric correlational analyses before moving to the machine learning phase. The sample exhibited a diverse range of scores across all measures. Aggressive behavior, the primary outcome variable, demonstrated significant positive correlations with all predictor variables. Specifically, trait anger exhibited the strongest positive, bivariate relationship with aggressive behavior, suggesting that adolescents with a higher baseline disposition for anger also reported the highest levels of general aggression. Social rejection and family chaos also showed moderate-to-strong positive correlations with aggressive behavior. Furthermore, higher scores on the executive function inhibition task, which indicate poorer inhibitory control, were significantly and positively correlated with aggression, confirming that cognitive deficits in impulse control are linked to aggressive outcomes. The descriptive statistics, including means, standard deviations, and Pearson correlation coefficients for all primary variables, are presented in Table 1.

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Table 1

Descriptive Statistics and Bivariate Correlations for Study Variables

Variable	M	SD	1	2	3	4	5
1. Aggressive Behavior	48.35	12.41	–				
2. Trait Anger	22.14	6.58	$.58^{**}$	–			
3. Inhibition Score	34.12	8.95	$.34^{**}$	$.21^{**}$	–		
4. Family Chaos	28.67	7.33	$.41^{**}$	$.30^{**}$	$.18^{**}$	–	
5. Social Rejection	31.45	9.82	$.47^{**}$	$.35^{**}$	$.22^{**}$	$.38^{**}$	–

Following the preliminary analyses, the Gradient Boosted Trees model was trained and evaluated to predict aggressive behavior. The model's performance was rigorously assessed comparing the training set, comprising $n = 673$participants, against the hold-out testing set, comprising $n = 169$participants. The hyperparameter-tuned XGBoost model demonstrated robust predictive capabilities without exhibiting severe overfitting, as evidenced by the comparable metrics between the training and testing phases. The model accounted for a substantial proportion of the variance in adolescent aggressive behavior, achieving an $R^2$of 0.68on the unseen testing data. This indicates that 68%of the variance in aggressive behavior could be accurately predicted by the combined non-linear effects of trait anger, executive function inhibition, family chaos, and social rejection. The Root Mean Square Error and Mean Absolute Error further confirmed the model's accuracy, showing relatively low average prediction errors in the context of the aggressive behavior scale's total range. The specific performance metrics for both the training and testing datasets are detailed in Table 2.

Table 2

Gradient Boosted Trees Model Performance Metrics

Metric	Training Set (**80**%)	Testing Set (**20**%)
Root Mean Square Error ($\boldsymbol{RMSE}$)	5.12	6.84
Mean Absolute Error ($\boldsymbol{MAE}$)	3.89	4.95
Coefficient of Determination ($\boldsymbol{R^2}$)	.76	.68

To understand the specific drivers of the model's predictions, SHapley Additive exPlanations values were calculated to determine feature importance. Unlike traditional linear regression coefficients, SHAP values provide a localized measure of how much each feature contributes to pushing the model's prediction away from the base value for every single participant. The mean absolute SHAP values were aggregated to rank the overall importance of each predictor. Trait anger emerged as the most critical determinant of aggressive behavior, carrying the highest relative importance weight in the model. Social rejection was identified as the second most important predictor, highlighting the severe behavioral consequences of peer marginalization during adolescence. Family chaos and executive function inhibition scores also made substantial, distinct contributions to the model's accuracy, confirming that environmental instability and cognitive impulsivity are vital components of the predictive algorithm. Table 3 illustrates the mean absolute SHAP values and the relative percentage of importance for each predictor variable.

Table 3

Feature Importance of Predictor Variables Based on Mean Absolute SHAP Values

Predictor Variable	Mean Absolute SHAP Value	Relative Importance (%)
Trait Anger	4.85	42.6
Social Rejection	2.94	25.8
Family Chaos	2.11	18.5
Executive Function Inhibition	1.48	13.1

A primary advantage of utilizing the Gradient Boosted Trees algorithm is its inherent ability to map complex, non-linear interactions between variables without requiring them to be explicitly predefined. To extract and quantify these interactions, SHAP interaction values were computed. The analysis revealed significant synergistic effects among the psychological and environmental predictors. The most prominent interaction occurred between trait anger and executive function inhibition. Adolescents exhibiting high trait anger coupled with high inhibition scores, indicative of poor cognitive control, demonstrated disproportionately higher levels of aggressive behavior than would be expected by the additive effects of these variables alone. A secondary, highly impactful interaction was observed between social rejection and family chaos, indicating that adolescents experiencing high marginalization at school alongside high disorganization at home face a compounded risk for aggressive behavior. The top identified interaction pairs and their corresponding mean absolute SHAP interaction values are presented in Table 4.

Table 4

Top Pairwise Interactions Driving Aggressive Behavior Predictions

Interaction Pair	Mean Absolute SHAP Interaction Value	Rank
Trait Anger ×Executive Function Inhibition	1.25	1
Social Rejection ×Family Chaos	0.98	2
Trait Anger ×Social Rejection	0.74	3
Family Chaos ×Executive Function Inhibition	0.45	4

4. Discussion

The primary objective of the current study was to rigorously predict and model adolescent aggressive behavior through the complex, non-linear interactions of trait anger, executive function inhibition scores, family chaos, and social rejection utilizing a sophisticated Gradient Boosted Trees machine learning approach. The results derived from the optimized XGBoost algorithm revealed a highly robust predictive model, successfully accounting for 68%of the variance in adolescent aggressive behavior on the unseen testing dataset ($R^2 = 0.68$). The relatively low error metrics, specifically a Root Mean Square Error ($RMSE$) of 6.84and a Mean Absolute Error (MAE) of 4.95, underscore the algorithm's precision in forecasting behavioral outcomes across a diverse sample. Through the extraction of SHapley Additive exPlanations (SHAP) values, the model illuminated the hierarchical importance of the predictor variables, identifying trait anger as the most dominant risk factor, sequentially followed by social rejection, family chaos, and executive function inhibition. Furthermore, the analysis successfully quantified profound synergistic interactions, most notably between trait anger and executive function, as well as between social rejection and familial disorganization, fundamentally validating the premise that adolescent aggression emerges from a deeply compounded interplay of intrinsic and extrinsic vulnerabilities.

Consistent with theoretical expectations and prior empirical investigations, trait anger emerged as the most critical determinant of aggressive behavior in the machine learning model, accounting for the highest relative importance weight. This finding strongly aligns with contemporary psychological literature, which consistently demonstrates that a stable, underlying disposition toward anger and severe emotional dysregulation acts as the primary catalyst for externalized hostility in youth (Darmadi & Badayai, 2021; Gong & Popescu, 2024). Adolescents harboring high levels of trait anger typically exhibit profoundly low frustration tolerance, which directly precipitates impulsive and destructive reactions to daily stressors, frequently elevating the risk for both overt aggression and severe internalizing issues such as suicidal ideation (Cornejo-Babida, 2020). The potent role of trait anger in our predictive model is further contextualized by research indicating that youths with such dispositions often suffer from deficits in affective theory of mind, rendering them incapable of accurately processing social cues and leading to hostile attribution biases (Clifford et al., 2020). This volatile emotional reactivity is not confined to physical environments; it also permeates modern digital domains, where acute frustration rapidly translates into aggressive behavior during online interactions and gaming (Nugroho & Reza, 2022). Consequently, the overwhelming predictive weight of trait anger in our model corroborates the critical necessity of targeted behavioral interventions, such as cognitive behavior-anger management therapies, which have been proven to effectively mitigate hostile dispositions

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by restructuring maladaptive emotional processing (Sari et al., 2022; Sukhodolsky et al., 2016).

Social rejection was identified as the second most impactful predictor of aggressive behavior, highlighting the devastating behavioral consequences of peer marginalization during the sensitive developmental window of adolescence. This result robustly supports previous models illustrating a reciprocal, escalating cycle where bullying victimization, forced social withdrawal, and intense social anxiety directly precipitate reactive, aggressive externalizations as a maladaptive coping mechanism (Sousa et al., 2024). The psychological trauma associated with peer rejection is frequently compounded by a lack of protective social scaffolding; for instance, the absence of multidimensional, empathetic bystander interventions allows hostile environments to flourish, thereby normalizing aggression and moral disengagement among socially marginalized youth (Wachs et al., 2023). Furthermore, experiences of social rejection often intersect with broader systemic marginalization, such as the cultural stress and institutional discrimination faced by minority and immigrant adolescents, which significantly amplifies both depressive symptomatology and externalizing behavioral problems (Cano et al., 2015). The modern manifestation of social rejection heavily involves the digital landscape, where social media addiction, cyber-victimization, and subsequent sleep deterioration serve as potent mediators linking chronic online vulnerability to real-world aggressive outbursts (Heiman et al., 2014; Lin et al., 2023). The substantial SHAP value attributed to social rejection in our algorithm underscores that perceived isolation and peer-level hostility are not merely transient developmental hurdles, but foundational drivers of serious conduct pathology.

The environmental context, specifically quantified as family chaos, emerged as a highly significant predictor, confirming that structural disorganization within the home critically undermines adolescent behavioral regulation. This finding is deeply consistent with studies demonstrating that chaotic, highly stressed familial environments—such as those frequently observed in unsupported single-parent households—can inadvertently foster both passive and overt aggressive behaviors due to chronic systemic instability (Fauziah et al., 2023). The profound impact of the family unit is largely mediated by parental treatment and the specific emotional socialization practices modeled by caregivers, which intrinsically dictate the psychosocial adjustment trajectories of developing youth (McQuade & Breaux, 2017; Mohammed, 2023). Furthermore, the stress generated by severe family chaos frequently interacts with underlying genetic vulnerabilities, disrupting healthy emotional attachment and significantly increasing the likelihood that an adolescent will direct hostile behavior toward parental figures (Zimmermann & Spangler, 2016). It is also crucial to acknowledge that assessments of aggressive behavior stemming from chaotic environments are subject to longitudinal discrepancies and reporter biases, emphasizing the complex, multifaceted nature of observing conduct issues within disorganized homes (Yang et al., 2021). By mathematically capturing the weight of family chaos, our model affirms that environmental predictability and structured familial support are absolutely essential buffers against the manifestation of delinquent behaviors.

Executive function inhibition, while ranking fourth in individual relative importance, played a vital role in the predictive accuracy of the model, particularly through its complex interactions with affective states. Poorer inhibitory control, represented by higher interference scores, fundamentally prevents an adolescent from overriding prepotent hostile impulses. This aligns seamlessly with structural equation modeling demonstrating that low self-control, poor self-regulation, and impaired decision-making styles—all core components of executive functioning—are fundamentally correlated with elevated aggression (Kaveh et al., 2025; Zhang et al., 2023). Effective prosocial behavior heavily relies on advanced social information processing and moral cognition, cognitive domains that are severely compromised in youths lacking basic inhibitory control (Laible et al., 2014). Because executive dysfunction removes the cognitive brakes on aggressive impulses, specialized clinical interventions targeting these precise neurological deficits are paramount. Feasibility studies on mentalization-based treatments, specialized somatic mindfulness techniques (such as meditation on the soles of the feet), and immersive psychodrama have all shown significant promise in actively rehabilitating executive oversight and subsequently reducing destructive behaviors in highly dysregulated and neurodivergent populations (Ahemaitijiang et al., 2020; Braithel & Allaouna, 2025; Hauschild et al., 2023).

The most profound advantage of employing the Gradient Boosted Trees algorithm was its ability to extract SHAP interaction values, which revealed that the comorbidity of these risk factors generates a synergistic exacerbation of aggressive behavior. The strongest interaction was observed between trait anger and executive function inhibition. This indicates that the combination of a highly reactive emotional

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disposition and a paralyzed cognitive braking system results in levels of aggression that far exceed the simple additive effects of either variable alone, shedding light on the complex biological and neurological pathomechanisms that often underlie severe conduct and explosive disorders (Chiocchetti et al., 2022; Radwan & Coccaro, 2020). A secondary, highly critical interaction was noted between social rejection and family chaos, suggesting that adolescents who are simultaneously alienated by their peers and deprived of a stabilizing home environment face a compounded, catastrophic risk for severe affective-behavioral disorders (Shalchi et al., 2017). These non-linear interactions powerfully validate the necessity of holistic, multi-domain conceptualizations of developmental psychopathology.

Despite the methodological rigor and advanced analytical techniques employed in this study, several important limitations must be acknowledged. First, the research utilized a cross-sectional design, which inherently precludes the establishment of definitive causal relationships between the predictor variables and aggressive behavior. While the machine learning model demonstrates high predictive accuracy, it captures a single snapshot in time, preventing an understanding of how these variables dynamically influence one another across the entire developmental span of adolescence. Second, the reliance on self-report measures for quantifying trait anger, social rejection, and aggressive behavior introduces the potential for common method bias and social desirability effects. Adolescents may underreport the severity of their aggressive actions or overstate their experiences of victimization due to defensive psychological mechanisms. Finally, while the sample was stratified to ensure representation across urban and semi-urban Mexican municipalities, the specific cultural and socioeconomic idiosyncrasies of this demographic may limit the generalizability of the Gradient Boosted Trees model to youth populations in vastly different global or cultural contexts.

To address these limitations and further advance the field of developmental psychopathology, future research should prioritize longitudinal study designs. Tracking cohorts of adolescents over several years would allow researchers to mathematically model the temporal precedence of changes in family chaos, social peer dynamics, and executive functioning, thereby mapping the precise developmental trajectories of aggressive behavior. Additionally, future investigations should strongly consider integrating objective, multimodal data sources to supplement self-report questionnaires. Incorporating functional neuroimaging to directly measure prefrontal cortex activation during inhibition tasks, alongside continuous physiological monitoring of autonomic nervous system reactivity during induced stress paradigms, would provide a much deeper, biologically grounded understanding of the trait anger-executive function interaction identified in our model. Finally, researchers should apply similar machine learning architectures to diverse, cross-cultural datasets to test the universality of these predictive algorithms and to identify specific demographic or cultural variables that might naturally moderate the impact of social rejection and family disorganization on youth hostility.

The findings of this study yield several critical, actionable suggestions for clinical practice and educational policy. Given that the interaction between trait anger and poor executive inhibition is the primary driver of explosive aggression, schools and pediatric clinical settings must implement multi-tiered screening protocols to identify youths exhibiting this specific dual vulnerability early in their development. Interventions should pivot away from purely punitive disciplinary models and instead adopt structural, cognitive-behavioral skills training designed to directly enhance emotional regulation and strengthen neurocognitive inhibitory control. Furthermore, because family chaos and social rejection interact synergistically to compound risk, therapeutic approaches cannot operate in isolation. Practitioners must engage in holistic, wrap-around care that simultaneously involves family therapy to establish predictable, structured home environments, alongside targeted school-based social skills groups designed to foster peer inclusion and fundamentally dismantle the toxic dynamics of bullying and marginalization. By addressing both the internal cognitive-emotional deficits and the external environmental stressors, mental health professionals can more effectively disrupt the complex pathways leading to adolescent violence.

5. Conclusion

In conclusion, the findings of this study unequivocally demonstrate that adolescent aggressive behavior cannot be attributed to a single, isolated risk factor; rather, it emerges from the complex, non-linear interplay of individual psychological traits, environmental influences, and adverse social experiences. By systematically evaluating the combined effects of trait anger, executive function inhibition, family chaos, and social rejection, this research

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provides a comprehensive map of the multifaceted etiology of youth hostility. The utilization of an advanced Gradient Boosted Trees machine learning approach was instrumental in elucidating these intricate, synergistic relationships, particularly revealing how intrinsic emotional reactivity and cognitive deficits compound external familial and peer-related stressors. Ultimately, by illuminating the deeply compounded nature of these risk architectures, this study provides a more holistic understanding of developmental psychopathology and strongly underscores the critical necessity for integrated, multi-domain clinical and educational interventions to effectively prevent and treat aggressive behavior in adolescents.

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,

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the massive prominence of physiological hyperarousal in the network's predictive model dictates that traditional, purely 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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