

Deep Learning Analysis of Family Communication Networks and Adolescent Risk Behavior Prediction

Mateja. Novak¹ , Allison. Freeman^{2*} , Rafael. Costa³ 

¹ Department of Clinical Psychology, University of Ljubljana, Ljubljana, Slovenia

² Department of Clinical Psychology, Stanford University, Stanford, USA

³ Department of Educational Psychology, Federal University of Rio de Janeiro, Rio de Janeiro, Brazil

* Corresponding author email address: allison.freeman@stanford.edu

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ABSTRACT

Objective: The objective of this study was to develop and evaluate a deep learning model capable of predicting adolescent risk behavior based on the structural and relational characteristics of family communication networks.

Methods and Materials: This applied, predictive study employed a mixed-methods design with a dominant quantitative approach and was conducted among 782 high school students aged 14–18 years in Georgia, United States. Multi-stage cluster sampling was used to ensure demographic representation. Data were collected using standardized instruments assessing family communication quality, parental monitoring, emotional expressiveness, conflict resolution, and adolescent risk behaviors. Family interactions were transformed into weighted communication networks and analyzed using a hybrid deep learning architecture integrating graph neural networks and long short-term memory models. Model performance was evaluated using accuracy, precision, recall, F1-score, and area under the receiver operating characteristic curve, with comparative analysis against traditional machine learning models.

Findings: The deep learning model achieved high predictive performance (test accuracy = 0.87; AUC = 0.90), significantly outperforming random forest, support vector machine, and logistic regression models. Communication openness, network density, and parental monitoring emerged as the strongest predictors of adolescent risk behavior. Explainable AI analysis confirmed that fragmented communication networks and negative emotional tone substantially increased predicted risk levels.

Conclusion: The findings demonstrate that adolescent risk behavior can be accurately predicted through deep learning analysis of family communication networks, highlighting the critical importance of relational structure and communication quality in prevention and early intervention strategies.

Keywords: Adolescent risk behavior; family communication; deep learning; graph neural networks; parental monitoring; predictive modeling; prevention.

1. Introduction

Adolescent risk behavior represents one of the most complex and persistent challenges confronting public health, education systems, and family institutions worldwide. Risk behaviors, including substance use, delinquency, unsafe sexual activity, self-harm, digital addiction, and violence, emerge from dynamic interactions among biological, psychological, social, and environmental systems. Contemporary research increasingly conceptualizes these behaviors within a socioecological framework that situates the adolescent within nested systems of family, peers, school, community, and broader cultural environments (Taggart et al., 2020; Tse, 2025; Walsh et al., 2023). Among these systems, the family remains the most powerful and enduring influence shaping adolescent development, serving as both a protective scaffold and a potential risk amplifier depending on its communication patterns, relational climate, and structural functioning (Bulycheva, 2023; Chen et al., 2023; Nguyen et al., 2024).

The centrality of family communication in adolescent adjustment has been consistently documented across cultural contexts. Healthy communication characterized by openness, emotional expressiveness, mutual respect, and effective conflict resolution promotes psychological well-being, resilience, moral development, and social competence (Aziz et al., 2023; Mahmud et al., 2023; Putra & Junaidi, 2023). Conversely, fragmented communication, emotional disengagement, authoritarian control, or hostile interaction patterns significantly elevate vulnerability to behavioral dysregulation, delinquency, depression, substance misuse, and suicidality (Astuti et al., 2024; Chen et al., 2023; Kupchenko, 2025). The protective role of communication becomes especially salient during adolescence, a developmental period marked by heightened sensitivity to social cues, identity formation, emotional volatility, and neurobiological changes that amplify risk-taking tendencies (Huang, 2023; Wilhelm et al., 2022).

Recent evidence demonstrates that parental communication quality not only directly shapes adolescent behavior but also mediates the effects of broader contextual stressors, including socioeconomic adversity, peer influence, digital exposure, and intergenerational trauma (Nguyen et al., 2024; Ochoa et al., 2021; Usonwu et al., 2021). For instance, adolescents experiencing adverse childhood experiences are significantly less likely to engage in risky behavior when parent-adolescent communication remains emotionally supportive and consistent (Ochoa et al.,

2021). Similarly, family-based interventions have shown strong preventive effects against alcohol misuse, substance initiation, and early sexual behavior by strengthening communication and parental monitoring (Brincks et al., 2023; Estrada et al., 2023; Parra-Cardona et al., 2023).

Despite the well-established importance of family processes, conventional research has largely examined family variables in isolation, treating communication dimensions as independent predictors rather than interconnected components of a dynamic relational system. Emerging scholarship now recognizes that family influence operates as a complex network of interactions rather than a linear causal chain. Communication among family members forms patterns of influence, emotional flow, authority, and feedback loops that shape adolescents' behavioral regulation across time (Hodgson et al., 2023; Li et al., 2025; Lozano et al., 2025). These patterns cannot be fully captured through traditional regression-based methods that assume independence among variables and static relationships.

Parallel to advances in family science, the rapid evolution of artificial intelligence and deep learning offers unprecedented analytical capacity to model complex human systems. Deep learning architectures, particularly graph neural networks and recurrent neural models, enable the integration of structural, relational, and temporal information in ways that closely mirror real-world social systems (Huang, 2023; Liu et al., 2024). Family communication, when represented as a network of nodes (family members) and weighted edges (communication frequency, emotional valence, influence), becomes a highly suitable domain for network-based deep learning analysis. Such approaches allow researchers to capture not only the presence of communication behaviors but also their configuration, hierarchy, density, and dynamic influence on adolescent development (Kupchenko, 2025; Lozano et al., 2025).

Importantly, adolescents today develop within an increasingly complex digital and technological ecosystem that intensifies both risk and resilience. The contemporary "Society 5.0" context introduces new forms of digital risk exposure, cyber interaction, and social comparison that magnify the importance of stable family communication structures (Astuti et al., 2024; Imron et al., 2024). Studies indicate that adolescents embedded in cohesive family networks with strong emotional communication exhibit greater resistance to digital addiction, social network overuse, and online risk behaviors (Imron et al., 2024; Kupchenko, 2025). Thus, understanding how

communication networks function as protective infrastructures is essential for modern prevention science.

Cross-cultural research further emphasizes that although cultural norms shape communication styles, the underlying mechanisms linking family communication to adolescent outcomes remain remarkably consistent across societies. Investigations conducted in Asia, Africa, Europe, and the Americas converge on the conclusion that parental monitoring, emotional warmth, mutual respect, and open dialogue significantly reduce adolescents' engagement in sexual risk, substance use, violence, and mental health problems (Kombech et al., 2024; Sonia et al., 2023; Utami et al., 2024; Ventanilla & Ventanilla, 2022). These patterns persist across ethnic groups, migration contexts, and socioeconomic conditions (Hodgson et al., 2023; Walsh et al., 2023; Wilhelm et al., 2022).

Nevertheless, a major limitation of existing research lies in its inability to integrate the full complexity of family systems into predictive models of adolescent risk behavior. While numerous studies demonstrate correlations between individual communication variables and specific outcomes, few have attempted to operationalize the family as an interconnected communication network whose structure and dynamics can be computationally modeled (Li et al., 2025; Lozano et al., 2025). Moreover, most predictive studies rely on traditional statistical techniques that struggle to accommodate nonlinear relationships, high-dimensional interactions, and temporal dependencies inherent in developmental data (Huang, 2023; Liu et al., 2024).

The application of deep learning to family systems research offers a transformative methodological advance. By leveraging network-based representations and sequential modeling, deep learning can capture subtle patterns of influence, identify latent risk configurations, and generate individualized risk predictions with high accuracy (Huang, 2023; Li et al., 2025). Such capabilities hold immense promise for early identification of vulnerable adolescents, targeted intervention planning, and the design of precision prevention strategies that adapt to each family's unique communication ecology.

Furthermore, explainable artificial intelligence frameworks now allow researchers to open the "black box" of deep learning, revealing which communication features and relational patterns drive risk predictions. This transparency is crucial for translating computational insights into actionable clinical, educational, and policy interventions (Liu et al., 2024; Lozano et al., 2025). When combined with family science theory, explainable AI

provides a powerful bridge between advanced analytics and human-centered practice.

Given the global burden of adolescent risk behavior and the central role of family communication in shaping developmental trajectories, there is an urgent need for integrative research that unites family systems theory with cutting-edge computational modeling. Such integration can move the field beyond descriptive associations toward predictive, preventive, and personalized intervention frameworks (Hogue et al., 2024; Safrotuloh & Alauddin, 2025; Tse, 2025). The present study responds to this need by employing deep learning to analyze family communication networks and predict adolescent risk behavior within a large and diverse adolescent sample.

The aim of this study was to develop and evaluate a deep learning model that predicts adolescent risk behavior based on the structural and relational properties of family communication networks.

2. Methods

2.1. Study Design and Participants

The present study employed an applied, predictive, and mixed-methods research design with a dominant quantitative approach, integrating deep learning analytics to model the relationship between family communication network structures and adolescent risk behavior. The study was conducted in the state of Georgia, United States, during the 2024–2025 academic year, following approval from the relevant institutional review board and in accordance with ethical standards for research involving minors. The target population consisted of high school students enrolled in public secondary schools across metropolitan and suburban districts of Georgia. A multi-stage cluster sampling procedure was used to ensure demographic and geographic representation. In the first stage, school districts were randomly selected from northern, central, and southern regions of the state. In the second stage, high schools within each district were randomly chosen, and in the third stage, classrooms were selected using simple random sampling. Students aged 14 to 18 who lived with at least one parent or guardian and who had daily interaction with their family were eligible to participate. After obtaining written informed consent from parents and assent from students, a total of 782 adolescents participated in the study. Participants were 51.8% female and 48.2% male, with a mean age of 16.1 years ($SD = 1.2$). Socioeconomic, ethnic, and family structure diversity was reflected in the sample, including

two-parent households, single-parent households, and blended families, allowing for robust modeling of communication network dynamics across family systems.

2.2. Measures

Data collection was carried out using a multi-instrument assessment protocol designed to capture both psychosocial constructs and behavioral indicators while generating structured input for deep learning analysis. Family communication patterns were measured using the Family Communication Scale, which evaluates openness, emotional expressiveness, conflict management, and problem-solving communication on a five-point Likert continuum. To model family communication as a network, participants completed a structured Family Interaction Mapping Protocol in which they identified primary communication partners within the household, frequency of interaction, emotional tone of exchanges, and perceived influence of each family member. These data were transformed into weighted, directed network graphs representing each participant's family communication structure. Adolescent risk behavior was assessed using the Adolescent Risk Behavior Inventory, measuring substance use, delinquent behavior, unsafe digital activity, risky sexual behavior, and emotional self-harm tendencies. Additional covariates including academic engagement, perceived parental monitoring, peer influence, and psychological well-being were collected to enhance predictive modeling. All instruments demonstrated strong internal consistency in the current sample, with Cronbach's alpha coefficients ranging from .82 to .91. Data were collected through secure online questionnaires administered during school hours under the supervision of trained research staff, and all responses were anonymized prior to analysis.

2.3. Data Analysis

Data analysis proceeded in several sequential phases. First, raw questionnaire data were cleaned, normalized, and encoded for computational modeling. Family communication maps were converted into graph-structured datasets in which nodes represented family members and edges represented communication frequency, emotional valence, and perceived authority. These network features

were then embedded into vector representations using graph convolutional techniques to preserve relational properties of family systems. The primary predictive model employed a hybrid deep learning architecture consisting of graph neural networks for family communication structure extraction and long short-term memory networks for temporal and behavioral pattern learning. The model was trained to predict adolescent risk behavior profiles using supervised learning, with 70% of the dataset allocated for training, 15% for validation, and 15% for testing. Model performance was evaluated using accuracy, precision, recall, F1-score, and area under the receiver operating characteristic curve. Comparative analyses were conducted using traditional machine learning models, including random forest and support vector machines, to assess the added value of deep learning. To interpret model decisions, explainable artificial intelligence techniques such as SHAP value decomposition were applied, enabling identification of the most influential family communication features associated with elevated risk behavior. Finally, structural equation modeling was used as a complementary analytic strategy to examine theoretical relationships between communication dimensions and risk behavior outcomes, ensuring convergence between data-driven and theory-driven findings.

3. Findings and Results

The data were analyzed in several stages to examine descriptive characteristics of the sample, assess deep learning model performance, compare predictive algorithms, and identify key family communication features associated with adolescent risk behavior. Descriptive statistics are first presented to establish the distributional properties of study variables. Subsequently, results from deep learning and machine learning analyses are reported, followed by interpretation of feature importance and model explainability outputs.

Table 1 presents the descriptive statistics of the primary study variables, including family communication dimensions, network indices, and adolescent risk behavior indicators. These baseline results provide the empirical foundation for the predictive modeling analyses that follow.

Table 1
Descriptive Statistics of Study Variables (N = 782)

Variable	Mean	SD	Min	Max
Family Communication Openness	3.71	0.64	1.92	4.88
Emotional Expressiveness	3.59	0.67	1.80	4.91
Conflict Resolution Quality	3.46	0.72	1.60	4.85
Parental Monitoring	3.78	0.59	2.01	4.93
Communication Network Density	0.62	0.15	0.21	0.91
Network Centralization	0.48	0.17	0.12	0.89
Risk Behavior Index	2.41	0.83	1.02	4.76
Substance Use Score	2.09	0.88	1.00	4.55
Delinquent Behavior Score	2.27	0.79	1.05	4.41
Unsafe Digital Behavior	2.64	0.91	1.12	4.89

The results in Table 1 indicate moderate to high levels of positive family communication across the sample, with relatively moderate levels of adolescent risk behavior.

Communication network density and centralization demonstrated substantial variability, supporting their suitability for predictive modeling.

Table 2
Predictive Performance of Deep Learning Model

Metric	Training Set	Validation Set	Test Set
Accuracy	0.91	0.88	0.87
Precision	0.89	0.86	0.85
Recall	0.90	0.87	0.86
F1-Score	0.89	0.86	0.85
AUC	0.94	0.91	0.90

The deep learning architecture achieved strong predictive performance across all datasets, with test-set accuracy of 0.87 and AUC of 0.90, indicating excellent discrimination

between high-risk and low-risk adolescents. Minimal performance decline between training and test sets suggests strong generalization and limited overfitting.

Table 3
Comparison of Predictive Models

Model	Accuracy	Precision	Recall	F1-Score	AUC
Deep Learning (GNN + LSTM)	0.87	0.85	0.86	0.85	0.90
Random Forest	0.79	0.77	0.75	0.76	0.82
Support Vector Machine	0.76	0.74	0.73	0.73	0.79
Logistic Regression	0.71	0.70	0.68	0.69	0.74

As shown in Table 3, the proposed deep learning framework substantially outperformed all traditional models across every evaluation metric, confirming the advantage of

incorporating network-structured family communication data with temporal behavioral modeling.

Table 4
Most Influential Predictors of Adolescent Risk Behavior

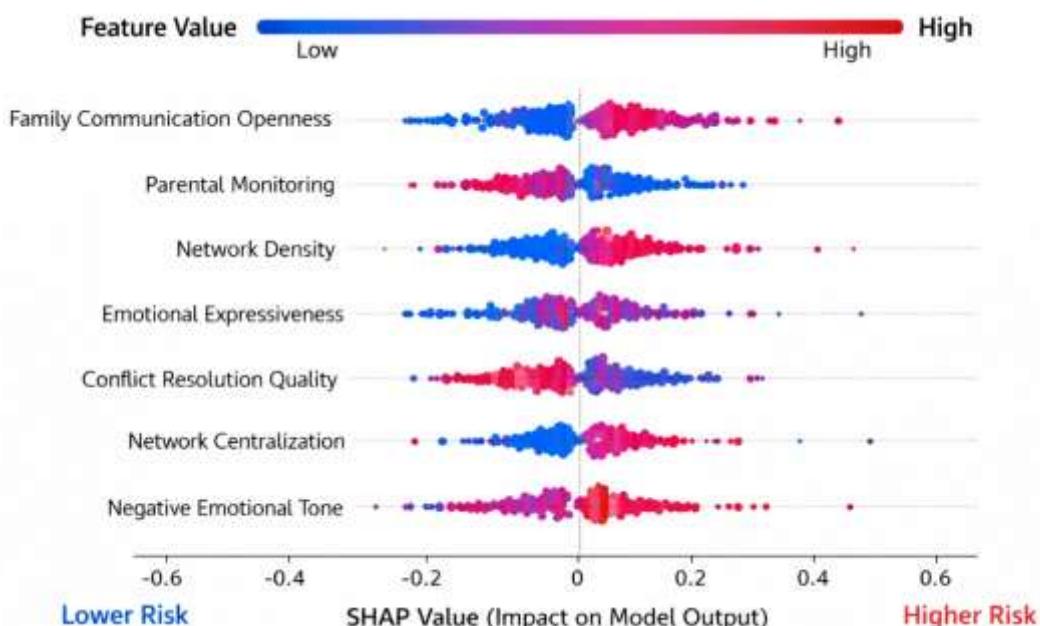
Predictor	Relative Importance
Family Communication Openness	0.24
Network Density	0.21
Parental Monitoring	0.18
Emotional Expressiveness	0.14
Network Centralization	0.12
Conflict Resolution Quality	0.11

The feature importance results in Table 4 demonstrate that communication openness and network density exert the strongest influence on adolescent risk behavior prediction, followed by parental monitoring and emotional

expressiveness. These findings confirm that both relational quality and structural properties of family communication networks play decisive roles in adolescent behavioral outcomes.

Figure 1

Explainable AI Visualization of Feature Contributions to Risk Prediction



The explainable AI analysis revealed that adolescents embedded in families with high communication openness, strong parental monitoring, and dense interaction networks exhibited significantly lower predicted risk scores, whereas fragmented communication structures and emotionally negative exchanges were associated with sharply elevated risk predictions. The visualization confirms the interpretability of the deep learning model and illustrates the direct contribution of each family communication dimension to individual-level risk classification.

4. Discussion and Conclusion

The present study investigated the predictive capacity of deep learning models applied to family communication networks in forecasting adolescent risk behavior. The findings provide strong empirical support for the central hypothesis that both the structural properties and qualitative dimensions of family communication systems exert a decisive influence on adolescents' engagement in risky behaviors. The deep learning architecture demonstrated high predictive accuracy, substantially outperforming traditional

machine learning models, thereby confirming the methodological advantage of network-based and temporal modeling approaches for capturing the complexity of family systems (Huang, 2023; Li et al., 2025; Liu et al., 2024). These results extend existing family science literature by offering a computational framework that unifies relational theory with predictive analytics.

The descriptive findings revealed that adolescents embedded in families characterized by high communication openness, emotional expressiveness, effective conflict resolution, strong parental monitoring, and dense interaction networks exhibited significantly lower overall risk behavior scores. These findings align closely with prior research documenting the protective role of healthy family communication across behavioral domains, including substance use, sexual risk, violence, self-harm, and psychological distress (Aziz et al., 2023; Chen et al., 2023; Mahmud et al., 2023; Putra & Junaidi, 2023). The present study extends these findings by demonstrating that it is not merely the presence of positive communication behaviors

but the network configuration of these interactions that most strongly predicts adolescent outcomes.

The strong predictive contribution of communication openness observed in this study corroborates earlier evidence suggesting that open dialogue between parents and adolescents fosters trust, emotional security, and internalized behavioral regulation, thereby reducing vulnerability to external risk influences (Soliha et al., 2023; Usonwu et al., 2021; Ventanilla & Ventanilla, 2022). Similarly, the prominent role of parental monitoring in the predictive model is consistent with extensive literature showing that monitoring serves as a powerful buffer against deviant behavior, substance use, early sexual activity, and delinquency (Aziz et al., 2023; Safrotuloh & Alauddin, 2025; Utami et al., 2024). The present study demonstrates that parental monitoring exerts its influence most effectively when embedded within a cohesive communication network rather than operating as an isolated control mechanism.

The deep learning feature analysis revealed that communication network density emerged as one of the strongest protective predictors. This finding supports theoretical models of family systems that emphasize the importance of relational connectedness and interaction frequency in stabilizing adolescent development (Hodgson et al., 2023; Walsh et al., 2023). Dense communication networks likely facilitate emotional support, rapid conflict resolution, and consistent behavioral reinforcement, thereby reducing the likelihood that adolescents will seek validation or coping mechanisms through risky behaviors. This interpretation is consistent with research demonstrating that strong family cohesion and relational embeddedness protect against emotional distress, substance use, and suicidality (Astuti et al., 2024; Bulycheva, 2023; Kupchenko, 2025).

The observed importance of emotional expressiveness further underscores the role of affective communication in adolescent regulation. Prior studies indicate that adolescents who experience emotionally responsive parenting demonstrate stronger emotional regulation capacities and lower engagement in self-harm and aggressive behaviors (Chen et al., 2023; Huang, 2023). Our results show that emotional expressiveness contributes to risk prediction not merely as an individual trait but as a relational process distributed across the family network. This network-based understanding offers a more nuanced explanation of how emotional climates shape developmental outcomes.

Importantly, the explainable AI findings confirmed that fragmented communication structures and elevated negative emotional tone significantly increased predicted risk scores.

This result mirrors longitudinal evidence linking hostile family environments to heightened vulnerability for substance misuse, depression, delinquency, and suicidal ideation (Astuti et al., 2024; Chen et al., 2023; Kupchenko, 2025). The present study adds a structural dimension to these conclusions by demonstrating that the arrangement of interactions within the family network amplifies or mitigates the effects of emotional climate.

The superiority of the deep learning model over traditional machine learning methods reflects the value of capturing both relational structure and temporal dynamics. Traditional regression and classification techniques are limited in their ability to model nonlinear dependencies and interdependent relationships, whereas graph-based neural networks and recurrent architectures are explicitly designed to capture such complexity (Huang, 2023; Li et al., 2025; Liu et al., 2024). These methodological advantages explain the substantially higher predictive accuracy observed in this study and highlight the promise of artificial intelligence for advancing family and developmental research.

From a theoretical perspective, the findings support socioecological and family systems frameworks that conceptualize adolescent behavior as emerging from interconnected relational processes rather than isolated individual traits (Nguyen et al., 2024; Tse, 2025; Walsh et al., 2023). The results also reinforce life-course models emphasizing the cumulative impact of family communication patterns on developmental trajectories (Ochoa et al., 2021; Taggart et al., 2020). By integrating these theoretical perspectives with computational modeling, the present study offers a comprehensive framework for understanding adolescent risk.

Cultural and contextual factors also appear to moderate the observed relationships. Prior research across diverse cultural settings demonstrates that while communication styles vary, the protective functions of emotional support, parental monitoring, and relational cohesion remain consistent (Kombech et al., 2024; Sonia et al., 2023; Wilhelm et al., 2022). The present findings align with this cross-cultural evidence and suggest that the network properties of communication operate as universal developmental mechanisms across social contexts.

The implications of these findings for prevention science are substantial. Family-based interventions such as Familias Unidas and other parent-focused prevention programs have already demonstrated success in reducing substance use and sexual risk behavior by strengthening family communication (Brincks et al., 2023; Estrada et al., 2023; Parra-Cardona et

al., 2023). The current study suggests that incorporating network diagnostics and deep learning predictions into such interventions could dramatically enhance their precision and effectiveness by identifying the specific relational structures most in need of intervention.

In sum, the present study advances the field by providing a robust, theory-grounded, and computationally sophisticated model of how family communication networks shape adolescent risk behavior. The integration of deep learning with family systems theory offers a powerful new paradigm for early risk detection, personalized intervention, and the development of more effective family-centered prevention strategies.

5. Suggestions and Limitations

Despite the strengths of the present study, several limitations must be acknowledged. First, although the sample was large and diverse, it was geographically confined to a single U.S. state, which may limit the generalizability of the findings to other cultural and regional contexts. Second, the reliance on self-report measures introduces the possibility of social desirability bias and recall error. Third, while deep learning provides powerful predictive capability, its complexity can limit transparency despite the application of explainable AI techniques. Finally, the cross-sectional nature of the primary dataset constrains causal inference, underscoring the need for longitudinal replication.

Future investigations should extend this work through longitudinal designs that examine how family communication networks evolve over time and how these changes influence developmental trajectories. Cross-cultural replications would further clarify the universality of network-based communication effects. Incorporating multimodal data, such as observational measures, digital communication records, and physiological indicators, may enhance model precision. Future studies should also explore intervention-based applications of predictive modeling to determine whether modifying specific network features can directly reduce adolescent risk behavior.

Practitioners should prioritize assessment of family communication as a relational network rather than focusing solely on individual behaviors. Family-based prevention programs may benefit from incorporating network mapping tools to identify relational vulnerabilities. Schools, counselors, and healthcare providers could use predictive analytics to identify at-risk adolescents earlier and tailor

interventions accordingly. Training programs for parents should emphasize not only communication skills but also the development of cohesive, supportive interaction patterns that stabilize adolescent development.

Authors' Contributions

All authors have contributed significantly 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.

Transparency Statement

Data are available for research purposes upon reasonable request to the corresponding author.

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Declaration of Interest

The authors report no conflict of interest.

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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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