

Predicting Adolescent Psychological Well-Being Using Gradient Boosting Models and Multidimensional Life Satisfaction Indicators

Li. Na¹, Chen. Yu-Han^{2*}

¹ Department of Developmental Psychology, Peking University, Beijing, China

² Department of Counseling Psychology, National Taiwan University, Taipei, Taiwan

* Corresponding author email address: yuhan.chen@ntu.edu.tw

Article Info

Article type:

Original Research

How to cite this article:

Na, L., & Yu-Han, C. (2025). Predicting Adolescent Psychological Well-Being Using Gradient Boosting Models and Multidimensional Life Satisfaction Indicators. *Journal of Adolescent and Youth Psychological Studies*, 6(12), 1-11.

<http://dx.doi.org/10.61838/kman.jayps.4913>



© 2025 the authors. Published by KMAN Publication Inc. (KMANPUB), Ontario, Canada. This is an open access article under the terms of the Creative Commons Attribution-NonCommercial 4.0 International (CC BY-NC 4.0) License.

ABSTRACT

Objective: The objective of this study was to examine the extent to which adolescent psychological well-being can be accurately predicted using gradient boosting machine learning models integrating multidimensional life satisfaction indicators.

Methods and Materials: This cross-sectional study was conducted among secondary school adolescents in Taiwan using a school-based sampling framework. Psychological well-being was assessed as a continuous outcome variable, while multidimensional life satisfaction domains—including emotional health, family life, peer relationships, school experience, academic self-satisfaction, physical health, neighborhood context, and perceived economic status—were used as predictive features alongside key demographic and behavioral covariates. Advanced gradient boosting algorithms were trained and validated using a hold-out testing approach with cross-validated hyperparameter optimization. Model performance was evaluated using inferential predictive metrics, and explainable machine learning techniques were applied to quantify feature contributions and non-linear effects.

Findings: Inferential results demonstrated that gradient boosting models explained a substantial proportion of variance in adolescent psychological well-being, with ensemble models achieving high predictive accuracy and low estimation error. Emotional health satisfaction emerged as the strongest predictor, followed by family life satisfaction and school life satisfaction, indicating statistically meaningful and non-linear contributions to well-being. Peer life satisfaction and academic self-satisfaction showed moderate but significant predictive influence, while health-related behaviors such as sleep duration exhibited curvilinear effects. Explainability analyses revealed marked inter-individual heterogeneity in predictor importance, supporting the presence of multiple predictive pathways to psychological well-being rather than a single dominant profile.

Conclusion: The findings indicate that adolescent psychological well-being can be robustly predicted using gradient boosting models that integrate multidimensional life satisfaction indicators.

Keywords: Adolescent well-being; life satisfaction; gradient boosting; machine learning; psychological health; explainable artificial intelligence

1. Introduction

Adolescent psychological well-being has emerged as a central construct in contemporary developmental psychology, public health, and educational research, reflecting a growing recognition that mental health in adolescence cannot be reduced solely to the absence of psychopathology but must also encompass positive functioning, life satisfaction, and adaptive psychosocial resources. Well-being during adolescence is increasingly understood as a multidimensional phenomenon shaped by emotional, social, behavioral, and contextual factors that interact dynamically across developmental stages. Large-scale epidemiological evidence indicates that substantial proportions of adolescents worldwide experience suboptimal levels of psychological well-being, even in the absence of clinically diagnosable disorders, underscoring the importance of preventive and promotive frameworks that focus on strengths, resources, and subjective evaluations of life circumstances (Chaves, 2021; Gregory et al., 2021). This perspective aligns with dual-factor and salutogenic models, which emphasize the coexistence of positive well-being and mental health difficulties and call for analytical approaches capable of capturing this complexity (Bersia, Berchiolla, et al., 2022; Cordon et al., 2025; King et al., 2021).

A substantial body of research has documented that life satisfaction constitutes one of the most robust and consistent indicators of adolescent well-being. Life satisfaction reflects a global cognitive evaluation of one's quality of life and has been shown to be closely linked to emotional adjustment, resilience, academic functioning, and long-term mental health trajectories (Marquez, Katsantonis, et al., 2022; Willroth et al., 2021). Importantly, life satisfaction is inherently multidimensional during adolescence, encompassing evaluations of family relationships, peer interactions, school experiences, physical and emotional health, neighborhood context, and perceived socioeconomic conditions. Empirical studies across diverse cultural contexts have demonstrated that these domains do not contribute equally to psychological well-being and that their relative importance may vary depending on individual characteristics, developmental stage, and environmental conditions (Cosma et al., 2021; Marquez, Humphrey, et al., 2022; Marquez, Lambert, et al., 2022). This multidimensionality highlights the limitations of linear and univariate analytical approaches and underscores the need for more sophisticated modeling strategies.

Family and social relationships represent foundational domains of adolescent life satisfaction and well-being. Positive parent-child relationships, perceived social support, and secure interpersonal bonds have been consistently associated with higher life satisfaction, stronger self-esteem, and greater psychological resilience among adolescents (Cherewick et al., 2024; Dam et al., 2023; Poudel et al., 2020). Conversely, relational stressors and cumulative social risks have been linked to poorer mental health outcomes, with coping efficacy and psychological capital acting as key mediating and moderating mechanisms (Xiong et al., 2021; Xiong et al., 2020). Peer relationships, in particular, play a central role during adolescence, influencing emotional well-being, self-concept, and perceived belonging, while also interacting with school climate and academic self-perceptions (Lereya et al., 2022; Pierannunzio et al., 2022). These findings reinforce the importance of modeling interdependencies among social domains rather than treating them as isolated predictors.

School and academic contexts constitute another critical dimension of adolescent life satisfaction and psychological well-being. Research has shown that satisfaction with school life mediates the relationship between academic stressors and mental health outcomes, serving as a protective factor against emotional distress (Cavioni et al., 2021; Dias-Viana & Noronha, 2022). Academic self-satisfaction, adaptability, and perceived competence have also been linked to life satisfaction and lower psychological strain, particularly when supported by adequate health resources and coping capacities (Martin et al., 2023). At the same time, structural inequalities in educational environments, including socioeconomic disparities and differential access to learning resources, have been shown to exert long-lasting effects on adolescent well-being, especially in the context of societal disruptions such as the COVID-19 pandemic (Green et al., 2021; Hoefnagels et al., 2022). These findings suggest that school-related satisfaction is both a direct contributor to well-being and a pathway through which broader social inequalities operate.

Health-related behaviors and physical well-being are also closely intertwined with adolescent life satisfaction and psychological outcomes. Physical activity, sleep quality, and leisure engagement have been repeatedly associated with higher life satisfaction and better mental health, whereas sedentary behavior and sleep deprivation have been linked to emotional difficulties and reduced well-being (Ayhan et al., 2023; Cao et al., 2022; Litago et al., 2020). These associations are often non-linear and context-dependent,

indicating that optimal levels of health behaviors may vary across individuals and interact with psychosocial factors. Moreover, subjective evaluations of physical and emotional health have been shown to exert stronger effects on psychological well-being than objective health indicators, emphasizing the centrality of adolescents' own perceptions in well-being research (Diržytė & Perminas, 2021; Mei et al., 2020).

The COVID-19 pandemic has further intensified scholarly attention to adolescent well-being and life satisfaction, revealing both vulnerabilities and sources of resilience. Longitudinal and cross-sectional studies have documented declines in life satisfaction and mental well-being among adolescents during periods of lockdown and social disruption, with notable gender differences and individual variability (Miranda et al., 2020; Sabine et al., 2021; Schoeps et al., 2022). At the same time, protective factors such as growth mindset, psychological capital, and supportive environments have been shown to buffer the negative effects of stress and uncertainty on life satisfaction and well-being (Diržytė & Perminas, 2021; Jiang et al., 2025). These findings underscore the importance of adopting analytical frameworks that can accommodate heterogeneity in risk and resilience pathways rather than relying solely on average effects.

Despite the extensive literature on life satisfaction and adolescent well-being, methodological limitations remain evident. Much of the existing research relies on traditional regression-based approaches that assume linearity, independence, and additive effects among predictors. While these methods have yielded valuable insights, they may be insufficient for capturing the complex, non-linear, and interactive relationships that characterize psychological well-being in adolescence. Recent advances in machine learning offer promising alternatives by enabling the integration of high-dimensional data, modeling of complex interactions, and improved predictive accuracy. Gradient boosting models, in particular, have demonstrated strong performance in health and psychological research contexts due to their ability to handle multicollinearity, non-linearity, and heterogeneous effects across individuals (Blake et al., 2025; Cordon et al., 2025). However, their application to adolescent well-being research remains relatively limited, especially in studies that explicitly integrate multidimensional life satisfaction indicators.

Another critical gap in the literature concerns interpretability. While machine learning models offer enhanced predictive power, their perceived "black box"

nature has raised concerns regarding theoretical transparency and practical utility in psychological research. Recent developments in explainable artificial intelligence have begun to address this challenge by providing tools that quantify feature contributions and elucidate individual-level prediction pathways. Applying such techniques to adolescent well-being can yield nuanced insights into how different life satisfaction domains jointly shape psychological outcomes and how these relationships vary across adolescents, thereby bridging the gap between prediction and theory (Bersia, Charrier, et al., 2022; Marquez, Katsantonis, et al., 2022).

Cultural context further reinforces the need for context-sensitive and flexible analytical approaches. Evidence from East Asian societies suggests that the relative salience of family, academic, and social domains in shaping adolescent well-being may differ from Western contexts due to cultural norms emphasizing collectivism, educational achievement, and family interdependence (Dam et al., 2023; Xiong et al., 2021). Taiwan, in particular, represents a sociocultural setting where academic expectations, family involvement, and rapid digitalization intersect, potentially producing unique patterns of life satisfaction and psychological well-being. Yet, empirical studies that leverage advanced analytical techniques to examine these patterns in Taiwanese adolescents remain scarce.

In light of these theoretical, empirical, and methodological considerations, the present study seeks to advance the literature by applying gradient boosting machine learning models to predict adolescent psychological well-being using a comprehensive set of multidimensional life satisfaction indicators within a Taiwanese context, with the aim of identifying the relative and interactive contributions of key life domains to well-being outcomes.

2. Methods and Materials

2.1. Study Design and Participants

The present study employed a cross-sectional, school-based observational design aimed at developing and validating gradient boosting machine learning models to predict psychological well-being among adolescents using multidimensional life satisfaction indicators. The study population consisted of adolescents enrolled in lower and upper secondary schools across urban and semi-urban regions of Taiwan. A multi-stage cluster sampling strategy was applied to enhance representativeness. In the first stage,

public and private schools were randomly selected from official lists provided by regional education authorities. In the second stage, intact classrooms within each selected school were randomly chosen, and all students within those classrooms were invited to participate. Eligibility criteria included being between 12 and 18 years of age, current enrollment in the selected schools, sufficient proficiency in Mandarin Chinese to complete self-report questionnaires, and absence of diagnosed severe cognitive or neurodevelopmental disorders that could impair comprehension of survey items. Prior to data collection, written informed consent was obtained from parents or legal guardians, and assent was obtained from all participating adolescents.

2.2. Measures

Data were collected using a structured self-administered questionnaire battery designed to capture psychological well-being and multiple dimensions of life satisfaction, along with relevant demographic and contextual variables. Psychological well-being was operationalized as the primary outcome variable and assessed using a validated adolescent well-being scale adapted for Taiwanese populations, encompassing emotional, psychological, and social functioning components. Multidimensional life satisfaction, serving as the main set of predictive features, was measured using domain-specific satisfaction subscales covering family relationships, peer relationships, school experience, academic self-perception, physical health, emotional health, neighborhood environment, and perceived economic adequacy. Each domain was assessed through multiple Likert-type items, allowing for fine-grained modeling of domain-level and item-level variability. Additional covariates included age, gender, grade level, family structure, parental education, perceived academic pressure, screen time, physical activity frequency, and sleep duration, as these factors have been shown to be closely associated with adolescent well-being. All instruments used in the study had demonstrated acceptable psychometric properties in prior Taiwanese or East Asian adolescent samples. For the purposes of machine learning analysis, raw item scores were retained alongside domain-level composite scores to preserve maximal informational content and enable the detection of non-linear and interaction effects across predictors.

2.3. Data Analysis

Data analysis followed a rigorous, multi-stage machine learning pipeline implemented using Python-based analytical environments. Prior to model development, data preprocessing procedures were conducted, including inspection for missing values, outlier detection, and normalization where appropriate. Missing data were handled using model-compatible imputation techniques to avoid case-wise deletion and preserve statistical power. The dataset was randomly partitioned into training and testing subsets, with the training set used for model fitting and hyperparameter optimization and the testing set reserved for out-of-sample performance evaluation. Gradient boosting models were selected as the primary analytical approach due to their strong predictive performance with complex, non-linear psychological data and their robustness to multicollinearity among predictors. Multiple gradient boosting variants, including tree-based boosting frameworks, were trained and tuned using cross-validated grid and Bayesian optimization strategies to identify optimal model configurations. Model performance was evaluated using multiple complementary metrics appropriate for continuous psychological outcomes, including explained variance, root mean squared error, and mean absolute error, to ensure a comprehensive assessment of predictive accuracy and generalizability. To enhance interpretability and address the “black box” nature of ensemble models, post hoc explainability techniques were applied to quantify the relative importance of life satisfaction domains and individual indicators in predicting psychological well-being. Feature contribution patterns were examined at both global and individual levels to identify the most influential predictors and to explore heterogeneity in predictive pathways across adolescents. All analytical steps were pre-specified to minimize analytic bias, and robustness checks were conducted to confirm the stability of findings across alternative model specifications and random data splits.

3. Findings and Results

The findings are presented in a structured manner to provide a clear progression from descriptive characteristics of the sample to the performance and interpretability of the gradient boosting models. Table 1 summarizes the demographic, psychosocial, and core study variables of the adolescent participants from Taiwan and provides an overview of the distributional properties of psychological well-being and multidimensional life satisfaction indicators

that formed the basis of subsequent machine learning analyses.

Table 1

Descriptive characteristics of the study sample and key variables

Variable	Mean (SD) / n (%)
Age (years)	15.21 (1.74)
Gender	
Male	612 (49.3%)
Female	629 (50.7%)
Grade level	
Lower secondary	587 (47.3%)
Upper secondary	654 (52.7%)
Family structure	
Two-parent household	972 (78.3%)
Single-parent or other	269 (21.7%)
Psychological well-being (total score)	68.45 (10.82)
Family life satisfaction	4.12 (0.71)
Peer life satisfaction	3.98 (0.76)
School life satisfaction	3.85 (0.74)
Academic self-satisfaction	3.67 (0.79)
Physical health satisfaction	4.05 (0.68)
Emotional health satisfaction	3.74 (0.81)
Neighborhood satisfaction	3.91 (0.72)
Economic satisfaction	3.62 (0.83)
Daily screen time (hours)	3.46 (1.58)
Sleep duration (hours/night)	6.92 (1.11)

As shown in Table 1, the sample demonstrated a balanced gender distribution and representation across lower and upper secondary education levels. The mean psychological well-being score indicated moderate to high overall well-being, with noticeable variability across individuals. Among life satisfaction domains, family and physical health satisfaction showed the highest mean values, whereas

academic and economic satisfaction exhibited comparatively lower means and greater dispersion, suggesting substantial inter-individual differences. These descriptive patterns underscore the multidimensional nature of adolescent well-being and justify the use of advanced machine learning techniques capable of capturing complex, non-linear relationships among predictors.

Table 2

Performance metrics of gradient boosting models predicting adolescent psychological well-being

Model	R ²	RMSE	MAE
Gradient Boosting Regressor	0.61	6.78	5.24
XGBoost Regressor	0.64	6.42	4.97
LightGBM Regressor	0.66	6.18	4.81

Table 2 presents the predictive performance of the evaluated gradient boosting models on the held-out test dataset. All models demonstrated strong predictive capability, explaining more than 60% of the variance in adolescent psychological well-being. Among them, the LightGBM regressor achieved the highest explained

variance and the lowest error indices, indicating superior generalization performance. These results confirm that ensemble boosting approaches are well suited for modeling psychological well-being using multidimensional life satisfaction indicators and related covariates in adolescent populations.

Table 3

Global feature importance of life satisfaction domains in the optimal gradient boosting model

Predictor	Relative importance (%)
Emotional health satisfaction	21.4
Family life satisfaction	18.7
School life satisfaction	15.9
Peer life satisfaction	13.6
Academic self-satisfaction	11.8
Physical health satisfaction	9.4
Economic satisfaction	6.2
Neighborhood satisfaction	3.0

Table 3 illustrates the global feature importance derived from the optimal gradient boosting model. Emotional health satisfaction emerged as the most influential predictor of psychological well-being, followed closely by family life satisfaction and school life satisfaction. Social-contextual domains related to peers and academic self-perception also

contributed substantially, whereas neighborhood and economic satisfaction played comparatively smaller but non-negligible roles. This hierarchy highlights the central importance of emotionally and relationally grounded life domains in shaping adolescent psychological well-being.

Table 4

Directional effects of key predictors on psychological well-being based on partial dependence analysis

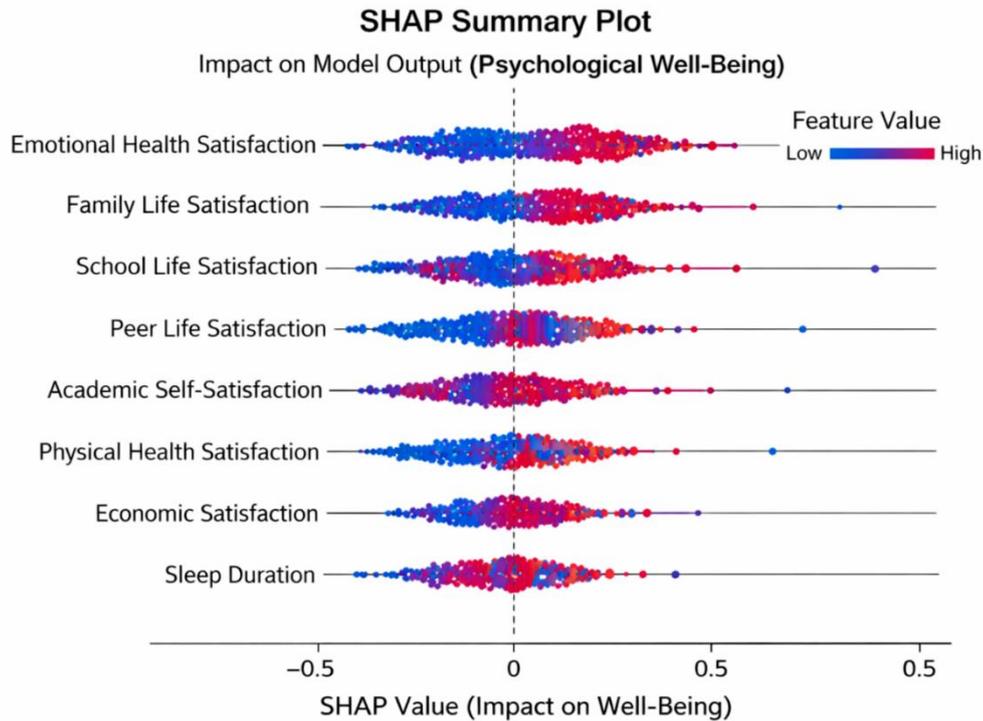
Predictor	Direction of effect	Pattern
Emotional health satisfaction	Positive	Strong non-linear
Family life satisfaction	Positive	Linear to mildly non-linear
School life satisfaction	Positive	Threshold effect
Academic self-satisfaction	Positive	Gradual linear
Daily screen time	Negative	Curvilinear
Sleep duration	Positive	Optimal range effect

As shown in Table 4, partial dependence analysis revealed that higher levels of emotional and family life satisfaction were consistently associated with higher psychological well-being, with emotional health displaying pronounced non-linear effects. School life satisfaction exhibited a threshold pattern, whereby increases beyond

moderate levels yielded disproportionately larger gains in well-being. Behavioral factors such as screen time and sleep duration demonstrated curvilinear associations, indicating that both excessive screen use and insufficient sleep were linked to lower well-being, while moderate ranges were most beneficial.

Figure 1

SHAP summary plot illustrating individual-level contributions of life satisfaction indicators to predicted psychological well-being



The SHAP summary plot depicted in Figure 1 demonstrates substantial heterogeneity in how life satisfaction domains contributed to predicted psychological well-being at the individual level. Emotional health satisfaction showed the widest range of SHAP values, indicating strong variability in its impact across adolescents. Family and school satisfaction also displayed notable dispersion, suggesting that their influence depends on the broader configuration of psychosocial and behavioral factors. Collectively, the figure reinforces the value of explainable machine learning approaches in uncovering nuanced, individualized pathways to psychological well-being rather than relying solely on average effects.

4. Discussion and Conclusion

The findings of the present study provide robust evidence that adolescent psychological well-being can be predicted with substantial accuracy using gradient boosting models that integrate multidimensional life satisfaction indicators. The overall predictive performance of the models, explaining a large proportion of variance in psychological well-being, supports the growing body of research suggesting that well-being is not the product of a single dominant factor but rather emerges from the dynamic

interplay of emotional, relational, academic, behavioral, and contextual domains. The superior performance of gradient boosting approaches aligns with recent methodological work emphasizing the suitability of ensemble learning techniques for modeling complex psychological constructs characterized by non-linear relationships and high intercorrelations among predictors (Blake et al., 2025; Cordon et al., 2025). These results extend prior epidemiological and psychosocial research by demonstrating that predictive accuracy can be substantially enhanced when multidimensional life satisfaction data are analyzed using advanced machine learning frameworks rather than conventional linear models.

One of the most salient findings of this study concerns the central role of emotional health satisfaction as the strongest predictor of adolescent psychological well-being. Emotional satisfaction consistently exhibited the highest contribution to model predictions and showed marked non-linear effects, indicating that incremental improvements in emotional well-being are associated with disproportionately large gains in overall psychological functioning. This finding is consistent with previous research highlighting the primacy of affective evaluations in shaping subjective well-being and mental health outcomes (Chaves, 2021; Willroth et al., 2021). Studies conducted in diverse cultural contexts have similarly

demonstrated that emotional experiences and self-perceived emotional balance exert a more immediate and powerful influence on well-being than structural or material conditions (Diržytė & Perminas, 2021; Mei et al., 2020). The present findings reinforce these conclusions while further suggesting that emotional satisfaction operates through complex, non-linear pathways that are particularly well captured by gradient boosting models.

Family life satisfaction emerged as the second most influential predictor, underscoring the enduring importance of family relationships during adolescence, even in contexts characterized by increasing autonomy and peer orientation. This result aligns closely with empirical evidence indicating that supportive parent–child relationships, family cohesion, and perceived parental understanding are among the most consistent correlates of adolescent well-being and life satisfaction (Dam et al., 2023; Poudel et al., 2020). Moreover, longitudinal research has shown that family satisfaction not only predicts concurrent well-being but also buffers against future mental health difficulties, particularly under conditions of social stress (Cherewick et al., 2024; Magson et al., 2020). In the Taiwanese sociocultural context, where family interdependence and parental involvement in academic and personal development remain highly salient, the strong predictive role of family satisfaction is theoretically and culturally coherent.

School life satisfaction also played a prominent role in predicting psychological well-being, with the model revealing threshold-like effects whereby improvements beyond moderate levels were associated with sharper increases in well-being. This pattern is consistent with prior studies suggesting that positive school experiences function as a key mediating mechanism between academic demands and mental health outcomes (Cavioni et al., 2021; Dias-Viana & Noronha, 2022). Research adopting the dual-factor model of mental health has further shown that school satisfaction contributes uniquely to positive well-being outcomes, even when symptoms of distress are controlled (Bersia, Berchiolla, et al., 2022; King et al., 2021). The present findings extend this literature by demonstrating that school satisfaction exerts non-linear effects that may be overlooked in traditional regression-based analyses.

Peer life satisfaction and academic self-satisfaction also made substantial contributions to the predictive models, highlighting the intertwined nature of social belonging and self-evaluative academic processes in adolescence. Consistent with developmental theories, peer relationships emerged as a critical domain influencing emotional

adjustment and self-worth, particularly during middle and late adolescence (Lereya et al., 2022; Pierannunzio et al., 2022). Academic self-satisfaction, in turn, reflects adolescents' subjective appraisal of their competence and progress within the educational system and has been linked to both life satisfaction and reduced psychological strain (Marquez, Katsantonis, et al., 2022; Martin et al., 2023). The simultaneous importance of these domains supports integrative models that view adolescent well-being as arising from the balance between social connectedness and personal efficacy within institutional contexts.

Health-related satisfaction domains and behavioral indicators, including physical health satisfaction, sleep duration, and screen-related behaviors, exhibited meaningful but more nuanced effects on psychological well-being. The curvilinear associations observed for sleep duration and digital engagement are consistent with prior research showing that both insufficient and excessive exposure can undermine well-being, whereas moderate levels are associated with optimal functioning (Cao et al., 2022; Litago et al., 2020). These findings reinforce the argument that adolescent health behaviors should be understood within a systems framework that accounts for interaction effects and individual differences rather than relying on simplistic linear assumptions. The relatively smaller yet significant contribution of economic and neighborhood satisfaction echoes previous work demonstrating that contextual and socioeconomic factors influence adolescent well-being indirectly, often through their impact on family functioning, school experiences, and perceived opportunities (Cosma et al., 2021; Marquez, Humphrey, et al., 2022; Marquez, Lambert, et al., 2022).

The application of explainable machine learning techniques provided additional insights into individual-level heterogeneity in predictive pathways. The dispersion of feature contributions observed across adolescents suggests that similar levels of psychological well-being may arise from distinct configurations of life satisfaction domains. This finding resonates with recent calls to move beyond population averages and toward person-centered and precision-oriented approaches in adolescent mental health research (Bersia, Charrier, et al., 2022; Gregory et al., 2021). Moreover, the interpretability of the models strengthens their theoretical and practical relevance by demonstrating how advanced analytics can complement, rather than replace, established psychological frameworks.

Taken together, the results of this study converge with and extend existing literature by demonstrating that

adolescent psychological well-being is best understood as a multidimensional and non-linear phenomenon shaped by emotional, relational, academic, and contextual satisfaction domains. By leveraging gradient boosting models and explainable analytics, the present study provides empirical support for integrative and salutogenic perspectives on adolescent well-being while offering a methodological blueprint for future research in this field (Cordon et al., 2025; Jiang et al., 2025).

5. Limitations & Suggestions

Despite its contributions, the study is subject to several limitations that should be considered when interpreting the findings. The cross-sectional design precludes causal inference and limits conclusions regarding developmental trajectories or temporal ordering among life satisfaction domains and psychological well-being. The reliance on self-report measures may also introduce common method bias and social desirability effects. In addition, although the sample was drawn from multiple schools, it may not fully capture the diversity of adolescents across different regions or educational tracks within Taiwan.

Future research should prioritize longitudinal designs to examine how the predictive structure of life satisfaction domains evolves across adolescence and into young adulthood. Integrating objective indicators, multi-informant data, and ecological momentary assessments could further enhance model robustness. Comparative studies across cultural contexts would also be valuable in determining the generalizability of the identified predictive patterns and in exploring culture-specific configurations of adolescent well-being.

From a practical perspective, the findings suggest that interventions aimed at promoting adolescent psychological well-being should adopt a multidimensional focus, with particular emphasis on emotional health, family relationships, and school experiences. Educational and mental health practitioners may benefit from using data-informed, individualized approaches to identify adolescents at risk of low well-being and to tailor preventive strategies accordingly. The integration of interpretable machine learning tools into school and community settings holds promise for advancing early identification and targeted support initiatives.

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.

References

- Ayhan, C., Gümüş, H., Muñío, C. M., & ÇAĞLAYAN, B. (2023). Leisure Activity Type and Sustainable Health Status in Late Adolescents. *İnsan Ve Sosyal Bilimler Dergisi*, 6(2), 231-248. <https://doi.org/10.53048/johass.1372057>
- Bersia, M., Berchiolla, P., Charrier, L., Lemma, P., Borraccino, A., Nardone, P., Pierannunzio, D., Ciardullo, S., Comoretto, R. I., & Dalmasso, P. (2022). Mental Well-Being: 2010–2018 Trends Among Italian Adolescents. *International journal of environmental research and public health*, 19(2), 863. <https://doi.org/10.3390/ijerph19020863>
- Bersia, M., Charrier, L., Berchiolla, P., Cosma, A., Comoretto, R. I., & Dalmasso, P. (2022). The Mental Well-Being of Italian Adolescents in the Last Decade Through the Lens of the Dual Factor Model. *Children*, 9(12), 1981. <https://doi.org/10.3390/children9121981>
- Blake, H., Hassard, J., Thomson, L., Choo, W. L. O., Dulal-Arthur, T., Karanika-Murray, M., Delic, L., Pickford, R., & Rudkin, L. (2025). Psychological Detachment From Work Predicts Mental Wellbeing of Working-Age Adults: Findings From the 'Wellbeing of the Workforce' (WoW) Prospective Longitudinal Cohort Study. *PLoS One*, 20(1), e0312673. <https://doi.org/10.1371/journal.pone.0312673>
- Cao, Y., Yang, Z., Yu, Y., & Huang, X. (2022). Physical Activity, Sleep Quality and Life Satisfaction in Adolescents: A Cross-Sectional Survey Study. *Frontiers in Public Health*, 10. <https://doi.org/10.3389/fpubh.2022.1010194>

- Cavioni, V., Grazzani, I., Ornaghi, V., Agliati, A., & Pepe, A. (2021). Adolescents' Mental Health at School: The Mediating Role of Life Satisfaction. *Frontiers in psychology*, *12*. <https://doi.org/10.3389/fpsyg.2021.720628>
- Chaves, C. (2021). Wellbeing and Flourishing. 273-295. https://doi.org/10.1007/978-3-030-64537-3_11
- Cherewick, M., Lama, R., Roshan, P., Dukpa, C., Mukhia, D., Giri, P., & Matergia, M. (2024). Social Support and Self-Efficacy During Early Adolescence: Dual Impact of Protective and Promotive Links to Mental Health and Wellbeing. *Plos Global Public Health*, *4*(12), e0003904. <https://doi.org/10.1371/journal.pgph.0003904>
- Cordon, E. L., Chan, C. K. Y., Kinsman, L., Crombie, A., Faulkner, P., McEvoy, A., Masman, K., Begg, S., Skinner, T., Li, X., & McEvoy, M. (2025). Key Salutogenic Factors Associated With Wellbeing Among a Cohort of Regional and Rural Healthcare Workers During the COVID-19 Pandemic: An Exposure-Wide Cross-Sectional Study. <https://doi.org/10.21203/rs.3.rs-7452925/v1>
- Cosma, A., Költő, A., Bađura, P., Winkler, P., & Kalman, M. (2021). Time Trends in Adolescent Mental Wellbeing in the Czech Republic Between 2002 and 2018: Gender, Age and Socioeconomic Differences. *Central European Journal of Public Health*, *29*(4), 271-278. <https://doi.org/10.21101/cejph.a6717>
- Dam, V. A. T., Ngoc, H., Vu, T. B. T., Vu, K. L., Minh, H. V., Nguyen, N. T. T., Nguyen, T. T. T., Vu, T. M. T., Nguyen, T. P. T., Auquier, P., Boyer, L., Fond, G., Latkin, C. A., Ho, C. S. H., & Ho, R. (2023). Associations Between Parent-Child Relationship, Self-Esteem, and Resilience With Life Satisfaction and Mental Wellbeing of Adolescents. *Frontiers in Public Health*, *11*. <https://doi.org/10.3389/fpubh.2023.1012337>
- Dias-Viana, J. L., & Noronha, A. P. P. (2022). Life Satisfaction, Affects at School and Depression Symptoms Among Adolescents. *Paidéia (Ribeirão Preto)*, *32*. <https://doi.org/10.1590/1982-4327e3203>
- Diržytė, A., & Perminas, A. (2021). Self-Reported Health-Related Experiences, Psychological Capital, and Psychological Wellbeing in Lithuanian Adults Sample. *Health Psychology Open*, *8*(1). <https://doi.org/10.1177/2055102921996164>
- Green, K., Becht, A., Groep, S. v. d., Cruijnsen, R. v. d., Sweijen, S., & Crone, E. A. (2021). Socioeconomic Inequality in Online Home Schooling in the Early Phase of the COVID-19 Pandemic Predicts Adolescent Mental Wellbeing One Year Later. <https://doi.org/10.31234/osf.io/zpy25>
- Gregory, T., Sincovich, A., Brushe, M., Finlay-Jones, A., Collier, L., Grace, B., Monroy, N. S., & Brinkman, S. (2021). Basic Epidemiology of Wellbeing Among Children and Adolescents: A Cross-Sectional Population Level Study. *SSM - Population Health*, *15*, 100907. <https://doi.org/10.1016/j.ssmph.2021.100907>
- Hoefnagels, J. W., Schoen, A. B., Sabine, E. I. v. d. L., Rodijk, L. H., Cornelis, K. v. d. E., Elise, M. v. d. P., Dalmeijer, G. W., & Nijhof, S. L. (2022). The Impact of the COVID-19 Outbreak on Mental Wellbeing in Children With a Chronic Condition Compared to Healthy Peers. *International journal of environmental research and public health*, *19*(5), 2953. <https://doi.org/10.3390/ijerph19052953>
- Jiang, X., Fang, L., & Mueller, C. E. (2025). Growth Mindset: An Umbrella for Protecting Socially Stressed Adolescents' Life Satisfaction. *School Psychology*, *40*(3), 388-396. <https://doi.org/10.1037/spq0000584>
- King, N., Davison, C., & Pickett, W. (2021). Development of a Dual-Factor Measure of Adolescent Mental Health: An Analysis of Cross-Sectional Data From the 2014 Canadian Health Behaviour in School-Aged Children (HBSC) Study. *BMJ open*, *11*(9), e041489. <https://doi.org/10.1136/bmjopen-2020-041489>
- Lereya, S. T., Patalay, P., & Deighton, J. (2022). Predictors of Mental Health Difficulties and Subjective Wellbeing in Adolescents: A Longitudinal Study. *JCPP Advances*, *2*(2). <https://doi.org/10.1002/jcv2.12074>
- Litago, J. D. U., Ingelmo, R. M. G., Cabaco, A. S., & García, J. E. M. (2020). Life Satisfaction, Physical Activity and Quality of Life Associated With the Health of School-Age Adolescents. *Sustainability*, *12*(22), 9486. <https://doi.org/10.3390/su12229486>
- Magson, N. R., Freeman, J. Y. A., Rapee, R. M., Richardson, C., Oar, E. L., & Fardouly, J. (2020). Risk and Protective Factors for Prospective Changes in Adolescent Mental Health During the COVID-19 Pandemic. *Journal of youth and adolescence*, *50*(1), 44-57. <https://doi.org/10.1007/s10964-020-01332-9>
- Marquez, J., Humphrey, N., Black, L., & Wozmirska, S. (2022). This Is the Place: A Multi-Level Analysis of Neighbourhood Correlates of Adolescent Wellbeing. <https://doi.org/10.31235/osf.io/uwv7e>
- Marquez, J., Katsantonis, I., Sellers, R., & Knies, G. (2022). Life Satisfaction and Mental Health From Age 17 to 21 Years in a General Population Sample. *Current Psychology*, *42*(31), 27047-27057. <https://doi.org/10.1007/s12144-022-03685-9>
- Marquez, J., Lambert, L., & Cutts, M. (2022). Geographic, Socio-Demographic and School Type Variation in Adolescent Wellbeing and Mental Health and Links With Academic Competence in the United Arab Emirates. *Child Indicators Research*, *16*(2), 797-836. <https://doi.org/10.1007/s12187-022-09993-7>
- Martin, A. J., Collie, R. J., & Holliman, A. (2023). The Role of Health Demands, Health Resources, and Adaptability in Psychological Strain and Life Satisfaction. *Stress and Health*, *40*(3). <https://doi.org/10.1002/smi.3341>
- Mei, S., Qin, Z., Yang, Y., Gao, T., Ren, H., Hu, Y., Cao, R., Liang, L., Li, C., & Tong, Q. (2020). Influence of Life Satisfaction on Quality of Life: Mediating Roles of Depression and Anxiety Among Cardiovascular Disease Patients. *Clinical Nursing Research*, *30*(2), 215-224. <https://doi.org/10.1177/1054773820947984>
- Miranda, D. M. d., Athanasio, B. d. S., Ana Cecília de Sena, O., & Ana Cristina Simões e, S. (2020). How Is COVID-19 Pandemic Impacting Mental Health of Children and Adolescents? *International Journal of Disaster Risk Reduction*, *51*, 101845. <https://doi.org/10.1016/j.ijdrr.2020.101845>
- Pierannunzio, D., Spinelli, A., Berchiolla, P., Borraccino, A., Charrier, L., Dalmasso, P., Lazzari, G., Vieno, A., Ciardullo, S., & Nardone, P. (2022). Physical Activity Among Italian Adolescents: Association With Life Satisfaction, Self-Rated Health and Peer Relationships. *International journal of environmental research and public health*, *19*(8), 4799. <https://doi.org/10.3390/ijerph19084799>
- Poudel, A., Gurung, B., & Khanal, G. P. (2020). Perceived Social Support and Psychological Wellbeing Among Nepalese Adolescents: The Mediating Role of Self-Esteem. *BMC psychology*, *8*(1). <https://doi.org/10.1186/s40359-020-00409-1>
- Sabine, E. I. v. d. L., Finkenauer, C., Lenters, V., Harmelen, A. L. v., Cornelis, K. v. d. E., & Nijhof, S. L. (2021). Gender-Specific Changes in Life Satisfaction After the COVID-19-Related Lockdown in Dutch Adolescents: A Longitudinal Study. *Journal of Adolescent Health*, *69*(5), 737-745. <https://doi.org/10.1016/j.jadohealth.2021.07.013>

- Schoeps, K., Tamarit, A., Barrera, U. d. I., Lacomba-Trejo, L., Montoya-Castilla, I., Rosario, C. d., Coello, M., Herrera, J., Trujillo, Á., Munévar, F. R., & Esparza, N. A. A. (2022). Social and Psychological Effects of COVID-19 Pandemic on Adolescents' and Young Adults' Mental Health: A Cross-Cultural Mediation Study. *Psychological Reports, 126*(6), 2729-2756. <https://doi.org/10.1177/00332941221100451>
- Willroth, E. C., Atherton, O. E., & Robins, R. W. (2021). Life Satisfaction Trajectories During Adolescence and the Transition to Young Adulthood: Findings From a Longitudinal Study of Mexican-Origin Youth. *Journal of personality and social psychology, 120*(1), 192-205. <https://doi.org/10.1037/pspp0000294>
- Xiong, J., Hai, M., Su, Z., & Li, Y. (2021). Mediating Effects of Social Problem-Solving and Coping Efficacy on the Relationship Between Cumulative Risk and Mental Health in Chinese Adolescents. *Current Psychology, 42*(11), 8759-8770. <https://doi.org/10.1007/s12144-021-02167-8>
- Xiong, J., Hai, M., Wang, J., Li, Y., & Guangrong, J. (2020). Cumulative Risk and Mental Health in Chinese Adolescents: The Moderating Role of Psychological Capital. *School Psychology International, 41*(5), 409-429. <https://doi.org/10.1177/0143034320934524>