

## Predicting Adolescent Risk Behavior via Family Monitoring, Sensation Seeking, and Peer Deviance with Machine Learning Analysis

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### Article Info

#### Article type:

Original Research

#### How to cite this article:

McKenzie, A., Chennoufi, A., & Langlois, S. (2026). Predicting Adolescent Risk Behavior via Family Monitoring, Sensation Seeking, and Peer Deviance with Machine Learning Analysis. *Journal of Psychosociological Research in Family and Culture*, 4(1), 1-10.

<https://doi.org/10.61838/kman.jprfc.5335>



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### ABSTRACT

**Objective:** The present study aimed to predict adolescent risk behavior by examining the combined effects of family monitoring, sensation seeking, and peer deviance using machine learning analytical approaches.

**Methods and Materials:** This cross-sectional predictive study was conducted among 512 adolescents aged 14 to 18 years recruited from secondary schools in Tunisia using multistage cluster random sampling. Data were collected using standardized self-report instruments, including the Youth Risk Behavior Surveillance Questionnaire, the Parental Monitoring Scale, the Brief Sensation Seeking Scale, and the Peer Delinquency Scale, all of which demonstrated acceptable reliability and validity. Statistical analyses were performed using SPSS-27 to compute descriptive indices and Pearson correlations. Machine learning models, including random forest, support vector machine, gradient boosting, and multilayer perceptron neural networks, were implemented in Python. Data preprocessing included normalization and feature scaling, and model performance was evaluated using k-fold cross-validation and metrics such as accuracy, precision, recall, F1-score, and area under the ROC curve.

**Findings:** The results revealed that adolescent risk behavior was significantly negatively associated with family monitoring and positively associated with sensation seeking and peer deviance. Among the predictive models, the neural network demonstrated the highest performance, achieving the greatest accuracy and discriminative power. Feature importance analyses consistently identified peer deviance as the strongest predictor of risk behavior, followed by sensation seeking, while family monitoring showed a weaker but still significant contribution. The models indicated that nonlinear interactions among predictors significantly improved prediction accuracy compared to linear approaches.

**Conclusion:** The findings highlight the critical role of peer deviance and sensation seeking in shaping adolescent risk behavior, while confirming the protective function of family monitoring. The superior performance of machine learning models underscores their utility in capturing complex behavioral patterns and enhancing predictive precision.

**Keywords:** Adolescent Risk Behavior; Family Monitoring; Sensation Seeking; Peer Deviance; Machine Learning; Predictive Modeling

## 1 Introduction

Adolescent risk behavior remains a central concern within developmental psychology, criminology, and public health due to its far-reaching implications for individual well-being and societal stability. Risk behaviors, including substance use, delinquency, aggression, and unsafe social practices, often emerge during adolescence as part of a broader developmental trajectory characterized by heightened exploration, identity formation, and sensitivity to environmental influences. While a certain degree of experimentation is considered normative during this period, persistent or escalated engagement in risk behaviors has been associated with adverse long-term outcomes, including criminal involvement, mental health disorders, and reduced socioeconomic attainment (Cavanagh, 2022; Gottfredson et al., 2021). Understanding the multifactorial origins of such behaviors is therefore essential for both prevention and intervention efforts.

Theoretical frameworks explaining adolescent risk behavior have increasingly emphasized the interaction between individual dispositions and environmental contexts. The dual-systems model posits that an imbalance between socioemotional reward systems and cognitive control mechanisms contributes to heightened risk-taking during adolescence, particularly under conditions of peer influence (Wojciechowski, 2021; Yim, 2020). This neurodevelopmental perspective aligns with criminological theories that highlight the role of low self-control and situational opportunities in shaping delinquent behavior (Osgood, 2023; Qu et al., 2021). Importantly, these frameworks converge on the notion that adolescent risk behavior is not solely an individual phenomenon but is embedded within complex social systems involving family dynamics, peer networks, and broader cultural contexts (Datchi, 2022).

Among the individual-level predictors, sensation seeking has been consistently identified as a robust determinant of adolescent risk-taking. Sensation seeking refers to the propensity to pursue novel, intense, and stimulating experiences, often accompanied by a willingness to take risks for such experiences. Empirical studies have demonstrated strong associations between sensation seeking and various forms of delinquency, substance use, and impulsive behavior (Mazza et al., 2025; Qamar & Qurat-ul-ain, 2023). Neurobiological evidence further suggests that heightened reward sensitivity during adolescence amplifies the appeal of risky behaviors, particularly when these

behaviors are perceived as socially rewarding or emotionally stimulating (Moore et al., 2024). Moreover, sensation seeking has been linked to positive affective responses during antisocial acts, indicating that for some adolescents, risk behavior may be intrinsically reinforcing (Moore et al., 2024).

However, individual predispositions alone cannot fully account for the variability in adolescent risk behavior. Family processes, particularly parental monitoring, play a critical role in shaping behavioral outcomes. Parental monitoring encompasses parents' knowledge of their children's activities, peers, and whereabouts, as well as the establishment of rules and expectations regarding behavior. High levels of parental monitoring have been consistently associated with lower levels of delinquency and substance use, as they limit opportunities for engagement in risky contexts and promote internalization of prosocial norms (Liu & Vazsonyi, 2023; Vaughan et al., 2022). Conversely, low parental supervision has been identified as a significant risk factor for antisocial behavior, particularly when combined with other vulnerabilities such as impulsivity or exposure to deviant peers (Friedman et al., 2021; Wallner et al., 2020). The protective function of family monitoring is further supported by research demonstrating its role in moderating the effects of peer influence and individual risk traits (Fine et al., 2023).

Peer influence constitutes another critical domain in understanding adolescent risk behavior. During adolescence, peer relationships become increasingly salient, often surpassing parental influence in shaping attitudes and behaviors. Association with deviant peers has been repeatedly shown to predict a wide range of risk behaviors, including substance use, aggression, and criminal activity (Jose et al., 2021; Ouellet et al., 2022). The mechanisms underlying this association include social learning, normative influence, and reinforcement processes, whereby adolescents adopt behaviors that are modeled and rewarded within their peer groups. Furthermore, the stability and intensity of deviant peer relationships have been found to amplify their impact, suggesting that not all peer influences are equally consequential (Ouellet et al., 2022). The role of peer deviance is also evident in digital contexts, where exposure to risky behaviors through social media and online interactions can further extend peer influence beyond traditional settings (Jensen et al., 2022).

Recent research has also highlighted the interplay between family monitoring, sensation seeking, and peer deviance, suggesting that these factors do not operate

independently but rather interact in complex ways. For instance, adolescents high in sensation seeking may be more likely to affiliate with deviant peers, thereby increasing their exposure to risky behaviors (Wilhoit & Goodnight, 2022). Similarly, inadequate parental monitoring may facilitate such affiliations by reducing constraints on adolescents' social interactions (Vaughan et al., 2022). Longitudinal studies have demonstrated bidirectional relationships among these variables, indicating that risk behavior can both influence and be influenced by changes in family and peer contexts over time (Liu & Vazsonyi, 2023). These findings underscore the need for integrative models that capture the dynamic interdependencies among individual, familial, and social factors.

In addition to these psychosocial determinants, broader contextual influences such as socioeconomic conditions, neighborhood environments, and institutional interactions have been shown to shape adolescent risk behavior. Exposure to harsh or unpredictable environments, for example, has been linked to the development of short-term decision-making strategies and increased propensity for delinquency (Deitzer, Frankenhuis, Jacobsen, et al., 2024; Deitzer, Frankenhuis, Ribeaud, et al., 2024). Similarly, early interactions with law enforcement and justice systems can influence adolescents' perceptions of authority and future behavior, potentially reinforcing deviant trajectories (Deitzer, Frankenhuis, Jacobsen, et al., 2024). Cultural and structural factors also play a role, as variations in norms, opportunities, and constraints across societies can lead to different patterns of risk behavior (Oliveira, 2025; Zedaker et al., 2024).

Despite substantial advances in identifying the determinants of adolescent risk behavior, traditional analytical approaches often face limitations in capturing the complexity and nonlinearity of these relationships. Conventional statistical models typically rely on linear assumptions and may struggle to account for high-dimensional interactions among variables. In contrast, machine learning techniques offer a powerful alternative by enabling the analysis of complex, nonlinear patterns and improving predictive accuracy. Recent applications of machine learning in behavioral science have demonstrated its utility in identifying risk profiles, predicting delinquent outcomes, and uncovering latent structures within data (Cioban et al., 2021; Mahbub & Rahman, 2023). These methods are particularly well-suited for integrating multiple domains of influence, including psychological traits, family dynamics, and peer networks.

Moreover, machine learning approaches allow for the evaluation of variable importance, providing insights into the relative contribution of different predictors. This capability is crucial for informing targeted interventions, as it enables researchers and practitioners to identify the most influential factors driving risk behavior. For example, distinguishing the relative impact of peer deviance versus family monitoring can guide the design of prevention programs that prioritize social or familial interventions accordingly. Additionally, machine learning models can be validated using cross-validation techniques, enhancing their generalizability and robustness across different populations (Mahbub & Rahman, 2023).

The integration of machine learning with established theoretical frameworks offers a promising avenue for advancing the study of adolescent risk behavior. By combining predictive analytics with developmental and criminological theories, researchers can achieve a more comprehensive understanding of how multiple risk factors interact over time. This approach aligns with contemporary calls for interdisciplinary research that bridges methodological innovation with theoretical rigor (Kübel et al., 2024; Sasson et al., 2022). Furthermore, such integration facilitates the translation of research findings into practical applications, including early identification of at-risk youth and the development of data-driven intervention strategies.

At the same time, it is important to recognize that adolescent risk behavior is not a uniform construct but encompasses diverse forms and trajectories. Studies have identified distinct profiles of risk-taking, ranging from occasional experimentation to chronic and severe delinquency (Couture et al., 2021). These profiles are influenced by a combination of individual vulnerabilities, social contexts, and developmental processes, highlighting the need for nuanced analytical approaches. Machine learning techniques, with their capacity for clustering and classification, are particularly well-suited for identifying such heterogeneous patterns within populations.

In summary, the literature underscores the multifaceted nature of adolescent risk behavior, emphasizing the roles of sensation seeking, family monitoring, and peer deviance as key determinants. While substantial progress has been made in understanding these factors, there remains a need for integrative models that capture their complex interactions and enhance predictive accuracy. The application of machine learning offers a valuable tool for addressing this gap, enabling the analysis of high-dimensional data and the identification of critical risk factors. Accordingly, the

present study aims to predict adolescent risk behavior using machine learning techniques by examining the combined effects of family monitoring, sensation seeking, and peer deviance among adolescents in Tunisia.

## 2 Methods and Materials

### 2.1 Study Design and Participants

This study was designed as a cross-sectional, predictive-correlational investigation aimed at modeling adolescent risk behavior using both traditional statistical approaches and advanced machine learning techniques. The target population consisted of secondary school students in Tunisia during the 2025 academic year. A total of 512 adolescents were selected using a multistage cluster random sampling method, ensuring representation across urban and semi-urban educational districts. Participants were aged between 14 and 18 years, with a balanced distribution in terms of gender and socioeconomic background. Inclusion criteria required participants to be currently enrolled in school and capable of completing self-report questionnaires, while exclusion criteria included incomplete responses or withdrawal during data collection. Ethical approval was obtained from the relevant institutional review board, and informed consent was secured from both participants and their guardians prior to participation. Data collection was conducted in classroom settings under standardized conditions to ensure consistency and minimize environmental bias.

### 2.2 Measures

Data collection was carried out using a set of standardized and psychometrically validated instruments that operationalized the core study variables. Adolescent risk behavior was assessed using the Youth Risk Behavior Surveillance Questionnaire, originally developed by the Centers for Disease Control and Prevention, which includes multiple subscales covering behaviors such as substance use, aggression, and unsafe activities; the instrument consists of 40 items rated on a Likert-type scale, with higher scores indicating greater engagement in risk behaviors, and prior research has confirmed its reliability and construct validity across diverse cultural contexts. Family monitoring was measured using the Parental Monitoring Scale developed by Stattin and Kerr, which evaluates parental knowledge, control, and adolescent disclosure through 9 items scored on a five-point Likert scale; this scale has demonstrated strong

internal consistency and predictive validity in adolescent populations. Sensation seeking was assessed in Arabic (بالتحقيق) the Brief Sensation Seeking Scale developed by Hoyle and colleagues, comprising 8 items that capture thrill and adventure seeking, experience seeking, disinhibition, and boredom susceptibility, with responses recorded on a five-point scale; the scale has been widely validated and shows robust reliability coefficients. Peer deviance was measured using the Peer Delinquency Scale, which assesses the extent of adolescents' exposure to deviant peer behaviors through 10 items rated on a Likert scale; this instrument has shown satisfactory psychometric properties in previous studies. All instruments were translated and back-translated into Arabic and French to ensure linguistic equivalence, and a pilot study confirmed their reliability in the Tunisian context with Cronbach's alpha coefficients exceeding acceptable thresholds.

### 2.3 Data Analysis

Data analysis was conducted using a hybrid analytical framework integrating classical statistical techniques and machine learning algorithms. Initially, descriptive statistics and Pearson correlation analyses were performed using IBM SPSS version 27 to examine the distributional properties and bivariate relationships among variables. Subsequently, predictive modeling was implemented in Python using libraries such as Scikit-learn and TensorFlow. The dataset was preprocessed through normalization, handling of missing values, and feature scaling to optimize model performance. Multiple supervised machine learning models were employed, including random forest, support vector machine, gradient boosting, and multilayer perceptron neural networks, to predict levels of adolescent risk behavior based on family monitoring, sensation seeking, and peer deviance. Model performance was evaluated using k-fold cross-validation to ensure generalizability, and key performance metrics such as accuracy, precision, recall, F1-score, and area under the receiver operating characteristic curve were computed. Feature importance analysis was conducted to identify the relative contribution of each predictor variable to the outcome. Hyperparameter tuning was performed using grid search optimization to enhance model accuracy and prevent overfitting. The integration of statistical and machine learning approaches allowed for both interpretability and predictive robustness in understanding adolescent risk behavior within the studied population.

### 3 Findings and Results

The final sample consisted of 512 adolescents from secondary schools in Tunisia, with a mean age of 16.21 years (SD = 1.17). Of the participants, 259 (50.6%) were female and 253 (49.4%) were male, indicating a balanced gender distribution. In terms of educational level, 34.2% were enrolled in lower secondary grades, while 65.8% were in upper secondary education. Socioeconomic status, assessed

via self-reported parental income and education indicators, showed that 28.7% of participants were from low-income families, 46.1% from middle-income families, and 25.2% from high-income families. Additionally, 61.3% of adolescents reported living in urban areas, whereas 38.7% resided in semi-urban regions. The descriptive profile indicates a heterogeneous sample suitable for examining variability in adolescent risk behavior and its psychosocial predictors.

**Table 1**

*Descriptive Statistics and Correlations Among Study Variables*

Variable	Mean	SD	1	2	3	4
1. Risk Behavior	47.36	10.84	—			
2. Family Monitoring	28.91	6.27	-0.42**	—		
3. Sensation Seeking	30.15	7.03	0.47**	-0.31**	—	
4. Peer Deviance	26.74	6.89	0.53**	-0.36**	0.44**	—

As presented in Table 1, the descriptive statistics indicate moderate levels of adolescent risk behavior, sensation seeking, and peer deviance, alongside relatively high levels of perceived family monitoring. Correlation analyses revealed that adolescent risk behavior was significantly and negatively associated with family monitoring ( $r = -0.42, p < 0.01$ ), suggesting that higher parental oversight corresponds to lower engagement in risky behaviors. In contrast, sensation seeking ( $r = 0.47, p < 0.01$ ) and peer deviance ( $r =$

$0.53, p < 0.01$ ) were both positively and significantly related to risk behavior, indicating that adolescents with higher tendencies toward novelty seeking and greater exposure to deviant peers are more likely to engage in risk behaviors. Additionally, family monitoring was negatively correlated with both sensation seeking and peer deviance, while sensation seeking showed a strong positive association with peer deviance, highlighting interconnected psychosocial dynamics underlying adolescent behavior.

**Table 2**

*Machine Learning Model Performance Metrics for Predicting Risk Behavior*

Model	Accuracy	Precision	Recall	F1-Score	AUC
Random Forest	0.84	0.82	0.83	0.82	0.89
Support Vector Machine	0.81	0.79	0.80	0.79	0.86
Gradient Boosting	0.86	0.84	0.85	0.84	0.91
Neural Network (MLP)	0.88	0.86	0.87	0.86	0.93

The results presented in Table 2 demonstrate the comparative performance of four machine learning models in predicting adolescent risk behavior. Among the models, the multilayer perceptron neural network achieved the highest performance across all evaluation metrics, with an accuracy of 0.88, precision of 0.86, recall of 0.87, F1-score of 0.86, and an AUC of 0.93, indicating excellent classification capability. Gradient boosting also performed strongly, with an accuracy of 0.86 and AUC of 0.91,

suggesting robust predictive power. The random forest model showed slightly lower but still substantial performance (accuracy = 0.84, AUC = 0.89), while the support vector machine demonstrated the lowest performance among the tested models, though still within acceptable predictive ranges. These findings suggest that nonlinear and ensemble-based models are particularly effective in capturing the complex interactions among psychosocial predictors of adolescent risk behavior.

**Table 3**

*Feature Importance Scores Across Machine Learning Models*

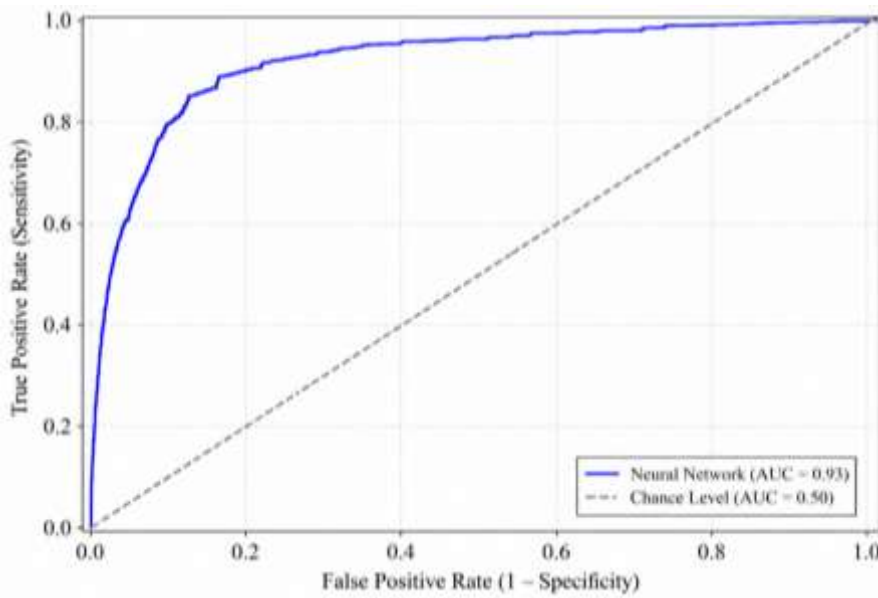
Predictor Variable	Random Forest	Gradient Boosting	Neural Network
Peer Deviance	0.41	0.44	0.46
Sensation Seeking	0.35	0.33	0.32
Family Monitoring	0.24	0.23	0.22

Table 3 presents the relative importance of predictor variables across the best-performing machine learning models. Peer deviance consistently emerged as the most influential predictor of adolescent risk behavior, with importance scores ranging from 0.41 to 0.46 across models. Sensation seeking was identified as the second most

important predictor, contributing between 0.32 and 0.35 to model predictions. Family monitoring, while still significant, showed comparatively lower importance scores (0.22–0.24), indicating a protective but less dominant role relative to peer and personality factors.

**Figure 1**

*Receiver Operating Characteristic (ROC) Curve for Neural Network Model Predicting Adolescent Risk Behavior*



The consistency of these importance patterns across different algorithms underscores the robustness of the findings and highlights the central role of peer-related influences in shaping adolescent behavioral outcomes.

**4 Discussion**

The present study aimed to predict adolescent risk behavior using a machine learning framework by examining the combined effects of family monitoring, sensation seeking, and peer deviance. The findings revealed several important patterns that contribute to both theoretical understanding and applied perspectives in adolescent behavioral research. First, the correlational analyses indicated that adolescent risk behavior was negatively

associated with family monitoring and positively associated with both sensation seeking and peer deviance. Second, the machine learning models demonstrated strong predictive performance, with the neural network model outperforming other algorithms, suggesting that nonlinear interactions among predictors play a significant role in explaining adolescent risk behavior. Third, feature importance analyses consistently identified peer deviance as the most influential predictor, followed by sensation seeking and family monitoring.

The negative association between family monitoring and adolescent risk behavior is consistent with a large body of developmental and criminological research emphasizing the protective role of parental oversight. High levels of parental monitoring reduce adolescents’ opportunities to engage in

risky contexts and promote adherence to social norms, thereby lowering the likelihood of delinquent behavior (Liu & Vazsonyi, 2023; Vaughan et al., 2022). The present findings reinforce this perspective by demonstrating that even within a multivariate predictive framework, family monitoring retains a significant, albeit comparatively smaller, influence on risk outcomes. This aligns with studies indicating that parental knowledge and rule-setting serve as key mechanisms through which families regulate adolescent behavior and buffer against external risks (Fine et al., 2023). Furthermore, the observed protective effect is consistent with ecological models of delinquency, which highlight the role of family-level controls in shaping behavioral trajectories (Datchi, 2022). However, the relatively lower feature importance of family monitoring compared to peer deviance suggests that its influence may be indirect or mediated through other factors, such as peer selection processes or individual traits.

The positive relationship between sensation seeking and adolescent risk behavior observed in this study supports existing theoretical and empirical work identifying sensation seeking as a central dispositional risk factor. Adolescents high in sensation seeking are more likely to pursue novel and stimulating experiences, often disregarding potential negative consequences (Mazza et al., 2025; Qamar & Qurat-ain, 2023). The present results are consistent with neurodevelopmental accounts suggesting that heightened reward sensitivity during adolescence amplifies the appeal of risky behaviors (Moore et al., 2024). Moreover, the moderate to strong contribution of sensation seeking across machine learning models indicates that it is not merely a background trait but a key driver of behavioral outcomes. This finding is also aligned with research demonstrating that sensation seeking is associated with various forms of delinquency, including substance use and aggressive behavior (Mahbub & Rahman, 2023). Importantly, sensation seeking may interact with environmental factors, such as peer influence, to further increase risk, highlighting the need for integrative models that consider both individual and contextual determinants.

Among all predictors, peer deviance emerged as the most influential factor in predicting adolescent risk behavior, a finding that is strongly supported by prior literature. The centrality of peer influence during adolescence has been well documented, with deviant peer affiliation serving as a primary pathway through which adolescents are exposed to and reinforced for engaging in risky behaviors (Jose et al., 2021; Ouellet et al., 2022). The high feature importance of

peer deviance in the present study suggests that social learning and normative processes within peer groups play a dominant role in shaping behavior. This is consistent with the unstructured socializing theory, which posits that time spent with peers in unsupervised contexts increases opportunities for delinquency (Osgood, 2023). Additionally, the findings align with research demonstrating that peer influence can mediate the effects of individual traits such as impulsivity and sensation seeking on risk behavior (Wilhoit & Goodnight, 2022). The robustness of peer deviance as a predictor across different machine learning models underscores its critical role and suggests that interventions targeting peer networks may be particularly effective.

The superior performance of the neural network model relative to other machine learning algorithms highlights the importance of capturing nonlinear relationships and complex interactions among predictors. Traditional statistical approaches often assume linearity and independence among variables, which may not adequately reflect the multifaceted nature of adolescent behavior. The higher accuracy and AUC observed for the neural network suggest that interactions among family monitoring, sensation seeking, and peer deviance contribute significantly to risk outcomes. This finding is consistent with recent research advocating for the use of advanced analytical techniques in behavioral science to better model complex systems (Cioban et al., 2021). The strong performance of ensemble methods such as gradient boosting further supports the notion that combining multiple decision pathways enhances predictive accuracy, particularly in high-dimensional datasets.

The integration of machine learning with established theoretical frameworks provides a more nuanced understanding of adolescent risk behavior. The findings support the dual-systems model, which emphasizes the interplay between reward sensitivity and regulatory processes, as well as ecological models that highlight the influence of family and peer contexts (Wallner et al., 2020; Wojciechowski, 2021). Moreover, the results are consistent with developmental criminology perspectives that view delinquency as the outcome of cumulative risk factors operating across multiple domains (Farrington & Bergström, 2021). The identification of peer deviance as the most influential predictor suggests that social environments may amplify or attenuate individual predispositions, thereby shaping behavioral trajectories over time.

The findings also resonate with research on environmental unpredictability and its impact on adolescent

decision-making. Exposure to unstable or harsh environments has been linked to the development of short-term mindsets and increased risk-taking behavior (Deitzer, Frankenhuis, Jacobsen, et al., 2024; Deitzer, Frankenhuis, Ribeaud, et al., 2024). In this context, peer deviance may serve as both a reflection of and a response to broader environmental conditions, further complicating the relationship between individual and contextual factors. Additionally, the role of digital and social media environments in extending peer influence beyond physical interactions should be considered, as these platforms provide additional avenues for exposure to deviant behaviors (Jensen et al., 2022).

Gender and contextual differences, although not the primary focus of the present study, may also influence the observed relationships. Previous research has documented variations in the impact of peer and family factors across gender and cultural contexts, suggesting that the strength and direction of these associations may differ depending on social norms and expectations (Oliveira, 2025; Zedaker et al., 2024). While the current findings provide a generalizable model within the Tunisian context, future studies should examine potential moderating effects of gender, culture, and socioeconomic status to further refine predictive models.

## 5 Conclusion

The present study contributes to the growing literature on adolescent risk behavior by demonstrating the utility of machine learning approaches in capturing complex, multidimensional relationships. By integrating psychological traits, family processes, and peer influences within a single predictive framework, the study provides a comprehensive model that reflects the dynamic nature of adolescent development. The findings highlight the importance of considering both individual and social factors in understanding risk behavior and underscore the potential of data-driven approaches for informing prevention and intervention strategies.

Despite its contributions, the present study is subject to several limitations that should be acknowledged. First, the cross-sectional design precludes causal inferences regarding the relationships among variables, limiting the ability to determine temporal ordering or directionality. Second, the reliance on self-report measures introduces the possibility of response bias, including social desirability and recall inaccuracies, which may affect the validity of the data. Third, although the sample was diverse within the Tunisian

context, the findings may not be fully generalizable to other cultural or geographic settings with different social norms and structural conditions. Additionally, the study focused on a limited set of predictors, and other relevant variables, such as mental health status, school environment, and community factors, were not included in the model. Finally, while machine learning models offer strong predictive capabilities, they may lack interpretability compared to traditional statistical methods, which can pose challenges for translating findings into practice.

Future research should adopt longitudinal designs to examine the developmental trajectories of adolescent risk behavior and to establish causal relationships among predictors. Expanding the range of variables to include psychological, environmental, and biological factors would provide a more comprehensive understanding of risk behavior. Additionally, future studies should explore the moderating and mediating mechanisms underlying the relationships among family monitoring, sensation seeking, and peer deviance. Cross-cultural comparisons would also be valuable in assessing the generalizability of findings and identifying culturally specific patterns. From a methodological perspective, integrating explainable artificial intelligence techniques could enhance the interpretability of machine learning models, making them more accessible for researchers and practitioners. Finally, future work should consider the role of digital environments and social media in shaping peer influence and risk behavior, given their increasing relevance in adolescents' lives.

The findings of this study have important implications for prevention and intervention efforts aimed at reducing adolescent risk behavior. Programs should prioritize strengthening family monitoring practices by equipping parents with skills to effectively supervise and communicate with their children. Interventions targeting sensation seeking should focus on providing safe and constructive outlets for novelty-seeking tendencies, such as engagement in sports or creative activities. Given the strong influence of peer deviance, strategies that address peer group dynamics, including peer mentoring and prosocial peer network development, are likely to be particularly effective. Schools and community organizations should implement programs that promote positive social norms and reduce opportunities for engagement in risky behaviors. Additionally, the use of data-driven approaches, including machine learning models, can support early identification of at-risk adolescents and facilitate targeted interventions. By addressing multiple levels of influence, from individual traits to social

environments, practitioners can develop more comprehensive and effective strategies for promoting healthy 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.

### Acknowledgments

We would like to express our gratitude to all individuals helped us to do the project.

### Declaration of Interest

The authors report no conflict of interest.

### Funding

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

### 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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