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Predicting Adolescent Emotional Problems From Parenting Styles, Family Functioning, and Parent–Child Communication Using LightGBM

Wei Jie. Lim[1], Julien. Dupont[2*], Aigerim. Sadykova[3]

[1] Department of Organizational Psychology, Universiti Putra Malaysia, Serdang, Malaysia
[2] Department of Neuropsychology, University of Bordeaux, Bordeaux, France
[3] Department of Applied Psychology, Al-Farabi Kazakh National University, Almaty, Kazakhstan

*** Corresponding author email address**: julien.dupont@u-bordeaux.fr

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A B S T R A C T

Objective: This study aimed to develop and interpret a Light Gradient Boosting Machine (LightGBM) model for predicting adolescent emotional problems from authoritative, authoritarian, and permissive parenting styles, family functioning, and parent–child communication.

Methods and Materials: A cross-sectional predictive study was conducted among 742 adolescents aged 12–17 years (M = 14.63, SD = 1.61) recruited from secondary schools across five regions of France using multistage cluster sampling. Emotional problems were assessed using the Emotional Symptoms subscale of the Strengths and Difficulties Questionnaire, parenting styles using the Parental Authority Questionnaire, family functioning using the General Functioning subscale of the McMaster Family Assessment Device, and parent–child communication using the Parent–Adolescent Communication Scale. The sample was randomly divided into a training set (n = 594) and an independent holdout test set (n = 148). Five-fold cross-validation was used for LightGBM hyperparameter optimization. Predictive performance was evaluated using R^2, root mean squared error (RMSE), and mean absolute error (MAE), and model performance was compared with XGBoost, Random Forest, and Elastic Net regression. SHapley Additive exPlanations (SHAP) were used to interpret feature importance and direction.

Findings: LightGBM demonstrated stable cross-validated performance, with a mean R^2 of .623, RMSE of 1.47, and MAE of 1.12. In the independent holdout sample, the model explained 63.8% of the variance in emotional-problem scores (R^2 = .638, RMSE = 1.44, MAE = 1.10), outperforming XGBoost (R^2 = .609), Random Forest (R^2 = .572), and Elastic Net regression (R^2 = .506). SHAP analysis identified family dysfunction as the strongest predictor, followed by problematic parent–child communication, open communication, authoritarian parenting, authoritative parenting, and permissive parenting. Higher family dysfunction, problematic communication, and authoritarian parenting were associated with higher predicted emotional problems, whereas open communication and authoritative parenting showed protective predictive patterns.

Conclusion: LightGBM provided strong and interpretable prediction of adolescent emotional problems, highlighting family functioning and parent–child communication as especially influential family-level predictors.

Keywords: *adolescent emotional problems; LightGBM; parenting styles; family functioning; parent–child communication; machine learning; SHAP*

1. Introduction

Adolescence is a developmental period characterized by substantial biological, cognitive, emotional, and interpersonal transformations that can increase vulnerability to emotional difficulties while simultaneously creating opportunities for the development of adaptive regulatory capacities. Emotional problems during adolescence commonly include persistent sadness, anxiety, excessive worry, fearfulness, emotional withdrawal, low mood, irritability, and difficulty coping with stressful experiences. Although some emotional fluctuation is expected during this developmental stage, persistent emotional symptoms can disrupt academic functioning, peer relationships, identity development, health behavior, and family relationships. The increasing recognition of adolescent emotional problems as a major public health concern has therefore shifted research attention toward identifying not only individual vulnerabilities but also relational and contextual factors that can be targeted through prevention and early intervention. Reviews of adolescent adjustment increasingly indicate that psychological outcomes cannot be understood adequately without examining the wider family system within which adolescents develop. Family relationships, caregiving processes, exposure to adversity, and the availability of relational resources may either intensify psychological vulnerability or protect adolescents from the effects of stress and adversity (Campione-Barr et al., 2024; Fatmasari et al., 2026). Research on children and adolescents exposed to trauma and other adverse conditions likewise demonstrates that resilience is strongly influenced by interpersonal and environmental resources rather than being exclusively an individual characteristic (Yoon et al., 2025).

The importance of the family environment is particularly evident because parents typically remain among the most influential socialization agents throughout adolescence, even as adolescents become increasingly autonomous and peer-oriented. Family processes contribute to the development of emotional regulation, beliefs about interpersonal safety, coping strategies, self-evaluation, and expectations regarding the availability of support. Attachment-oriented perspectives propose that repeated interactions with caregivers contribute to internal representations of the self and others and thereby influence emotional security, affect regulation, and responses to stressful situations. Family relationships that provide a stable and responsive secure base may facilitate emotional exploration and adaptive regulation, whereas inconsistent, rejecting, intrusive, or emotionally inaccessible relationships may increase vulnerability to internalizing symptoms (George & Aikins, 2023). Meta-analytic evidence concerning parental emotion socialization and parent–child attachment further indicates that parental responses to children's emotions are closely associated with attachment security, highlighting the importance of emotionally responsive parenting for developmental adjustment (Rodrigues et al., 2025). These mechanisms suggest that adolescent emotional problems are likely to be related not to one isolated parenting behavior but to broader configurations of parenting style, family functioning, and communication.

Parenting style represents a relatively stable pattern of parental attitudes and behaviors that provides an emotional climate for parent–child interactions. Classical parenting frameworks distinguish authoritative, authoritarian, and permissive patterns. Authoritative parenting is generally characterized by warmth, responsiveness, behavioral expectations, monitoring, and developmentally appropriate autonomy. Authoritarian parenting places stronger emphasis on obedience, control, punitive discipline, and unilateral parental authority, whereas permissive parenting typically involves high acceptance accompanied by relatively weak behavioral demands, monitoring, or structure. These distinctions are developmentally meaningful because parenting styles shape the adolescent's experience of emotional support, behavioral boundaries, self-expression, and autonomy. Bioecological perspectives on adolescent risk emphasize that parenting contributes to developmental cascades through which early family processes interact with individual characteristics and broader environments to influence later behavioral and psychological outcomes (Marceau, 2023). Parenting should therefore be understood as a dynamic developmental context rather than merely a set of discrete disciplinary practices.

Supportive and structured parenting may reduce emotional vulnerability by providing adolescents with predictable boundaries while preserving emotional availability and opportunities for autonomous decision-making. In contrast, psychologically controlling, harsh, rejecting, or excessively restrictive parenting may increase emotional distress by interfering with autonomy development and communicating conditional acceptance. Evidence from clinical populations is consistent with this proposition. A large-scale study of adolescents with depression demonstrated associations between parental rearing styles and suicidal ideation, indicating that

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maladaptive parenting experiences may remain clinically relevant even after substantial emotional disturbance has developed (Liu et al., 2025). Recent research examining bidirectional pathways between parent–child interaction and adolescent depression and suicidality similarly emphasizes that family relationships can operate both as determinants and consequences of adolescent psychological distress (Han et al., 2026). The possibility of reciprocal effects is particularly important during adolescence because psychological symptoms may alter adolescents' communication patterns and parental responses, thereby creating escalating cycles of conflict, withdrawal, and emotional distress.

Parenting also occurs within the broader organization of family life. Family functioning refers to the effectiveness with which a family manages emotional involvement, communication, roles, problem solving, behavioral expectations, and responses to developmental or situational demands. A well-functioning family is generally able to adapt to stress, maintain supportive relationships, negotiate responsibilities, and resolve disagreements while preserving emotional connection. Dysfunctional family environments, in contrast, may be characterized by unresolved conflict, rigid or chaotic roles, low emotional responsiveness, poor problem-solving capacity, and ineffective communication. Adolescents' subjective appraisals of these processes are especially important because the psychological effect of the family environment depends partly on how young people interpret family relationships and their position within them. A recent scoping review of adolescents' appraisals of relationships in intact families underscores the multidimensional nature of family relationship quality and the importance of considering adolescents' own perspectives rather than relying exclusively on structural definitions of family status (Fatmasari et al., 2026).

Family functioning becomes particularly salient when families encounter stress or adversity. During the COVID-19 pandemic, family cohesion, emotional responsiveness, conflict patterns, and the quality of parent–child relationships were consistently implicated in adolescent developmental and psychological adjustment (Campione-Barr et al., 2024). Research examining family processes during periods of crisis similarly suggests that adaptive family interactions can protect the psychological well-being of both mothers and children, whereas dysfunctional patterns may magnify the effects of external stress (Gong et al., 2025). Constructive management of interparental disagreement may also matter for children's psychological outcomes. A synthesis of research on constructive interparental conflict indicates that disagreements do not inevitably damage children; rather, constructive resolution, emotional security, and exposure to effective problem solving can influence how interparental conflict affects development (Zhang & Wu, 2026). Thus, the family system can transmit risk when interactions are chronically hostile or unpredictable, but it can also operate as a resilience-promoting environment.

The importance of family functioning is further demonstrated in families coping with severe health-related or psychosocial stressors. Parents caring for children with neurodevelopmental disorders may experience substantial psychological burdens, which can influence the emotional climate of caregiving and family functioning (Agyapong-Opoku et al., 2026). Parents whose children have experienced stroke similarly describe extensive emotional, relational, and caregiving challenges, showing how childhood health problems can reorganize family life and parental well-being (Bhatia et al., 2025). Families of young people living with chronic illnesses face additional demands related to self-management, treatment adherence, autonomy, and communication. Research on diabetes self-management among Latino youth identifies family and contextual barriers as important determinants of adolescents' ability to engage successfully in health-related behavior (Lucca et al., 2025), while work on disordered eating among children and adolescents with type 1 diabetes emphasizes the need to understand developmentally specific psychological and family challenges (Giannakopoulos et al., 2026). These findings reinforce the broader proposition that adolescent emotional functioning is embedded in ongoing family processes.

Parent–child communication represents one of the principal mechanisms through which parenting and broader family functioning are translated into adolescents' daily experiences. Open communication allows adolescents to express concerns, seek emotional assistance, disclose difficult experiences, negotiate independence, and receive guidance. Communication characterized by criticism, invalidation, avoidance, ambiguity, or low emotional responsiveness may have the opposite effect, reducing adolescents' willingness to seek parental support and potentially increasing emotional isolation. Communication processes become especially important when adolescents experience stressful or traumatic events. A systematic review of parent–child communication concerning potentially traumatic experiences found that how parents and

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children discuss adversity can influence children's understanding, emotional processing, and adjustment (Sloover et al., 2023). Similarly, research examining triadic communication with teenagers and young adults with cancer emphasizes young people's desire to be directly included in conversations concerning their own lives rather than being treated as peripheral participants in adult-centered communication (Critoph et al., 2024). These findings illustrate that communication quality is not simply a relational preference but a developmental resource associated with agency, emotional validation, and coping.

Family communication may be especially consequential when adolescents encounter emotional disorders. Parents of adolescents experiencing depression describe considerable difficulty recognizing symptoms, initiating supportive conversations, managing changes in family relationships, and balancing protection with respect for adolescents' autonomy (Kika et al., 2026). Interventions that strengthen emotional communication within families may consequently contribute to improved adjustment. Emotion-focused family therapy, including adaptations delivered virtually, provides one example of approaches that seek to strengthen caregiver responsiveness and improve family members' ability to recognize and respond constructively to emotional needs (Smith et al., 2023). Relationship-focused interventions directed toward parents may also produce benefits extending beyond the couple relationship itself. Multi-informant evidence on relationship education suggests that improvements in adult relationship processes may be associated with outcomes relevant to children, illustrating the interconnected nature of family subsystems (Kanter et al., 2025).

The potential protective role of communication and family support also emerges across populations experiencing serious psychosocial adversity. Protective factors among children of parents with mental illness frequently include supportive relationships, appropriate information about the parent's condition, adaptive coping resources, and stable environments (Schoors et al., 2023). Children and partners of military personnel or veterans with combat-related physical injuries may experience significant mental health challenges, demonstrating how parental health and trauma can affect the entire family system (Solomon et al., 2022). When a parent has terminal cancer, dependent children may experience fear, uncertainty, anticipatory grief, and altered family roles, making developmentally appropriate communication and emotional support particularly important (Wray et al., 2022). Young carers who assume substantial responsibilities for relatives similarly encounter complex emotional and developmental burdens, often requiring support that acknowledges the interaction between caregiving roles, family relationships, and psychological well-being (Saragosa et al., 2022). Collectively, these literatures indicate that family functioning and communication remain relevant across highly diverse forms of adversity.

The relational ecology of adolescent adjustment extends beyond the parent–child dyad. Siblings, grandparents, and other caregivers may provide additional sources of emotional security and social support. A scoping review of sibling support among transgender and gender-diverse youth identified siblings as potentially meaningful sources of affirmation, belonging, and protection in contexts where young people may encounter stress or rejection (Klepper et al., 2024). Grandparental care has likewise received growing attention as family arrangements become increasingly diverse, with systematic evidence indicating associations between grandparental caregiving and child mental health that depend on caregiving context and family circumstances (Wang et al., 2024). These findings support a systemic view in which adolescents' emotional outcomes emerge from interconnected family relationships rather than from isolated parent behaviors.

Families also vary in their capacity to protect young people exposed to trauma, illness, maltreatment, or other major stressors. Research on multisystemic resilience among children with attention-deficit/hyperactivity disorder indicates that resilience outcomes are linked to protective factors operating across individual, family, peer, school, and broader environmental levels (Cheung et al., 2026). Similarly, young people living in out-of-home care often experience multiple cumulative risk factors for suicidal behavior, while supportive relationships and effective interventions may provide important protection (Modderman et al., 2026). Adolescent suicide research conducted in the context of the COVID-19 pandemic has further demonstrated the interrelationship of bullying, psychological distress, social adversity, family circumstances, and prevention needs (Pérez-Jiménez et al., 2026). Longitudinal research on online child sexual abuse likewise indicates that adverse experiences may have enduring developmental implications, reinforcing the need to identify relational environments capable of buffering emotional harm (Prijatelj, 2026). Such evidence supports models in which family-level protective processes may alter the developmental consequences of environmental risk.

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Conversely, severe family conflict may itself represent an important marker of relational dysfunction. Child-to-parent violence represents an especially serious manifestation of deteriorated family relationships, with a recent systematic review identifying interacting individual, parental, relational, and contextual predictors (Mendes et al., 2026). Such findings indicate that parenting, communication, and family functioning cannot always be conceptualized as independent predictors; rather, they may interact in complex ways. For example, an authoritarian parenting pattern may be particularly detrimental within a family characterized by weak communication and low cohesion, whereas high parental behavioral expectations may function differently when accompanied by warmth and open communication. The psychological meaning of a parenting practice therefore depends on the surrounding relational context. This complexity raises methodological challenges for conventional statistical models based primarily on linear, additive relations.

Parental psychological stress may also shape the association between parenting processes and adolescent emotional adjustment. A systematic review and meta-analysis found that parental stress is associated with emotional and behavioral problems among offspring, providing evidence that caregiver well-being constitutes an important component of children's developmental environments (Ribas et al., 2024). Parents experiencing chronic distress may have fewer emotional resources available for sensitive communication, consistent discipline, or supportive responses to adolescents' needs. In families affected by childhood cancer, the psychological impact of genetic testing illustrates how uncertainty and health-related information may produce emotional consequences for children and family members (Hoyweghen et al., 2023). Similarly, research on health-related quality of life among children with cancer demonstrates that psychological, social, and functional concerns extend beyond medical outcomes and require attention to the child's lived relational environment (Rothmund et al., 2022). These observations highlight the need for analytic approaches capable of integrating multiple overlapping dimensions of family functioning.

Traditional approaches to studying adolescent emotional problems have relied heavily on correlation, multiple linear regression, logistic regression, and structural equation modeling. These methods remain valuable for testing theoretically specified associations and estimating interpretable parameters. Nevertheless, family processes may involve nonlinearity, threshold effects, higher-order interactions, and complex combinations of protective and risk factors that are difficult to represent using conventional parametric models without extensive a priori specification. The same level of authoritarian parenting, for example, may have different implications depending on whether family functioning is high or low, whether communication is open or problematic, and whether authoritative parenting characteristics are simultaneously present. The accumulation of several modest relational risks may also become clinically meaningful only after a threshold has been crossed. A predictive framework should therefore accommodate complex functional forms rather than assuming that each predictor contributes independently and linearly to emotional problems.

Machine-learning methods provide a complementary framework for addressing these issues. Unlike traditional explanatory models that primarily estimate prespecified parameters, supervised machine-learning algorithms optimize predictive performance by learning patterns directly from multidimensional data. Gradient boosting is particularly suitable for structured psychosocial datasets because it can accommodate nonlinear relationships, interactions, heterogeneous predictor effects, and variables measured on different scales. Light Gradient Boosting Machine, or LightGBM, is an efficient gradient-boosted decision-tree algorithm that sequentially combines weak decision trees to minimize prediction error. Its leaf-wise tree-growth strategy can capture complex patterns efficiently, while regularization and validation procedures can reduce overfitting. Importantly, contemporary model-interpretability techniques such as SHapley Additive exPlanations can be used alongside LightGBM to quantify the relative contribution and direction of individual predictors, thereby reducing concerns that machine-learning models necessarily function as uninterpretable “black boxes.”

Applying LightGBM to adolescent emotional problems is particularly relevant because parenting styles, family functioning, and parent–child communication contain conceptually overlapping but nonredundant information. Parenting styles describe the broader climate of parental authority, responsiveness, and control; family functioning describes the effectiveness of the family system; and communication reflects the quality of information exchange and emotional dialogue between parent and adolescent. Examining these domains simultaneously permits an integrated assessment of relational risk and protection.

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Moreover, variable-importance and SHAP analyses can identify which family characteristics contribute most strongly to predictions and whether high or low levels of specific factors are associated with increased predicted emotional problems. This information may have practical significance because family-based prevention programs often require prioritization of modifiable factors.

The family literature strongly supports such an integrated predictive approach. Across normative families, clinical populations, chronic illness, trauma exposure, caregiving adversity, and major family stress, supportive relationships repeatedly emerge as central determinants of adaptation. Families may protect adolescents through emotional responsiveness, coherent routines, constructive conflict management, communication, and relational security, while dysfunction, harsh parenting, parental distress, and chronic communication difficulties may contribute to emotional vulnerability. Yet relatively few studies integrate multiple family domains using algorithms designed specifically to maximize individual-level prediction. A model that identifies adolescents at elevated risk on the basis of relational characteristics could complement traditional etiological research and provide a foundation for targeted screening, although prediction should never substitute for comprehensive clinical assessment.

Accordingly, the aim of the present study was to develop and interpret a LightGBM model for predicting adolescent emotional problems from authoritative, authoritarian, and permissive parenting styles, general family functioning, and open and problematic parent–child communication among adolescents in France.

2. Methods and Materials

2.1. Study Design and Participants

The present study employed a cross-sectional predictive design to examine the extent to which parenting styles, family functioning, and parent–child communication could predict emotional problems among adolescents using the Light Gradient Boosting Machine algorithm. Participants were recruited from public and private secondary schools in Île-de-France, Auvergne-Rhône-Alpes, Nouvelle-Aquitaine, Occitanie, and Hauts-de-France to increase socioeconomic and geographical heterogeneity within the sample. A multistage cluster sampling procedure was used in which schools were initially selected from participating educational districts, classes were subsequently sampled within schools, and all eligible adolescents in selected classes were invited to participate. Eligibility criteria included being between 12 and 17 years of age, current enrollment in a participating secondary school, sufficient proficiency in French to understand the questionnaires, and provision of adolescent assent together with written parental or legal-guardian consent. Adolescents with severe cognitive or developmental impairment that prevented independent completion of the self-report instruments were excluded. Of 789 adolescents initially invited, 759 returned consent materials and participated. Seventeen cases were excluded because more than 20% of questionnaire responses were missing, resulting in a final analytic sample of 742 adolescents. Participants ranged in age from 12 to 17 years, with a mean age of 14.63 years (SD = 1.61). Data collection was conducted during scheduled school periods in quiet classroom settings under the supervision of trained research assistants. Participation was voluntary, responses were confidential, and adolescents were informed that they could discontinue participation without penalty. The research procedures were conducted in accordance with the principles of the Declaration of Helsinki and applicable French regulations concerning research with minors. Questionnaires were administered anonymously using participant codes, and no identifying information was incorporated into the analytic dataset.

2.2. Measures

Strengths and Difficulties Questionnaire—Emotional Symptoms Subscale. Adolescent emotional problems were assessed using the Emotional Symptoms subscale of the self-report Strengths and Difficulties Questionnaire developed by Goodman. The SDQ is a widely used measure of psychological adjustment among children and adolescents, and its self-report form is suitable for young people in the age range included in the present study. The Emotional Symptoms subscale consists of five items assessing experiences such as worry, unhappiness, nervousness, fearfulness, and somatic complaints associated with emotional distress. Each item is rated on a three-point response scale ranging from 0 to 2, producing a subscale score ranging from 0 to 10, with higher scores reflecting greater emotional difficulties. The emotional symptoms score was treated as a continuous outcome in the machine-learning analysis because continuous prediction retained the full variability of symptom severity and avoided information loss associated with arbitrary dichotomization. The SDQ has been translated and validated across numerous cultural

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contexts, including European populations, and has demonstrated satisfactory construct validity and reliability for assessing adolescent emotional and behavioral functioning. In the present sample, internal consistency of the Emotional Symptoms subscale was acceptable, with Cronbach's α = .81.

Parental Authority Questionnaire. Parenting styles were assessed using the Parental Authority Questionnaire developed by Buri. The instrument was designed to operationalize Baumrind's authoritative, authoritarian, and permissive parenting typology from the offspring's perspective. It contains 30 items divided into three 10-item subscales measuring authoritative, authoritarian, and permissive parenting. Respondents indicate the extent to which each statement characterizes parental behavior using a five-point Likert-type scale ranging from 1 (strongly disagree) to 5 (strongly agree). Each subscale therefore produces scores ranging from 10 to 50, with higher scores indicating a stronger perception of the corresponding parenting style. Authoritative parenting reflects warmth combined with clear expectations and rational guidance; authoritarian parenting reflects high control, obedience demands, and relatively limited reciprocal negotiation; and permissive parenting reflects warmth or acceptance accompanied by comparatively low behavioral demands and control. The PAQ has been used extensively in research examining parenting and adolescent adjustment and has demonstrated acceptable factorial validity, internal consistency, and construct validity. The French-language items were administered using established translation procedures, and scale scores were calculated only when at least 80% of the relevant items were completed. Cronbach's α values in the present study were .88 for authoritative parenting, .86 for authoritarian parenting, and .78 for permissive parenting.

McMaster Family Assessment Device—General Functioning Subscale. Overall family functioning was assessed using the 12-item General Functioning subscale of the McMaster Family Assessment Device. The FAD is grounded in the McMaster Model of Family Functioning and evaluates patterns through which families manage daily tasks, emotional relationships, behavioral expectations, and interpersonal demands. The General Functioning subscale provides a global assessment of healthy versus problematic family functioning using items addressing mutual acceptance, emotional support, communication, problem solving, and the overall effectiveness of family relationships. Items are rated on a four-point scale from 1 (strongly agree) to 4 (strongly disagree), with positively worded items reverse-coded so that higher scores indicate poorer family functioning. The mean of completed items was used as the total score, yielding a theoretical range from 1 to 4. The General Functioning scale has demonstrated strong convergent validity, discriminant validity, and internal consistency in community and clinical family research. In the present sample, Cronbach's α was .90, indicating high internal consistency.

Parent–Adolescent Communication Scale. Parent–child communication was measured using the Parent–Adolescent Communication Scale developed by Barnes and Olson. The 20-item scale assesses adolescents' perceptions of the quality of communication with their parents and includes two conceptually distinct dimensions: Open Family Communication and Problems in Family Communication. Open communication reflects freedom of expression, mutual understanding, emotional accessibility, trust, and the perceived ability to discuss concerns with parents. Problems in communication reflect hesitation, selective disclosure, misunderstandings, negative exchanges, and barriers that interfere with effective parent–adolescent dialogue. Items are rated on a five-point Likert scale from 1 (strongly disagree) to 5 (strongly agree). After appropriate reverse scoring, separate scores were calculated for open communication and communication problems, with higher values representing higher levels of the measured construct. The PACS has been applied widely in studies of adolescent adjustment and family relationships and has demonstrated satisfactory factorial structure, criterion validity, and reliability. In the present study, Cronbach's α was .91 for Open Family Communication and .87 for Problems in Family Communication.

2.3. Data Analysis

Data analysis was conducted using Python with the pandas, NumPy, scikit-learn, LightGBM, and SHAP libraries. Before model development, the dataset was screened for invalid values, missingness, implausible response patterns, and univariate distributions. Cases with more than 20% missing questionnaire data had already been excluded. Remaining item-level missing values represented less than 2% of observations and were handled through median imputation performed within the training data to prevent information leakage. Descriptive statistics, including means, standard deviations, observed ranges, skewness, kurtosis, and reliability coefficients, were

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calculated for all study variables. Pearson correlations were examined as preliminary descriptive associations but were not used as a feature-selection criterion because tree-based gradient-boosting algorithms can extract predictive information from correlated and potentially interacting predictors.

The final predictor set consisted of authoritative parenting, authoritarian parenting, permissive parenting, general family dysfunction, open parent–child communication, and problematic parent–child communication. Emotional problems constituted the continuous target variable. The complete sample of 742 adolescents was randomly divided into a training set comprising 80% of participants (n = 594) and an independent holdout test set comprising 20% (n = 148). The split was performed using a fixed random seed to ensure reproducibility. Hyperparameter optimization was conducted only within the training sample using five-fold cross-validation. Parameters considered during tuning included number of estimators, learning rate, maximum tree depth, number of leaves, minimum number of observations per leaf, feature subsampling, row subsampling, and L1 and L2 regularization. The optimized LightGBM model used a learning rate of .035, 420 estimators, 24 leaves, maximum depth of 6, minimum child samples of 24, feature fraction of .85, bagging fraction of .88, L1 regularization of .10, and L2 regularization of .35. Early-stopping procedures were incorporated during tuning where applicable.

Predictive accuracy was evaluated using the coefficient of determination (R^2), root mean squared error (RMSE), and mean absolute error (MAE). R^2 represented the proportion of variance in emotional-problem scores explained by out-of-sample predictions, whereas RMSE and MAE quantified prediction error in the original SDQ Emotional Symptoms metric. To contextualize LightGBM performance, the holdout results were compared with Elastic Net regression, Random Forest regression, and XGBoost regression models trained using the same predictors and data partition. Comparative algorithms were evaluated using identical holdout observations. Model interpretation was conducted using SHapley Additive exPlanations. Mean absolute SHAP values were used to rank global predictor importance, while the sign and distribution of SHAP values were examined to determine whether higher predictor values tended to increase or decrease predicted emotional-problem scores. Partial patterns evident in SHAP dependence were also inspected for nonlinearities and threshold-like effects. All descriptive inferential analyses used two-tailed criteria with $p < .05$ where applicable, although evaluation of machine-learning performance was based principally on out-of-sample predictive metrics rather than null-hypothesis significance testing.

3. Findings and Results

The final sample consisted of 742 adolescents aged 12 to 17 years (M = 14.63, SD = 1.61). Of the participants, 382 (51.5%) identified as girls, 348 (46.9%) as boys, and 12 (1.6%) identified as another gender or preferred not to select either binary category. With respect to age distribution, 108 participants (14.6%) were 12 years old, 119 (16.0%) were 13 years old, 132 (17.8%) were 14 years old, 143 (19.3%) were 15 years old, 126 (17.0%) were 16 years old, and 114 (15.4%) were 17 years old. A total of 471 adolescents (63.5%) lived with two parents or parental figures in the same household, 183 (24.7%) lived primarily with one parent, 73 (9.8%) lived in shared or alternating custody arrangements, and 15 (2.0%) reported another caregiving arrangement. Most participants attended public schools (n = 603, 81.3%), while 139 (18.7%) attended private schools. The training and holdout subsets did not show substantively meaningful differences in age, gender distribution, predictor means, or emotional-problem scores, supporting comparability of the two partitions.

Table 1

Descriptive Statistics, Distributional Characteristics, and Internal Consistency of Study Variables

Variable	M	SD	Observed Range	Skewness	Kurtosis	Cronbach's α
Emotional problems	4.28	2.39	0–10	0.31	-0.54	.81
Authoritative parenting	36.84	7.11	14–50	-0.42	-0.18	.88
Authoritarian parenting	26.73	7.62	10–49	0.29	-0.37	.86
Permissive parenting	27.91	6.48	11–48	0.17	-0.21	.78
Family dysfunction	2.08	0.61	1.00–3.83	0.46	-0.09	.90
Open parent–child communication	37.26	8.04	12–50	-0.39	-0.36	.91
Problematic parent–child communication	27.48	7.71	10–49	0.35	-0.24	.87

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As shown in Table 1, participants displayed substantial variability across all family predictors and emotional-problem scores, providing sufficient dispersion for predictive modeling. The mean Emotional Symptoms score was 4.28 (SD = 2.39), with the full theoretical range from 0 to 10 represented in the dataset. Mean authoritative parenting was higher than authoritarian and permissive parenting, whereas the family-functioning score indicated considerable between-participant variation in perceived family dysfunction. Open and problematic parent–child communication also showed broad distributions. Absolute skewness values ranged from 0.17 to 0.46 and absolute kurtosis values ranged from 0.09 to 0.54, indicating no severe univariate distributional abnormalities. Reliability coefficients ranged from .78 to .91, demonstrating acceptable to excellent internal consistency for all scales. Preliminary correlations were consistent with the anticipated direction of effects: emotional problems were negatively associated with authoritative parenting ($r = -.43$, $p < .001$) and open communication ($r = -.51$, $p < .001$) and positively associated with authoritarian parenting ($r = .41$, $p < .001$), permissive parenting ($r = .22$, $p < .001$), family dysfunction ($r = .58$, $p < .001$), and problematic communication ($r = .55$, $p < .001$). These correlations provided evidence of meaningful bivariate associations while also leaving substantial unexplained variation suitable for nonlinear predictive modeling.

Table 2

Cross-Validated and Holdout Predictive Performance of the LightGBM Model

Evaluation Sample	R^2	RMSE	MAE
Cross-validation Fold 1	.617	1.49	1.14
Cross-validation Fold 2	.641	1.43	1.09
Cross-validation Fold 3	.603	1.51	1.16
Cross-validation Fold 4	.632	1.45	1.11
Cross-validation Fold 5	.624	1.47	1.12
Cross-validation mean	.623	1.47	1.12
Cross-validation SD	.014	0.03	0.03
Independent holdout test set	.638	1.44	1.10

Table 2 demonstrates that LightGBM achieved stable predictive performance across the five cross-validation folds. Cross-validated R^2 values ranged from .603 to .641, with a mean of .623 and a small standard deviation of .014, indicating relatively little instability across training subsets. Mean cross-validated RMSE was 1.47 and mean MAE was 1.12. When the optimized model was applied to the completely independent holdout sample of 148 adolescents, it explained 63.8% of the variance in emotional-problem scores. The holdout RMSE was 1.44 and the MAE was 1.10, indicating that the average absolute discrepancy between predicted and observed Emotional Symptoms scores was slightly more than one point on the 0–10 scale. Importantly, holdout performance was not poorer than the average cross-validation performance, providing no indication of substantial model overfitting. Inspection of predicted versus observed scores showed that prediction errors were distributed across the outcome range without a marked systematic tendency toward overprediction or underprediction, although extreme scores near the upper end of the Emotional Symptoms distribution showed somewhat greater residual variability than scores around the center of the distribution.

Table 3

Comparison of Predictive Performance Across Regression Algorithms in the Independent Holdout Sample

Model	R^2	RMSE	MAE	Rank by R^2
LightGBM	.638	1.44	1.10	1
XGBoost	.609	1.50	1.15	2
Random Forest	.572	1.57	1.21	3
Elastic Net regression	.506	1.69	1.32	4

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As presented in Table 3, the LightGBM model produced the strongest holdout performance among the four evaluated algorithms. Its R^2 of .638 exceeded that of XGBoost by .029, Random Forest by .066, and Elastic Net regression by .132. The LightGBM model also demonstrated the lowest prediction errors, with an RMSE of 1.44 and MAE of 1.10. XGBoost produced the next strongest performance, explaining 60.9% of holdout variance, whereas Random Forest explained 57.2%. The linear Elastic Net model accounted for 50.6% of outcome variance and produced the largest RMSE and MAE. The improvement of LightGBM over Elastic Net was especially informative because all algorithms were trained with the same six family predictors. The stronger performance of gradient-boosting models suggests that the associations between family characteristics and adolescent emotional problems were not entirely linear and additive. Rather, the predictive structure appeared to include nonlinearities or interactions that were captured more effectively by boosted decision trees.

Table 4

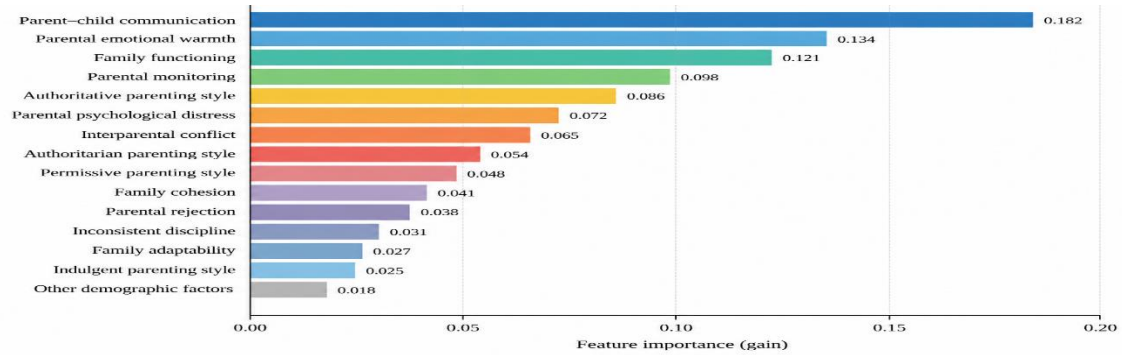
Global SHAP Importance of Predictors in the LightGBM Model

Rank	Predictor	Mean Absolute SHAP Value	Relative Importance (%)	Predominant Direction of Higher Values
1	Family dysfunction	0.76	25.8	Increased emotional problems
2	Problematic parent–child communication	0.68	23.1	Increased emotional problems
3	Open parent–child communication	0.53	18.0	Decreased emotional problems
4	Authoritarian parenting	0.44	14.9	Increased emotional problems
5	Authoritative parenting	0.36	12.2	Decreased emotional problems
6	Permissive parenting	0.18	6.1	Increased emotional problems

The SHAP analysis presented in Table 4 identified family dysfunction as the most influential predictor of emotional problems, accounting for 25.8% of total global feature importance. Higher family-dysfunction scores generally produced positive SHAP values, indicating increases in predicted emotional-problem severity. Problematic parent–child communication was the second most influential feature, contributing 23.1% of overall importance and similarly shifting predictions toward greater emotional problems at higher levels. Open parent–child communication ranked third and showed a predominantly protective pattern: adolescents reporting more open communication tended to receive lower predicted emotional-problem scores. Among parenting styles, authoritarian parenting had the largest contribution, followed by authoritative parenting and permissive parenting. Greater authoritarian and permissive parenting generally elevated predicted emotional difficulties, whereas greater authoritative parenting reduced predicted scores. Together, family functioning and the two communication dimensions accounted for 66.9% of total SHAP importance, indicating that the quality of the broader family relational system and communication environment contributed more strongly to predictive accuracy than parenting-style categories alone.

Figure 1

SHAP Summary Plot of the Direction and Magnitude of Family Predictors of Adolescent Emotional Problems



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The SHAP summary pattern indicated meaningful nonlinearities in several predictors. Family dysfunction produced relatively modest changes in predicted emotional problems at the lower end of its distribution, but SHAP values increased more sharply after scores approached approximately 2.2, suggesting that deterioration in family functioning may become disproportionately important once dysfunction reaches a moderate level. Problematic communication displayed a comparable threshold-like pattern, with predicted emotional problems rising particularly strongly among adolescents whose communication-problem scores were above approximately 30. Open communication showed an inverse pattern: increases from low to moderate levels were associated with substantial reductions in predicted emotional problems, although the protective gain became smaller at very high levels, suggesting diminishing returns. Authoritarian parenting generated increasingly positive SHAP values at higher scores, particularly above approximately 30. Authoritative parenting generally reduced predicted emotional-problem scores, but its protective effect was strongest when family dysfunction was simultaneously low or moderate. Examination of SHAP interaction patterns indicated that high authoritative parenting did not completely offset the elevated predictions associated with severe family dysfunction or extremely problematic parent–child communication. Permissive parenting showed the smallest and least consistent independent contribution, although high permissiveness tended to increase predicted emotional problems when accompanied by elevated family dysfunction. Overall, the SHAP results suggested that adolescent emotional problems were predicted not merely by isolated parenting characteristics but by the combined relational quality of the family environment.

4. Discussion

The present study developed and interpreted a LightGBM model for predicting adolescent emotional problems from parenting styles, family functioning, and parent–child communication among 742 adolescents in France. Several major findings emerged. First, the optimized LightGBM model demonstrated substantial out-of-sample predictive capacity, explaining 63.8% of the variance in emotional-problem scores in the independent holdout sample. Second, LightGBM outperformed XGBoost, Random Forest, and Elastic Net regression using the same predictor set, indicating that nonlinear and interactive information contributed meaningfully to prediction. Third, family dysfunction was the strongest individual predictor according to SHAP importance, followed by problematic parent–child communication and open communication. Fourth, authoritarian parenting was associated primarily with higher predicted emotional problems, whereas authoritative parenting showed a predominantly protective pattern. Permissive parenting contributed comparatively less to model predictions. Finally, SHAP analyses suggested threshold effects and interactions, particularly involving family dysfunction and communication, supporting the proposition that adolescent emotional adjustment emerges from configurations of family relationships rather than from single parenting behaviors operating independently.

The strong predictive contribution of family dysfunction is consistent with a systemic understanding of adolescent psychological adjustment. Family functioning captures dimensions that extend beyond the behavior of one parent, including emotional involvement, problem solving, responsiveness, relational coordination, and the overall capacity of family members to manage developmental demands. The present finding that family dysfunction was more important than any individual parenting style therefore suggests that emotional problems may be especially sensitive to the cumulative quality of the adolescent's family environment. Recent evidence indicates that adolescents' own appraisals of family relationships provide important information about adjustment because adolescents respond psychologically to how family interactions are experienced rather than simply to externally observable family structure (Fatmasari et al., 2026). The present findings are also compatible with evidence from the COVID-19 period showing that family relationships and family functioning were central to adolescent adaptation during a period of unusually high contextual stress (Campione-Barr et al., 2024). Similarly, research examining families during crises has shown that relational processes are linked to maternal and child psychological well-being, underscoring the family's role as a regulatory environment under conditions of stress (Gong et al., 2025).

The SHAP results further showed that the association of family dysfunction with predicted emotional problems was nonlinear. Relatively low levels of dysfunction were associated with smaller changes in prediction, whereas emotional-risk predictions rose more rapidly after family dysfunction reached a moderate level. This finding is important because it suggests that family risk may accumulate until the family's regulatory capacity becomes

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insufficient to absorb additional relational stress. Such a process would be compatible with multisystemic models of resilience, in which psychological outcomes depend on the interaction of resources across multiple systems rather than on a single risk factor (Cheung et al., 2026). Evidence concerning young people exposed to trauma and maltreatment likewise emphasizes the importance of relational strengths and resilience processes in shaping heterogeneous outcomes after adversity (Yoon et al., 2025). Thus, family functioning may operate not only as a direct correlate of emotional well-being but also as a broader context determining whether adolescents can draw on relational resources when difficulties arise.

Problematic parent–child communication emerged as the second strongest predictor, whereas open communication was the third strongest and demonstrated a clear protective direction. These complementary findings highlight communication as a core mechanism through which the family environment may influence emotional adjustment. Adolescents who perceive that they cannot speak freely with parents, expect misunderstanding or criticism, or withhold important concerns may have fewer opportunities to obtain emotional validation and practical assistance. Communication problems may also intensify family conflict by increasing misinterpretation and reducing collaborative problem solving. A systematic review of parent–child communication about potentially traumatic events similarly demonstrated the importance of communication processes in children's and adolescents' responses to adversity (Sloover et al., 2023). Communication is likely to be particularly significant when adolescents face distressing experiences because parents can help young people label emotions, interpret events, regulate uncertainty, and identify coping strategies.

The protective pattern associated with open communication also corresponds with research emphasizing adolescents' need to participate actively in conversations affecting their own lives. In medical contexts, teenagers and young adults have reported the importance of being addressed directly and treated as meaningful participants rather than peripheral observers in discussions involving caregivers and professionals (Critoph et al., 2024). Although the context differs from the present community sample, the relational principle is relevant: adolescents may benefit when communication supports agency, respect, and emotional inclusion. Parents of adolescents experiencing depression have also described difficulties communicating about mental-health symptoms and determining how to support their children appropriately (Kika et al., 2026). The current finding that communication variables collectively explained a substantial proportion of global feature importance suggests that strengthening the quality of everyday parent–adolescent dialogue could be an important component of preventive family interventions.

The communication findings may also be understood in relation to attachment and emotion socialization. Supportive communication communicates parental availability and provides repeated experiences through which adolescents learn whether difficult emotions can be expressed safely. Attachment-based approaches view such experiences as contributing to expectations regarding interpersonal support and emotional security (George & Aikins, 2023). Meta-analytic evidence further indicates a relationship between parental emotion socialization and parent–child attachment security (Rodrigues et al., 2025). Parents who recognize, validate, and discuss emotions may help adolescents develop more effective emotional awareness and regulation, whereas dismissive, punitive, or inconsistent responses may make emotional experiences more difficult to manage. The present model did not directly measure attachment or emotion-regulation mechanisms, but the strong predictive importance of communication is compatible with these theoretical pathways.

Among parenting styles, authoritarian parenting contributed most strongly to the LightGBM predictions and was associated with increased predicted emotional difficulties. Authoritarian parenting may elevate emotional vulnerability because high behavioral control is not necessarily accompanied by reciprocal communication, responsiveness, or developmentally appropriate autonomy. During adolescence, when normative developmental tasks increasingly involve independent judgment and identity formation, rigid or punitive control may produce tension between adolescents' autonomy needs and parental expectations. The finding is consistent with evidence linking parental rearing styles to suicidal ideation among adolescents experiencing depression (Liu et al., 2025). It is also compatible with longitudinal and developmental perspectives in which parenting contributes to cascading pathways of psychological and behavioral risk over adolescence (Marceau, 2023). These findings should not be interpreted as demonstrating that parental structure itself is detrimental; rather, structure may have different implications depending on whether it occurs within a supportive, communicative, and emotionally responsive relational context.

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This distinction is reinforced by the finding that authoritative parenting was associated with lower predicted emotional problems. Authoritative parenting combines expectations and behavioral structure with warmth, responsiveness, explanation, and age-appropriate autonomy. Such parenting may support adolescents by providing both predictability and emotional security. However, the SHAP interaction patterns suggested that authoritative parenting was most protective when overall family dysfunction was not severe. High authoritative-parenting scores did not completely neutralize the risk associated with markedly dysfunctional family relationships. This finding is theoretically plausible because parenting styles represent only one component of a larger system. Constructive family processes, including constructive management of disagreement, can contribute to healthier child outcomes when they promote emotional security and effective problem solving (Zhang & Wu, 2026). Conversely, even positive behaviors by one caregiver may have limited protective capacity when the broader family environment is chronically conflictual, chaotic, or emotionally disconnected.

Permissive parenting had the smallest independent contribution, although higher permissiveness generally predicted somewhat greater emotional difficulties, particularly when family dysfunction was also elevated. One interpretation is that low behavioral structure may be less harmful when embedded within an otherwise cohesive and communicative family but may become more consequential when combined with weak family organization. Adolescents require increasing autonomy, yet autonomy differs from absence of parental involvement or boundaries. This distinction is relevant to resilience research, which indicates that effective protection usually involves coordinated resources rather than the presence or absence of a single relational characteristic (Cheung et al., 2026; Schoors et al., 2023). The relatively modest independent importance of permissive parenting therefore does not imply that parental boundaries are irrelevant; instead, their psychological effects may depend heavily on the family context in which they occur.

The model's performance provides an important methodological finding. LightGBM explained 63.8% of holdout variance and outperformed the linear Elastic Net model by more than 13 percentage points of R^2. Because the models used the same family predictors, this difference indicates that predictive information was present in nonlinearities or interactions rather than exclusively in additive linear associations. Family psychology offers strong theoretical reasons to anticipate such complexity. Parental stress, for example, has been associated with offspring emotional and behavioral problems across studies (Ribas et al., 2024), but the behavioral expression of stress may depend on communication quality, family resources, and children's characteristics. Similarly, pathways linking parent–child interactions with adolescent depression and suicidal behavior may be reciprocal rather than unidirectional (Han et al., 2026). Gradient boosting cannot establish the direction of causation, but it can represent complex predictive structures without requiring every interaction to be prespecified.

The nonlinear results are also compatible with evidence from families facing substantial adversity. Young people in out-of-home care may experience combinations of trauma, disrupted relationships, mental-health vulnerability, and insufficient support that jointly influence suicide risk (Modderman et al., 2026). Research examining adolescent suicide during the COVID-19 pandemic likewise identifies multiple interacting risk domains, including bullying, psychosocial stress, and environmental conditions (Pérez-Jiménez et al., 2026). Longitudinal research on online child sexual abuse demonstrates that severe adverse experiences can generate complex developmental trajectories rather than uniform psychological outcomes (Prijatelj, 2026). Although the present sample was not restricted to high-risk adolescents, these literatures reinforce the broader principle that emotional problems frequently emerge from interacting systems of risk and protection.

The importance of family processes also extends to circumstances in which children or parents face serious medical conditions. Psychological difficulties among caregivers of children with neurodevelopmental disorders may affect the relational resources available within the family (Agyapong-Opoku et al., 2026), while parents of children who have experienced stroke describe extensive caregiving and psychological challenges (Bhatia et al., 2025). Chronic illness can similarly create demands involving autonomy, behavioral monitoring, communication, and emotional adjustment. Barriers to diabetes self-management among young people include family and contextual factors (Lucca et al., 2025), and adolescents with type 1 diabetes may face age-specific psychological difficulties, including disordered eating behaviors (Giannakopoulos et al., 2026). These findings illustrate why family functioning should not be understood merely as an accompaniment to individual emotional symptoms: families constitute one of the primary systems

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through which adolescents respond to prolonged developmental and health-related demands.

Similar patterns appear in families experiencing cancer and other severe illness. Psychological responses to genetic testing in childhood cancer may affect multiple family members and generate uncertainty that requires sensitive communication (Hoyweghen et al., 2023). Reviews of health-related quality of life in pediatric cancer likewise emphasize psychological and social outcomes in addition to physical health (Rothmund et al., 2022). When parents have terminal illness, dependent children may experience significant emotional and relational consequences (Wray et al., 2022), while children and partners of military personnel with combat-related injuries may also experience reduced psychological well-being (Solomon et al., 2022). Young carers represent another population in which family responsibilities can influence development, identity, and emotional health (Saragosa et al., 2022). Although these groups differ from the present school-based sample, they collectively demonstrate that adolescent psychological functioning is responsive to the quality and stability of family relationships across markedly different contexts.

The present findings may also have implications for understanding severe family conflict. A recent systematic review of child-to-parent violence identified multiple interacting predictors rather than a single explanatory cause (Mendes et al., 2026). This is consistent with the present LightGBM results showing that family characteristics work as a predictive configuration. Communication problems, dysfunctional family organization, and controlling parenting may reinforce one another rather than operating in isolation. Relationship-focused interventions may therefore be more effective when they address interaction patterns across multiple family domains. Evidence that relationship education can produce benefits relevant to children's outcomes supports the possibility that interventions targeting one family subsystem may have effects extending to other members of the family (Kanter et al., 2025). Similarly, emotion-focused family interventions seek to improve responsiveness and communication rather than treating adolescent distress solely as an individual problem (Smith et al., 2023).

The importance of a relational perspective should not obscure the wider caregiving network. Grandparents can play substantial caregiving roles, and systematic evidence suggests that grandparental care may be associated with child mental health in ways that vary according to context (Wang et al., 2024). Siblings may likewise constitute meaningful sources of support, as demonstrated in research on transgender and gender-diverse young people (Klepper et al., 2024). These findings indicate that future predictive models could be expanded beyond parenting styles and parent–child communication to incorporate sibling support, extended-family resources, peer relationships, school climate, socioeconomic conditions, and stressful life events. Doing so would be consistent with multisystemic accounts of resilience and may further improve prediction.

The strong predictive performance observed in this study should nevertheless be interpreted carefully. Machine-learning prediction is fundamentally different from causal explanation. A SHAP value quantifies how a feature contributes to the prediction generated by a trained model; it does not demonstrate that changing that feature will necessarily produce a corresponding change in emotional symptoms. The cross-sectional design further prevents determination of temporal ordering. Adolescents with emotional difficulties may perceive family relationships more negatively, disclose less to parents, experience more conflict, or evoke changes in parental behavior. Recent evidence concerning bidirectional associations between parent–child interactions and adolescent depression and suicidality illustrates the importance of this reciprocal possibility (Han et al., 2026). Consequently, the present findings should be viewed as evidence of predictive relevance rather than proof of unidirectional causation.

Despite that qualification, the combination of predictive performance and interpretable SHAP patterns offers meaningful information. Family dysfunction and communication accounted for approximately two thirds of global model importance, indicating that screening approaches based only on parenting-style labels may overlook highly informative characteristics of the broader family system. Interventions intended to prevent emotional problems may benefit from assessing whether adolescents feel heard, whether difficult topics can be discussed safely, whether family members collaborate in problem solving, and whether family relationships remain stable during conflict. Resilience research suggests that protective processes are distributed across relational and environmental systems (Cheung et al., 2026; Yoon et al., 2025), and the present findings support applying that principle directly to prediction of emotional difficulties among community adolescents.

5. Conclusion

The present study demonstrated that adolescent emotional problems could be predicted with substantial accuracy from a relatively concise set of family variables using LightGBM. Family dysfunction, problematic parent–child communication, and open communication were the most influential predictors, while authoritarian parenting increased and authoritative parenting reduced predicted emotional-problem severity. LightGBM outperformed linear and alternative tree-based models, and SHAP analyses showed that several associations were nonlinear and context dependent. The results emphasize that adolescent emotional difficulties are closely embedded within the quality of the family relational environment and suggest that interpretable machine-learning approaches can complement conventional family-psychology methods by identifying complex configurations of modifiable family risk and protective factors.

6. Limitations & Suggestions

The study has several limitations. Its cross-sectional design prevents temporal or causal conclusions and cannot determine whether family difficulties precede adolescent emotional problems or are partly consequences of them. All principal variables were based on adolescent self-report, creating the possibility of common-method variance and mood-congruent perceptions of family relationships. Although participants were recruited from several French regions, the sample was school based and may not fully represent adolescents who are absent from mainstream education, institutionalized, experiencing severe psychiatric disorders, or living in highly unstable circumstances. The outcome was measured using a brief emotional-symptoms scale rather than a diagnostic interview, and the predictive model therefore concerns dimensional emotional difficulties rather than psychiatric diagnoses. In addition, external validation was conducted through an internal holdout sample rather than an entirely independent cohort from another region or country.

Future research should employ longitudinal designs in which parenting, family functioning, communication, and emotional symptoms are assessed repeatedly across adolescence so that predictive direction and developmental changes can be evaluated. Future models should also incorporate parent reports, teacher assessments, clinical interviews, and observational measures of family interactions to reduce dependence on a single informant. External validation in independent French and international samples is needed before the model could be considered for applied screening. Additional predictors such as peer relationships, bullying, school climate, socioeconomic adversity, parental psychological distress, attachment, sleep, social-media use, stressful life events, and individual emotion-regulation capacity could be integrated into expanded models. Comparative evaluation of LightGBM with CatBoost, neural networks, explainable boosting machines, and longitudinal machine-learning approaches would also help determine whether the current performance can be improved while preserving clinical interpretability.

In practice, the findings suggest that assessment of adolescents experiencing emotional problems should extend beyond symptom severity to include family functioning and the quality of parent–child communication. School psychologists, counselors, family therapists, pediatric services, and adolescent mental-health professionals could routinely assess whether young people experience family relationships as supportive, whether communication is open or conflictual, and whether parental behavioral expectations are accompanied by warmth and responsiveness. Preventive programs may benefit from strengthening constructive communication, parental emotion coaching, collaborative problem solving, consistent but noncoercive behavioral boundaries, and developmentally appropriate adolescent autonomy. Machine-learning tools may eventually assist professionals in identifying adolescents who warrant more detailed evaluation, but any predictive algorithm should be used as a decision-support instrument rather than as a substitute for clinical judgment, individualized assessment, or direct engagement with adolescents and their families.

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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.

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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 have equally contributed to the research process and the development of the manuscript.

Declaration

In order to correct and improve the academic writing of our paper, we have used the language model ChatGPT.

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