KMAN PUBLISHING INSTITUTE
Journal Website

Article history:
Received 27 September 2025
Revised 29 November 2025
Accepted 06 December 2025
Published online 10 January 2026

Journal of Adolescent and Youth Psychological Studies

Volume 7, Issue 1, pp 1-9

E-ISSN: 2981-2526

Neural Network Analysis of Adolescent Depression: The Interactive Roles of Loneliness, Family Communication Quality, and Digital Media Dependency

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A r t i c l e I n f o

Article type:
Original Research

How to cite this article:
Ben Amor, L., Prasetyo, A., & Nikolaidis, A. (2026). Neural Network Analysis of Adolescent Depression: The Interactive Roles of Loneliness, Family Communication Quality, and Digital Media Dependency. *Journal of Adolescent and Youth Psychological Studies, 7*(1), 1-9.
http://dx.doi.org/10.61838/kman.jayps.4990

A B S T R A C T

Objective: This study aimed to examine the nonlinear and interactive effects of loneliness, family communication quality, and digital media dependency on depressive symptoms among Indonesian adolescents using neural network modeling.

Methods and Materials: A cross-sectional design was implemented with 684 secondary school students aged 14–18 years selected via multistage cluster sampling from urban regions of Indonesia. Participants completed validated measures assessing depressive symptoms, loneliness, family communication quality, and digital media dependency. Data were analyzed using a multilayer perceptron neural network constructed in Python with TensorFlow. The dataset was partitioned into training, validation, and test sets. Model performance was evaluated using root mean square error, mean absolute error, and coefficient of determination. Predictor contributions and interaction effects were interpreted using SHAP values and partial dependence analyses.

Findings: The neural network demonstrated high predictive accuracy (R^2 = .79 on the test set). Loneliness emerged as the strongest predictor of depressive symptoms, followed by digital media dependency and family communication quality. Significant nonlinear interaction effects were observed, indicating that the combination of high loneliness, poor family communication, and elevated digital media dependency produced the highest levels of depressive symptoms. Family communication quality exerted a strong buffering effect that attenuated the impact of loneliness and digital dependency on depression.

Conclusion: Adolescent depression is shaped by complex, interactive psychosocial and digital factors that are effectively captured through neural network modeling. Strengthening family communication and promoting healthy digital engagement may substantially reduce depressive risk among adolescents.

Keywords: *Adolescent depression; neural networks; loneliness; family communication; digital media dependency; mental health modeling*

1. Introduction

Adolescent depression has emerged as one of the most urgent public health challenges of the twenty-first century, with global prevalence rates increasing steadily across diverse sociocultural contexts. Contemporary adolescents navigate an unprecedented convergence of psychosocial, familial, and digital influences that fundamentally reshape emotional development, identity formation, and mental health vulnerability. Large-scale epidemiological investigations consistently demonstrate that depressive symptomatology during adolescence predicts academic failure, substance abuse, interpersonal dysfunction, and long-term psychiatric morbidity into adulthood, thereby positioning adolescent depression as both a developmental and societal crisis (Lim & Kwon, 2023; Runcan et al., 2023; Song et al., 2020). The digital transformation of social life has further complicated this landscape by introducing persistent online exposure, algorithmic social feedback loops, and novel forms of psychological dependence that intersect with traditional developmental stressors (Nesi, 2020; Olson et al., 2023; Roberts & David, 2023).

A rapidly expanding body of research confirms that depressive symptoms in youth are shaped not by isolated variables but by complex networks of interacting psychological, familial, and technological factors. Loneliness, in particular, has reemerged as a central predictor of emotional distress in both clinical and non-clinical adolescent populations. Studies spanning multiple cultural contexts indicate that perceived social isolation exerts powerful effects on mood regulation, self-worth, and cognitive vulnerability to depression (Güveli et al., 2024; Kılınç et al., 2022; Simard & Volicer, 2020). Importantly, loneliness is no longer confined to physical isolation but increasingly manifests within digitally saturated social environments where connection is abundant yet emotionally shallow, creating a paradoxical intensification of social disconnection (Kusumota et al., 2022; Wetzel et al., 2021).

Parallel to the growing salience of loneliness is the escalating impact of digital media dependency on adolescent psychological functioning. Excessive engagement with smartphones, social networking platforms, streaming services, and interactive digital content has been linked to heightened emotional dysregulation, sleep disturbances, anxiety, and depressive symptomatology (Fitzpatrick et al., 2022; Gong et al., 2023; Sohn et al., 2021). Cross-national investigations reveal consistent associations between problematic smartphone use and depression, underscoring the global nature of this phenomenon (Alqaderi et al., 2023; Olson et al., 2023). Moreover, adolescents demonstrate heightened vulnerability to algorithmic reinforcement patterns embedded within social media platforms that amplify emotional comparison, fear of missing out, and attentional capture, thereby intensifying depressive risk (Nesi, 2020; Roberts & David, 2023).

Family communication quality represents another foundational determinant of adolescent mental health. Extensive empirical literature confirms that open, emotionally supportive, and consistent family communication serves as a protective buffer against stress, anxiety, and depressive symptom development. Conversely, dysfunctional communication patterns—characterized by emotional invalidation, conflict avoidance, and limited parental responsiveness—substantially increase vulnerability to internalizing disorders (Davies et al., 2021; Dean et al., 2023; Özbek et al., 2025). Adolescents residing in environments where communication is constrained by parental mental illness, chronic stress, or socioeconomic adversity exhibit elevated depressive trajectories and impaired help-seeking behaviors (Davies et al., 2021; Dean et al., 2023). Parenting practices also shape adolescents' engagement with digital technologies, influencing susceptibility to problematic media use and subsequent mental health outcomes (Özbek et al., 2025; Vossen et al., 2024).

The intersection of loneliness, family communication, and digital media dependency forms a multidimensional risk architecture for adolescent depression. Empirical studies demonstrate that adolescents experiencing poor family communication are more likely to seek emotional fulfillment through digital environments, thereby increasing exposure to maladaptive online interactions and deepening loneliness, which in turn accelerates depressive symptom progression (Sabah et al., 2025; Vossen et al., 2024; Yu & Du, 2022). These processes are further amplified during periods of societal disruption, such as the COVID-19 pandemic, when social restrictions, educational instability, and heightened online engagement intensified mental health challenges among youth worldwide (Hong et al., 2023; Song et al., 2020; Yang et al., 2021).

Despite extensive research on each of these variables independently, conventional linear statistical approaches remain limited in their capacity to model the nonlinear, interactive, and synergistic relationships that characterize adolescent psychological development. Human emotional

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systems do not operate in isolation; rather, they function within dynamic networks where small changes in one domain may trigger cascading effects across multiple systems. Traditional regression-based models are ill-equipped to capture such complexity, often underestimating interaction effects and oversimplifying psychological causation (Gewali et al., 2021; Stiles-Shields et al., 2022). Consequently, there is a growing demand for analytic frameworks capable of modeling high-dimensional interactions with interpretability and clinical relevance.

Artificial intelligence and neural network methodologies offer transformative potential in this regard. Neural networks are uniquely designed to model nonlinear dependencies, hierarchical interactions, and emergent patterns within complex psychological datasets. In recent years, these methods have been successfully applied to the detection, monitoring, and prediction of depressive disorders using digital phenotyping, sensor data, and behavioral metrics (Gardea-Reséndez et al., 2024; Hilty et al., 2023). Digital technologies now allow continuous tracking of emotional states, behavioral rhythms, and social engagement patterns, generating unprecedented volumes of data that demand advanced computational analysis (Kouvonen et al., 2021; Wei & Guo, 2023). The integration of neural network modeling into adolescent mental health research therefore represents not merely a methodological innovation but a conceptual shift toward systems-based psychological science.

Moreover, digital interventions increasingly complement traditional psychotherapy, reshaping mental health service delivery. Smartphone-based cognitive behavioral programs, online support platforms, and automated screening systems have demonstrated feasibility and efficacy in reducing depressive symptoms, particularly among young populations with limited access to face-to-face care (Gewali et al., 2021; Stiles-Shields et al., 2022; Swartz & Novick, 2020). However, these same technologies simultaneously introduce new psychological risks through excessive use, behavioral dependency, and emotional overload, creating a dual-edged influence on adolescent well-being (Hilty et al., 2023; Lukenga et al., 2023).

Cultural and contextual factors further complicate this landscape. Studies across diverse societies reveal that the psychological effects of digital engagement and family communication are deeply embedded within cultural norms, socioeconomic conditions, and educational systems (Lukenga et al., 2023; Vuong et al., 2022; Wei & Guo, 2023). Adolescents' exposure to online advertising, vaping promotion, and digital consumer culture introduces additional stressors that intersect with emotional vulnerability and risk behaviors (Aldukhail, 2025; Vuong et al., 2022). Simultaneously, psychosocial stressors such as appearance anxiety, academic pressure, and societal expectations amplify depressive risk in contemporary youth (Lim & Kwon, 2023; Malik et al., 2025).

Collectively, this expanding literature underscores the necessity of integrative, computationally sophisticated approaches capable of modeling adolescent depression as an emergent phenomenon arising from interacting psychosocial systems. Neural network analysis offers a powerful lens through which the complex interplay of loneliness, family communication quality, and digital media dependency can be examined with both predictive precision and theoretical depth. By illuminating nonlinear interaction effects and uncovering hidden relational structures, such models advance both scientific understanding and practical intervention design.

Therefore, the present study applies neural network modeling to investigate how loneliness, family communication quality, and digital media dependency interactively predict depressive symptoms among adolescents in Indonesia, with the aim of identifying high-risk psychological profiles and clarifying the dynamic mechanisms through which digital and familial environments shape adolescent mental health.

2. Methods and Materials

2.1. Study Design and Participants

The present study employed a quantitative, cross-sectional correlational design integrated with advanced neural network modeling to investigate the interactive effects of loneliness, family communication quality, and digital media dependency on depressive symptoms among adolescents. The target population consisted of secondary school students enrolled in public and private high schools in three major urban regions of Indonesia, including Jakarta, Bandung, and Surabaya. A multistage cluster random sampling procedure was used to ensure demographic and socioeconomic representativeness. In the first stage, schools were randomly selected from official education district lists. In the second stage, classrooms within each selected school were randomly chosen, and all students within those classrooms were invited to participate. A total sample of 684 adolescents aged 14 to 18 years participated in the study, with a balanced distribution of gender and grade levels.

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Written informed consent was obtained from both students and their legal guardians. Participation was voluntary, anonymity was strictly preserved, and students were assured that withdrawal from the study was possible at any point without any academic or personal consequences.

2.2. *Measures*

Data were collected using a battery of standardized self-report instruments administered in classroom settings under the supervision of trained research assistants. Adolescent depressive symptoms were measured using the Depression subscale of the Depression Anxiety Stress Scales-21 (DASS-21), which consists of seven items rated on a four-point Likert scale ranging from zero to three, with higher scores indicating greater severity of depressive symptomatology. Loneliness was assessed using the UCLA Loneliness Scale Version 3, a 20-item measure rated on a four-point Likert scale from "never" to "often," which captures subjective feelings of social isolation and relational dissatisfaction. Family communication quality was evaluated using the Parent–Adolescent Communication Scale, comprising two dimensions of open communication and communication problems, with items rated on a five-point Likert continuum. Digital media dependency was measured through the Digital Media Dependency Scale for Adolescents, a 24-item instrument assessing compulsive usage, emotional reliance, tolerance, and withdrawal symptoms associated with digital media engagement. All instruments underwent forward–backward translation procedures into Bahasa Indonesia, followed by expert panel review and pilot testing with 60 students to confirm linguistic clarity and cultural relevance. Reliability analyses in the current sample demonstrated strong internal consistency for all scales, with Cronbach's alpha coefficients exceeding 0.85 for each construct. Convergent and discriminant validity were confirmed through confirmatory factor analysis prior to model construction.

2.3. *Data Analysis*

Data analysis proceeded in several systematic stages. Preliminary analyses were conducted using SPSS version 27 to screen for missing data, univariate and multivariate normality, outliers, and multicollinearity. Descriptive statistics and Pearson correlation coefficients were computed to establish baseline associations among study variables. Subsequently, neural network modeling was performed using Python with the TensorFlow and Keras frameworks. The dataset was randomly partitioned into training (70%), validation (15%), and testing (15%) subsets. Input variables included standardized scores of loneliness, family communication quality subscales, and digital media dependency dimensions, while depressive symptoms served as the output variable. A multilayer perceptron architecture was employed, consisting of an input layer, three hidden layers with rectified linear unit activation functions, and a single-node output layer using linear activation. The model was trained using the Adam optimization algorithm with mean squared error as the loss function. Hyperparameters, including learning rate, number of neurons per layer, and batch size, were optimized through grid search and cross-validation procedures. Model performance was evaluated using root mean square error, mean absolute error, and coefficient of determination on the test dataset. To interpret the model and identify the relative importance and interaction effects of predictors, SHAP (Shapley Additive Explanations) values and partial dependence plots were computed. These techniques enabled transparent interpretation of the neural network's decision-making processes and clarified the complex nonlinear relationships among loneliness, family communication quality, digital media dependency, and adolescent depression.

3. Findings and Results

Table 1 presents the demographic profile and descriptive statistics of the study variables for the total sample.

Table 1

Demographic Characteristics and Descriptive Statistics of Study Variables (N = 684)

Variable	Category / Range	Frequency (%) / Mean (SD)
Gender	Male	338 (49.4%)
	Female	346 (50.6%)
Age (years)	14–15	214 (31.3%)
	16–17	297 (43.4%)
	18	173 (25.3%)
School Type	Public	412 (60.2%)

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	Private	272 (39.8%)
Depression Score	0–21	10.84 (5.12)
Loneliness Score	20–80	47.62 (9.41)
Family Communication Quality	1–5	3.11 (0.74)
Digital Media Dependency	24–120	71.45 (13.96)

As shown in Table 1, the sample exhibited a balanced gender distribution and represented a wide age range across mid-to-late adolescence. The mean depression score indicates a moderate level of depressive symptoms within the population. Loneliness levels were elevated above the scale midpoint, while family communication quality was slightly below the optimal range. Digital media dependency scores reflected high engagement and behavioral reliance on digital platforms among participants.

Table 2

Pearson Correlation Matrix of Study Variables

Variable	1	2	3	4
1. Depression	1			
2. Loneliness	.61**	1		
3. Family Communication Quality	−.48**	−.42**	1	
4. Digital Media Dependency	.53**	.49**	−.37**	1

The correlational analysis presented in Table 2 reveals strong and statistically significant associations among the study variables. Depression was positively correlated with loneliness and digital media dependency, and negatively correlated with family communication quality. These results provide preliminary support for the hypothesized relational structure underlying the neural network model.

Table 3

Neural Network Model Performance Indices

Dataset	RMSE	MAE	R^2
Training Set	1.92	1.47	.83
Validation Set	2.05	1.59	.80
Test Set	2.11	1.63	.79

The performance metrics reported in Table 3 demonstrate strong predictive accuracy and generalization of the neural network model. High coefficients of determination across all datasets indicate that the combined effects of loneliness, family communication quality, and digital media dependency explain a substantial proportion of variance in adolescent depressive symptoms.

Table 4

Relative Predictor Importance Based on SHAP Values

Predictor	Relative Importance (%)
Loneliness	39.6
Digital Media Dependency	33.1
Family Communication Quality	27.3

Table 4 illustrates the relative contribution of each predictor to the neural network's output. Loneliness emerged as the strongest determinant of adolescent depression, followed by digital media dependency, with family communication quality also exerting a substantial protective influence.

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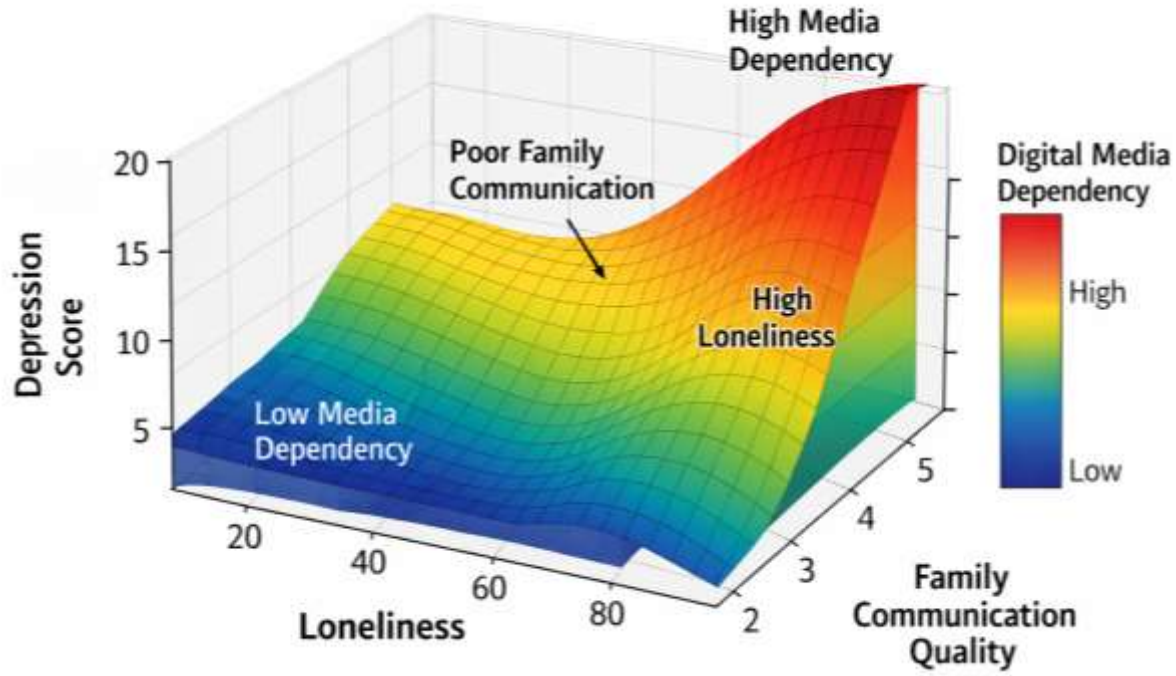
Figure 1

Interactive Effects of Loneliness, Family Communication Quality, and Digital Media Dependency on Adolescent Depression



The graphical output of the model (Figure 1) demonstrates a nonlinear interaction pattern, whereby high loneliness combined with poor family communication quality produces the steepest increase in depressive symptoms, an effect that is further amplified under conditions of elevated digital media dependency. This figure visually confirms the synergistic and compounding effects identified by the neural network model, highlighting the complex interplay among psychosocial and behavioral factors in shaping adolescent mental health outcomes.

4. Discussion

The present study employed neural network modeling to examine the interactive effects of loneliness, family communication quality, and digital media dependency on depressive symptoms among Indonesian adolescents. The findings revealed a robust and non-linear predictive structure, wherein loneliness emerged as the most powerful contributor to depressive symptomatology, followed by digital media dependency, with family communication quality exerting a significant protective influence. These results corroborate the growing body of international research indicating that adolescent depression is best understood as the product of interacting psychosocial and technological systems rather than isolated risk factors (Güveli et al., 2024; Kılınç et al., 2022; Nesi, 2020; Olson et al., 2023).

The strong association between loneliness and depression observed in the neural network model aligns closely with prior empirical findings across both adolescent and adult populations. Loneliness has been consistently identified as a central psychological mechanism driving emotional dysregulation, negative cognitive appraisal, and vulnerability to internalizing disorders (Kusumota et al., 2022; Simard & Volicer, 2020; Wetzel et al., 2021). The present study extends this literature by demonstrating that loneliness does not merely act as an independent predictor but operates as a core node within a dynamic system of interacting variables. Neural network interpretation using SHAP values indicated that high loneliness amplified the depressive impact of both poor family communication and excessive digital media use, revealing a synergistic effect that conventional linear models would likely underestimate.

Digital media dependency also emerged as a dominant predictor of adolescent depression. This finding is consistent with extensive evidence linking problematic smartphone use, social media overconsumption, and digital engagement patterns with increased depressive symptoms, anxiety, sleep

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disruption, and emotional exhaustion (Fitzpatrick et al., 2022; Gong et al., 2023; Sohn et al., 2021). Cross-national data further demonstrate that digital dependency exhibits consistent psychological consequences across cultural contexts (Alqaderi et al., 2023; Olson et al., 2023). The neural network results clarify that digital media dependency exerts both direct and indirect effects on depressive symptoms, intensifying loneliness while simultaneously weakening emotional regulation capacities.

The protective role of family communication quality identified in the present model is strongly supported by prior research. Open, supportive, and emotionally responsive family communication has been repeatedly shown to buffer adolescents against stress, anxiety, and depression, whereas dysfunctional communication patterns heighten emotional vulnerability (Davies et al., 2021; Dean et al., 2023; Özbek et al., 2025). Importantly, the neural network analysis revealed that high family communication quality significantly attenuated the depressive impact of loneliness and digital media dependency. This interactive buffering effect provides computational confirmation of family systems theories emphasizing the centrality of relational context in adolescent psychological development.

The nonlinear interaction patterns identified in Figure 1 illustrate how these variables co-evolve within adolescent psychological systems. High loneliness combined with low family communication quality produced the steepest increase in depressive symptoms, particularly under conditions of elevated digital media dependency. These findings are consistent with research demonstrating that adolescents often compensate for poor familial relationships by seeking emotional validation online, which can paradoxically intensify loneliness and depressive affect (Sabah et al., 2025; Vossen et al., 2024; Yu & Du, 2022). During periods of societal disruption such as the COVID-19 pandemic, such feedback loops have been shown to intensify, with adolescents experiencing heightened digital engagement alongside deteriorating mental health (Hong et al., 2023; Song et al., 2020; Yang et al., 2021).

The superior predictive performance of the neural network model relative to traditional statistical approaches highlights the necessity of adopting advanced computational frameworks in adolescent mental health research. Prior studies utilizing machine learning and digital phenotyping techniques have demonstrated significant improvements in identifying depressive risk patterns, emotional trajectories, and behavioral precursors to psychopathology (Gardea-Reséndez et al., 2024; Hilty et al., 2023; Wei & Guo, 2023). The present findings reinforce this methodological shift, illustrating that adolescent depression emerges from high-dimensional interaction spaces that demand analytic tools capable of modeling nonlinear complexity.

Furthermore, the results support emerging perspectives that digital technologies function simultaneously as therapeutic instruments and psychological stressors. While digital platforms enable innovative interventions such as online cognitive behavioral programs, automated screening systems, and remote mental health support, they also introduce new forms of dependency, emotional overload, and social comparison pressures (Gewali et al., 2021; Lukenga et al., 2023; Swartz & Novick, 2020). The dual role of technology underscores the importance of developing balanced digital engagement strategies within adolescent mental health frameworks.

Cultural context also plays a critical role in shaping these dynamics. Indonesian adolescents navigate rapid technological expansion alongside traditional family structures, creating unique intersections of modern digital influence and collectivist relational values. Prior cross-cultural studies have demonstrated that the psychological impact of digital engagement, loneliness, and family processes varies substantially across societies, influenced by educational systems, social norms, and socioeconomic conditions (Malik et al., 2025; Vuong et al., 2022; Wei & Guo, 2023). The present study contributes valuable data from a Southeast Asian context, expanding the global understanding of adolescent depression within digitally transforming societies.

5. Conclusion

In summary, the findings provide strong empirical support for conceptualizing adolescent depression as an emergent property of interacting psychosocial and technological systems. Loneliness, family communication quality, and digital media dependency operate not as isolated variables but as mutually reinforcing forces that shape emotional vulnerability and resilience. Neural network modeling offers a powerful methodological lens for capturing these complex dynamics and advancing precision mental health research.

6. Limitations & Suggestions

Despite the strengths of the present study, several limitations should be acknowledged. The cross-sectional design restricts causal inference, preventing definitive

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conclusions regarding temporal relationships among variables. Reliance on self-report instruments may introduce response bias and shared method variance. Additionally, although the sample was socioeconomically diverse, it was limited to urban regions of Indonesia, which may constrain generalizability to rural populations or other cultural contexts.

Future studies should employ longitudinal designs to examine developmental trajectories and causal pathways linking loneliness, family communication, digital media dependency, and depression. Incorporating multimodal data sources, including physiological indicators, behavioral logs, and digital phenotyping, may further enhance model precision. Cross-cultural replications are recommended to explore contextual variations and strengthen global applicability.

Intervention programs should prioritize strengthening family communication skills, promoting healthy digital habits, and addressing adolescent loneliness through school-based and community-level initiatives. Clinicians and educators may benefit from integrating technology-assisted monitoring tools while maintaining safeguards against digital overexposure. Policy frameworks should encourage collaborative partnerships among families, schools, and mental health services to create comprehensive support ecosystems for adolescent well-being.

Acknowledgments

We would like to express our appreciation and gratitude to all those who cooperated in carrying out this study.

Declaration of Interest

The authors of this article declared no conflict of interest.

Ethical Considerations

The study protocol adhered to the principles outlined in the Helsinki Declaration, which provides guidelines for ethical research involving human participants.

Transparency of Data

In accordance with the principles of transparency and open research, we declare that all data and materials used in this study are available upon request.

Funding

This research was carried out independently with personal funding and without the financial support of any governmental or private institution or organization.

Authors' Contributions

All authors equally contributed to this article.

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E-ISSN: 2981-2526