

Classifying Panic-Symptom Risk among Taiwanese Youth Based on Anxiety Sensitivity, Interoceptive Awareness, Sleep Disturbance, and Perceived Stress Using a Support Vector Machine

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ABSTRACT

Objective: This study aimed to develop and internally validate a support vector machine model for classifying elevated panic-symptom risk among Taiwanese youth based on anxiety sensitivity, multidimensional interoceptive awareness, sleep disturbance, and perceived stress.

Methods and Materials: A cross-sectional predictive classification study was conducted with 512 Taiwanese youths aged 15–24 years who were recruited from senior high schools, vocational schools, universities, and community youth centers. Participants completed the Anxiety Sensitivity Index–3, Multidimensional Assessment of Interoceptive Awareness–2, Pittsburgh Sleep Quality Index, Perceived Stress Scale–10, and Panic Disorder Severity Scale–Self-Report. Panic-symptom risk was categorized using a predetermined cutoff score. The sample was stratified into a training set of 410 participants and an independent testing set of 102 participants. A radial basis function support vector machine was developed using repeated stratified 10-fold cross-validation, class weighting, probability calibration, and hyperparameter optimization. Model performance was assessed using accuracy, balanced accuracy, sensitivity, specificity, predictive values, F1 score, receiver operating characteristic area under the curve, precision–recall area under the curve, and Brier score.

Findings: All psychological predictors differed significantly between elevated-risk and low-risk participants, with the largest effects observed for anxiety sensitivity, perceived stress, body trusting, interoceptive not-worrying, and sleep disturbance, all $p < .001$. In the independent testing dataset, the support vector machine achieved an accuracy of .882, balanced accuracy of .875, sensitivity of .857, specificity of .892, positive predictive value of .750, negative predictive value of .943, and F1 score of .800. The model produced an area under the receiver operating characteristic curve of .928 and an area under the precision–recall curve of .836. Anxiety sensitivity was the most influential predictor, followed by perceived stress, body trusting, sleep disturbance, interoceptive not-worrying, and interoceptive self-regulation.

Conclusion: Panic-symptom risk among Taiwanese youth can be classified with high accuracy using a multidimensional psychological profile, particularly anxiety sensitivity, perceived stress, body trust, sleep disturbance, and interoceptive regulation.

Keywords: Panic symptoms; anxiety sensitivity; interoceptive awareness; sleep disturbance; perceived stress; support vector machine; youth; Taiwan

1. Introduction

Panic symptoms constitute a clinically significant form of psychological distress characterized by abrupt surges of intense fear, autonomic arousal, catastrophic interpretations of bodily sensations, and a perceived loss of control. Although panic disorder is formally diagnosed according to specific clinical criteria, panic-like symptoms occur across a continuum and may emerge before a full disorder becomes evident. This dimensional perspective is particularly important in adolescence and young adulthood, when biological maturation, changing social roles, educational pressure, sleep irregularity, and heightened emotional reactivity may converge to increase vulnerability to anxiety. Youth who experience recurrent palpitations, dizziness, shortness of breath, chest discomfort, trembling, derealization, or fear of losing control may not initially seek clinical care, especially when symptoms are interpreted as transient stress or physical illness (Banellis et al., 2025). Consequently, identifying patterns that distinguish youths with elevated panic-symptom risk from those with lower risk may support earlier screening and more targeted preventive intervention.

Panic symptoms are not produced by a single psychological process. They are better understood as emerging from interacting cognitive, physiological, emotional, behavioral, and contextual mechanisms. Contemporary models increasingly emphasize the role of altered perception and interpretation of internal bodily signals. Interoception refers broadly to the detection, representation, appraisal, and regulation of signals arising from within the body, including cardiac, respiratory, gastrointestinal, thermal, and visceral sensations. These processes contribute to emotional awareness, self-regulation, and the sense of bodily safety, but they may also become sources of distress when sensations are monitored excessively or interpreted as evidence of imminent danger. Interoception has therefore become a central construct in psychiatric theory, particularly in relation to anxiety and affective disorders (Nayok et al., 2023; Nord & Garfinkel, 2022).

Recent transdiagnostic accounts propose that altered interoceptive processing may represent a shared mechanism across multiple anxiety and affective conditions rather than a feature unique to one diagnosis. Such accounts distinguish among the objective accuracy of bodily-signal detection, subjective attention to internal sensations, metacognitive confidence, emotional interpretation, and the capacity to

regulate responses to bodily changes (Saltafossi et al., 2024, 2025). This distinction is important because individuals may be highly attentive to their bodies without accurately interpreting bodily signals, or they may detect sensations effectively while experiencing them as threatening and uncontrollable. A large psychophysical investigation reported that objective interoceptive performance may not be directly related to mental health symptoms across all domains, suggesting that subjective appraisal and regulatory aspects of interoception may be more clinically informative than performance accuracy alone (Banellis et al., 2025). Accordingly, research on panic risk should not assume that greater bodily awareness is uniformly adaptive or maladaptive.

Neurobiological research further supports the relevance of interoceptive dysfunction to anxiety. A systematic review and meta-analysis of depressive and anxiety disorders identified altered neural activity within brain systems involved in bodily representation, salience detection, emotional appraisal, and regulatory control (Bednarek et al., 2026). Heartbeat-evoked potentials have also been proposed as promising neurophysiological markers of altered cortical processing of internal cardiac signals in clinical populations (Wang, 2026). These findings suggest that vulnerability to panic symptoms may involve not only conscious beliefs about bodily sensations but also disruptions in how internal signals are encoded and integrated by the nervous system. Nevertheless, neural and psychophysiological measures are often costly and difficult to implement in community screening. Self-report indicators of anxiety sensitivity and multidimensional interoceptive awareness may therefore provide practical proxies for clinically relevant aspects of bodily threat processing.

Anxiety sensitivity is especially relevant to panic symptoms because it reflects fear of anxiety-related sensations based on beliefs that these sensations will produce harmful physical, psychological, or social consequences. A youth with high anxiety sensitivity may interpret a rapid heartbeat as evidence of cardiac danger, dizziness as a sign of fainting or losing control, and visible trembling as a source of humiliation. Such interpretations can intensify attention to bodily sensations and amplify autonomic arousal, producing a self-reinforcing cycle in which fear of symptoms increases the symptoms themselves. Interoceptive anxiety-related processes have been identified as important for understanding the co-occurrence of anxiety, health-related fear, and maladaptive behaviors during periods of widespread uncertainty, including the COVID-19

pandemic (Zvolensky et al., 2022). These mechanisms are highly compatible with panic models in which bodily sensations become conditioned danger cues.

Body vigilance represents a related but distinct process involving sustained attention to internal sensations and heightened monitoring for bodily changes. The development and validation of measures such as the Body Vigilance Scale across different linguistic and cultural populations demonstrates the growing interest in evaluating this form of somatic monitoring (Chahine et al., 2025). Heightened vigilance may be particularly problematic when it occurs alongside anxiety sensitivity, because ordinary variations in breathing, heart rate, temperature, or balance may be detected rapidly and then catastrophically interpreted. However, attention to bodily sensations is not necessarily pathological. Research comparing women with and without histories of intimate partner violence has shown that interoceptive abilities may relate differently to somatic complaints depending on psychological history and the quality of body connection (Machorrinho et al., 2025). Thus, the clinical significance of bodily attention depends on whether sensations are approached with trust, curiosity, and regulatory capacity or with fear, worry, and avoidance.

Multidimensional models of interoceptive awareness help clarify this distinction. Adaptive dimensions may include the ability to regulate attention, use bodily awareness for emotional regulation, listen to the body for useful information, and experience bodily sensations as trustworthy. Conversely, risk may be reflected in worry about unpleasant sensations, distrust of the body, difficulty remaining present with discomfort, and limited ability to regulate distress through bodily awareness. Longitudinal research conducted during the COVID-19 period found that changes in interoception were associated with psychophysiological health and well-being, indicating that interoceptive functioning is dynamic and responsive to environmental stress (Vabba et al., 2023). These findings support examining interoceptive awareness as a multidimensional predictor rather than reducing it to a single global score.

Interoceptive processes also have direct implications for intervention. A systematic review of randomized controlled trials concluded that psychological interventions can modify aspects of interoception across mental health disorders, although intervention effects vary according to the target process, method, and clinical population (Heim et al., 2023). Interoceptive exposure is particularly relevant to panic-related symptoms because it deliberately induces feared

bodily sensations so that individuals can learn that discomfort is tolerable and not inherently dangerous. A broad scoping review found that interoceptive exposure has applications across physical and mental health conditions and may reduce fear and avoidance of internal sensations (Farris et al., 2025). These findings strengthen the rationale for identifying youths whose symptom profiles are characterized by bodily fear, vigilance, and impaired interoceptive regulation, as such individuals may benefit from interventions that directly target interpretation and tolerance of physical discomfort.

Mindfulness-based approaches similarly seek to alter the individual's relationship with internal experiences. Rather than eliminating bodily sensations, these interventions cultivate nonjudgmental observation, emotional regulation, and reduced reactivity. Preliminary findings indicate that mindfulness-based interventions may improve psychological functioning in conditions involving distressing bodily experiences, including psychogenic non-epileptic seizures (Ciacchini et al., 2025). Mindfulness interventions have also reduced distress among patients with chronic pain conditions such as fibromyalgia and low back pain (Ciacchini et al., 2024). In anxiety disorders that have not responded adequately to pharmacotherapy, mindfulness-based cognitive therapy has been investigated as a potentially useful adjunctive treatment with follow-up support (Sado et al., 2021, 2022). These intervention studies imply that awareness of bodily and emotional states becomes therapeutic when accompanied by acceptance, attentional flexibility, and regulatory skills.

Other mind-body approaches provide complementary evidence. A systematic review of interventions for healthcare workers during the COVID-19 period found that mind-body modalities may support stress management and psychological well-being under sustained occupational pressure (Kwon & Lee, 2022). A tailored mind-body physical activity program for college students likewise demonstrated potential benefits for stress and well-being during pandemic-related disruption (Strehli et al., 2022). Mindfulness-based stress reduction supported by smartwatch physiological feedback has been shown to improve mindfulness and reduce stress, although effects on anxiety and depression were less consistent (Sumińska & Rynkiewicz, 2025). Trauma-informed mindful recovery programs have also been applied to individuals experiencing overlapping pain, anxiety, and substance-use concerns, illustrating the relevance of integrated approaches when somatic and emotional distress are intertwined (Schuman-

Olivier et al., 2022). Together, these studies suggest that panic-related vulnerability may be reduced by strengthening the capacity to observe and regulate arousal rather than responding to bodily changes with escalating fear.

Respiratory and autonomic regulation may be especially important because panic symptoms frequently involve breathing irregularity and sympathetic activation. Brief structured respiration practices have been found to improve mood and reduce physiological arousal, demonstrating that deliberate breathing can influence both subjective and autonomic states (Balban et al., 2023). Heart rate variability biofeedback has similarly produced improvements in psychological well-being and physical symptoms in medically affected populations (Dolgilevica et al., 2025). These interventions are relevant to panic risk because they target the physiological systems that often become objects of catastrophic attention. However, symptom reduction may depend on whether individuals reinterpret bodily arousal more adaptively rather than using regulation strategies as rigid safety behaviors.

Exercise also influences stress perception, repetitive negative thinking, and anxiety-related physiology. Changes in repetitive negative thinking and perceived stress have been found to mediate the effects of transdiagnostic exercise interventions, suggesting that physical activity may improve mental health partly by modifying cognitive and stress-appraisal processes (Frei et al., 2026). In panic disorder, cortisol responses during low-intensity exercise conducted within cognitive-behavioral therapy have been associated with therapeutic outcomes, indicating that physiological reactivity may carry prognostic information (Wintermann et al., 2022). These findings reinforce the need to examine panic symptoms through an integrated framework in which physiological sensations, cognitive interpretations, and perceived stress interact.

Perceived stress is likely to be a major contextual amplifier of panic vulnerability. When youths experience their lives as unpredictable, uncontrollable, and overwhelming, baseline arousal may increase and recovery from daily stressors may become more difficult. Heightened stress may also increase repetitive negative thinking, impair concentration, disrupt sleep, and reduce tolerance for ambiguous bodily sensations. Research conducted among Chinese college students after the Shanghai lockdown documented continuing mental and physical health concerns in a population exposed to prolonged disruption and uncertainty (Sun & Cicchella, 2025). Such findings are particularly relevant to young people in East Asian

educational contexts, where academic pressure, social expectations, family obligations, and transitions into higher education or employment may contribute to sustained stress. Inflammation and other individual psychophysiological factors may further moderate the relationship between stress and emotional states, emphasizing that stress responses vary across individuals (Yamaoka et al., 2025).

Sleep disturbance may constitute another critical pathway linking stress and panic symptoms. Insomnia is increasingly viewed not merely as a nighttime complaint but as a systemic condition involving cognitive, emotional, autonomic, metabolic, and immune processes (Yun & Jo, 2021). Poor sleep can heighten emotional reactivity, reduce prefrontal regulatory control, increase autonomic arousal, and intensify sensitivity to physical sensations. Insomnia symptoms have also been associated with altered neurofunctional patterns in clinically vulnerable populations, indicating that sleep disruption may affect brain systems relevant to reward, stress, and self-regulation (White et al., 2024). For youths, irregular schedules, academic demands, nighttime technology use, and circadian changes may increase the likelihood of insufficient or fragmented sleep.

The relationship between sleep and interoception is likely bidirectional. Interoceptive processes can influence awareness of fatigue, breathing, heartbeat, tension, and bodily discomfort, while sleep loss may distort the detection and interpretation of those sensations. Research examining factors that link interoception and sleep across adulthood suggests that these domains are closely connected and may vary according to age and individual characteristics (Seo et al., 2025). In the context of panic risk, a sleep-deprived youth may experience palpitations, dizziness, derealization, or shortness of breath more frequently and may also possess fewer cognitive resources for interpreting these sensations accurately. Sleep disturbance may therefore amplify the effects of anxiety sensitivity and perceived stress rather than operating as an isolated predictor.

Broader biological and medical conditions must also be considered when interpreting panic-like symptoms. Nutritional and neurological abnormalities can produce sensory, cognitive, and autonomic complaints that overlap with anxiety manifestations. For example, vitamin B12 deficiency among neurology outpatients has been associated with diverse neurological presentations (Zhou et al., 2024). Likewise, psychobiotic research has examined whether modulation of the gut microbiome and its metabolites can influence mood and emotional functioning, reflecting the expanding recognition of bidirectional communication

among bodily systems and psychological states (Garzone et al., 2025). These lines of evidence do not imply that panic symptoms can be reduced to medical causes, but they demonstrate why bodily sensations are complex and why youths may experience uncertainty about whether symptoms are psychological or physical.

Clinical complexity is further illustrated by studies in medically affected and trauma-exposed populations. Remote eye movement desensitization and reprocessing has been used for posttraumatic stress disorder in adults with congenital heart disease, a context in which genuine cardiac sensations may interact with trauma-related fear (Callus, 2025). This is relevant to panic mechanisms because individuals with real medical vulnerability may develop heightened vigilance toward bodily signals, making it especially difficult to distinguish adaptive monitoring from anxiety-driven threat interpretation. Such complexity supports probabilistic risk classification rather than simplistic reliance on any single symptom or predictor.

Digital interventions may increase access to early treatment for panic symptoms. Self-guided virtual reality-based cognitive-behavioral therapy has demonstrated effectiveness for panic disorder, suggesting that technology-assisted exposure and cognitive restructuring can be delivered beyond traditional face-to-face settings (Shin et al., 2021). Nonetheless, not all patients respond to psychotherapy, and recent work has emphasized the need to classify non-response according to maintenance mechanisms rather than treating unsuccessful outcomes as a single category (Sasin et al., 2026). This perspective is relevant to risk prediction because different youths may reach similar levels of panic symptoms through different pathways. One individual may be characterized primarily by anxiety sensitivity, another by chronic stress and sleep disruption, and another by low body trust and impaired interoceptive regulation.

Traditional statistical methods are valuable for estimating average associations, but they may be limited when predictors interact nonlinearly or when the objective is classification at the individual level. Panic-symptom risk may arise when several moderately adverse characteristics occur together, even if no single variable reaches an extreme level. Support vector machines are well suited to this problem because they identify decision boundaries that maximize separation between classes and can model nonlinear relationships through kernel functions. By simultaneously considering anxiety sensitivity, multiple dimensions of interoceptive awareness, sleep disturbance,

and perceived stress, an SVM may detect multivariate patterns that are not apparent from isolated correlations or mean comparisons.

A classification approach is especially appropriate for preventive youth mental health because screening decisions concern whether an individual is more likely to belong to an elevated-risk group. However, such models should complement rather than replace clinical assessment. Their value lies in identifying youths who may warrant further evaluation, psychoeducation, sleep intervention, stress management, interoceptive training, or cognitive-behavioral support. The present combination of predictors is theoretically coherent: anxiety sensitivity represents fear-based interpretation of arousal, interoceptive awareness reflects how bodily signals are noticed and regulated, sleep disturbance represents a physiological and behavioral vulnerability, and perceived stress reflects the broader appraisal context in which symptoms occur. Examining these variables together may therefore provide a more comprehensive representation of panic-symptom risk than any single-domain model.

Accordingly, the aim of this study was to develop and internally validate a support vector machine model for classifying elevated panic-symptom risk among Taiwanese youth based on anxiety sensitivity, multidimensional interoceptive awareness, sleep disturbance, and perceived stress.

2. Methods and Materials

2.1. Study Design and Participants

This study employed a cross-sectional, predictive classification design to develop and internally validate a support vector machine model for distinguishing Taiwanese youths with elevated panic-symptom risk from those with low panic-symptom risk. The study population consisted of adolescents and young adults aged 15 to 24 years residing in Taiwan. Participants were recruited between September 2025 and January 2026 from senior high schools, vocational schools, universities, and community youth centers located in northern, central, and southern Taiwan. To increase the diversity of the sample in terms of age, educational level, and geographical location, a multistage stratified sampling procedure was used. Recruitment settings were first stratified according to geographical region and educational context, after which eligible institutions and youth centers were approached. Within participating settings, students and community-based youths were invited through classroom

announcements, institutional electronic mailing systems, posters, and online information notices.

A total of 556 youths were invited to participate, of whom 529 completed and returned the study questionnaires. Seventeen responses were excluded because more than 10% of the questionnaire items were unanswered, the response pattern indicated indiscriminate responding, or the completion time was considered implausibly short. Consequently, the final analytic sample consisted of exactly 512 Taiwanese youths. This sample size was considered sufficient for developing and validating the proposed classification model, maintaining an adequate number of participants in both panic-risk categories, and reducing instability in the estimation of model performance. The sample was divided into a training dataset containing 410 participants and an independent testing dataset containing 102 participants. The allocation was performed through stratified random sampling to preserve the proportion of participants with elevated and low panic-symptom risk in both datasets.

Participants were eligible for inclusion when they were between 15 and 24 years of age, had resided in Taiwan for at least one year, were able to read and understand Traditional Chinese, and provided informed consent to participate. For participants younger than 18 years, written parental or guardian consent and participant assent were required. Individuals were excluded when they reported a neurological or cognitive condition that substantially interfered with their ability to understand the questionnaire items, were experiencing an acute psychiatric crisis requiring immediate intervention, or submitted substantially incomplete questionnaires. Receiving psychological counseling or psychiatric treatment was not considered an exclusion criterion because excluding treatment-seeking youths could have artificially reduced the representation of clinically meaningful panic symptoms in the sample.

Data were collected through a secure electronic survey platform. Participants were provided with a detailed explanation of the study objectives, the voluntary nature of participation, confidentiality protections, and their right to discontinue participation without penalty. No personally identifying information was included in the analytic dataset, and each participant was assigned a numerical research code. Participants completed the questionnaires individually in a quiet setting using a computer, tablet, or smartphone. Completion required approximately 25 to 35 minutes.

2.2. Measures

A demographic information form was used to collect participants' age, sex, educational level, geographical region, current living arrangement, history of psychological counseling, history of psychiatric treatment, use of psychiatric medication, and self-reported history of panic attacks. These variables were primarily used to describe the sample and conduct supplementary sensitivity analyses. They were not included in the primary support vector machine model because the principal objective was to classify panic-symptom risk specifically from anxiety sensitivity, interoceptive awareness, sleep disturbance, and perceived stress.

Anxiety sensitivity was assessed using the Anxiety Sensitivity Index-3. This 18-item self-report instrument measures the extent to which an individual fears anxiety-related sensations because of beliefs that these sensations may have harmful physical, cognitive, or social consequences. Items are rated on a five-point scale ranging from 0, indicating very little agreement, to 4, indicating very much agreement. The instrument contains physical concerns, cognitive concerns, and social concerns subscales, with six items included in each dimension. A total score is calculated by summing all item responses and ranges from 0 to 72. Higher scores indicate greater fear of anxiety-related sensations and stronger beliefs that the experience of anxiety may lead to dangerous or socially undesirable outcomes. The total anxiety sensitivity score was used as the primary anxiety-sensitivity predictor because it represented the participant's general tendency to interpret physiological and psychological arousal as threatening. The three subscale scores were additionally examined in supplementary analyses to determine whether particular dimensions of anxiety sensitivity contributed differently to panic-risk classification.

Interoceptive awareness was measured using the Multidimensional Assessment of Interoceptive Awareness-2. This 37-item instrument evaluates how individuals perceive, interpret, regulate, and respond to sensations originating within the body. Items are rated on a six-point scale ranging from 0, indicating never, to 5, indicating always. The instrument consists of eight dimensions: noticing bodily sensations, not distracting oneself from uncomfortable sensations, not worrying about unpleasant sensations, regulating attention toward bodily experiences, emotional awareness, self-regulation through attention to the body, listening to the body for insight, and trusting bodily

sensations. After reverse scoring the relevant items, the mean score for each dimension is calculated separately, with higher scores representing a greater presence of the corresponding aspect of interoceptive awareness. Because interoceptive awareness is a multidimensional construct and some of its dimensions may have different relationships with panic symptoms, the eight subscale scores were entered separately into the machine-learning model rather than being combined into a single total score. This approach allowed the classifier to distinguish potentially protective dimensions, such as body trust and self-regulation, from potentially maladaptive patterns, such as worry about uncomfortable bodily sensations.

Sleep disturbance was evaluated using the Pittsburgh Sleep Quality Index. This 19-item self-report measure assesses sleep experiences during the preceding month. The questionnaire generates seven component scores representing subjective sleep quality, sleep latency, sleep duration, habitual sleep efficiency, sleep disturbances, use of sleep medication, and daytime dysfunction. Each component is scored from 0 to 3, and the components are summed to produce a global sleep-quality score ranging from 0 to 21. Higher scores indicate more severe sleep-related difficulties, and a global score greater than 5 is commonly interpreted as reflecting poor sleep quality. In the present study, the global score was used as the primary indicator of sleep disturbance because it captured the combined severity of difficulties involving sleep initiation, sleep maintenance, sleep duration, sleep efficiency, and daytime consequences. The seven component scores were retained for supplementary analyses examining whether particular sleep problems were especially relevant to elevated panic-symptom risk.

Perceived stress was assessed using the 10-item Perceived Stress Scale. This instrument measures the extent to which individuals perceive situations in their lives during the previous month as unpredictable, uncontrollable, or overwhelming. Participants rate each item on a five-point scale ranging from 0, indicating never, to 4, indicating very often. Positively worded items are reverse scored, after which all item scores are summed to produce a total score ranging from 0 to 40. Higher scores indicate greater perceived stress. The instrument evaluates subjective appraisal of stress rather than the number of objectively stressful events experienced by the participant. The total score was included in the classification model because persistent perceptions of uncontrollability and overload may increase physiological arousal, attentional monitoring of

bodily sensations, and vulnerability to panic-related interpretations.

Panic-symptom severity was measured using the Panic Disorder Severity Scale–Self-Report. This seven-item instrument assesses the frequency of panic attacks, distress associated with panic attacks, anticipatory anxiety, avoidance of situations, avoidance of physical sensations, impairment in occupational or academic functioning, and impairment in social functioning. Each item is rated from 0 to 4, producing a total score ranging from 0 to 28. Higher scores indicate more frequent, severe, and impairing panic symptoms. For the machine-learning analysis, participants with a total score of 8 or higher were classified as having elevated panic-symptom risk, whereas those with scores below 8 were classified as having low panic-symptom risk. This threshold was selected to identify participants experiencing at least a moderate level of clinically relevant panic symptoms. The classification was intended as a risk-screening outcome and was not interpreted as a formal diagnosis of panic disorder. A clinical diagnosis would require a structured diagnostic interview conducted by a qualified mental health professional.

Traditional Chinese versions of all instruments were administered. Before the primary data collection, the wording, cultural appropriateness, and comprehensibility of the questionnaires were reviewed by two Taiwanese clinical psychologists, one health psychologist, and one bilingual specialist in psychological assessment. The full questionnaire package was pilot tested with 30 Taiwanese youths who were not included in the final sample. Participants in the pilot study reported that the instructions and items were understandable and culturally appropriate. Internal consistency was subsequently evaluated in the main sample using Cronbach's alpha and McDonald's omega. Reliability coefficients of .70 or higher were regarded as acceptable, although interpretation also considered the number of items and multidimensional structure of each measure.

2.3. Data Analysis

Data analysis was conducted using statistical software for preliminary analyses and Python-based machine-learning libraries for model development, validation, and interpretation. Before constructing the classification model, the dataset was examined for duplicate submissions, invalid values, missing responses, response-pattern irregularities, and implausibly short completion times. Participants with

more than 10% missing responses across the principal measures were excluded. For retained participants, sporadically missing values were imputed using the median of the relevant variable. To prevent information leakage, imputation parameters were estimated exclusively from the training data within each cross-validation fold and were then applied to the corresponding validation or testing data. Continuous predictors were standardized to a mean of zero and a standard deviation of one using parameters estimated from the training data. Standardization was necessary because support vector machines are sensitive to differences in the measurement scales of predictor variables.

Descriptive statistics were calculated for all demographic and psychological variables. Means, standard deviations, medians, ranges, skewness, and kurtosis were examined for continuous variables, while frequencies and percentages were calculated for categorical variables. The internal consistency of each scale and subscale was examined using Cronbach's alpha and McDonald's omega. Pearson correlation coefficients were calculated for approximately normally distributed continuous variables, whereas Spearman correlation coefficients were used when substantial deviations from normality were observed. Group differences between participants with elevated and low panic-symptom risk were explored using independent-samples *t* tests or Mann–Whitney *U* tests for continuous variables and chi-square tests for categorical variables. These conventional statistical analyses were used to describe the data and characterize the two risk groups rather than to select predictors for the machine-learning model.

The binary outcome variable represented elevated versus low panic-symptom risk based on the Panic Disorder Severity Scale–Self-Report threshold. The predictor set in the primary model consisted of the Anxiety Sensitivity Index–3 total score, the eight Multidimensional Assessment of Interoceptive Awareness–2 subscale scores, the Pittsburgh Sleep Quality Index global score, and the Perceived Stress Scale total score. Thus, the primary classification model included 11 psychological predictor variables. Demographic variables were excluded from the principal model to ensure that classification was based specifically on the psychological constructs identified in the study objective. A supplementary model including age, sex, educational level, treatment history, and previous panic-attack history was examined as a sensitivity analysis to determine whether the addition of demographic and clinical background information meaningfully improved classification performance.

A support vector machine with a radial basis function kernel was specified as the primary classifier. The radial basis function kernel was selected because the associations between panic-symptom risk and anxiety sensitivity, interoceptive awareness, sleep disturbance, and perceived stress were expected to be potentially nonlinear and interactive. The model identified a decision boundary that maximized the margin between elevated-risk and low-risk participants while allowing controlled classification errors. The penalty parameter and kernel coefficient were optimized using a logarithmically spaced hyperparameter grid. Larger penalty values imposed stronger consequences for misclassification, whereas the kernel coefficient controlled the influence of individual observations on the shape of the decision boundary.

The complete sample was divided into a stratified training set of 410 participants and an independent testing set of 102 participants. The testing set was isolated before model fitting and was not used during preprocessing, feature selection, hyperparameter optimization, probability calibration, or decision-threshold selection. Within the training set, hyperparameters were optimized through stratified 10-fold cross-validation. The cross-validation procedure was repeated to reduce the influence of a single random partition. All preprocessing operations, including missing-value imputation and standardization, were incorporated into the cross-validation pipeline so that information from validation folds could not influence the fitted model.

Because elevated panic-symptom risk was expected to be less common than low risk, class imbalance was addressed by assigning class weights inversely proportional to class frequencies within the training data. This procedure increased the penalty for incorrectly classifying participants from the less frequent risk category without generating synthetic observations. The principal decision threshold was determined from cross-validated predictions in the training sample by maximizing the Youden index while also considering sensitivity as a clinically important screening criterion. Once established, the threshold was locked and applied unchanged to the independent testing set. Posterior risk probabilities were estimated through probability calibration conducted exclusively within the training procedure.

Classification performance was evaluated using accuracy, balanced accuracy, sensitivity, specificity, positive predictive value, negative predictive value, F1 score, the area under the receiver operating characteristic curve, and the area under the precision–recall curve.

Sensitivity represented the model's ability to correctly identify youths with elevated panic-symptom risk, whereas specificity represented its ability to correctly identify youths with low risk. Balanced accuracy was emphasized because it gives equal importance to the two outcome categories and is less affected by unequal class sizes than ordinary accuracy. The F1 score summarized the balance between sensitivity-related precision and recall, while the precision–recall curve provided additional information about performance for the less frequent elevated-risk class. A confusion matrix was used to report the numbers of true-positive, true-negative, false-positive, and false-negative classifications.

Ninety-five percent confidence intervals for testing-set performance measures were estimated using 2,000 stratified bootstrap resamples. Model calibration was examined using the Brier score and a calibration curve comparing predicted probabilities with observed elevated-risk proportions. The support vector machine was also compared with a majority-class classifier and a penalized logistic regression model to determine whether the nonlinear machine-learning approach provided meaningful improvement over simple and conventional benchmarks. All comparator models were trained using the same data partitions, predictors, preprocessing procedures, and class-balancing principles to ensure a fair comparison.

Permutation importance was used to interpret the contribution of each predictor to the final support vector machine. Each predictor was randomly permuted in the independent testing data while the remaining predictors were held unchanged, and the resulting reduction in classification performance was recorded. Larger reductions indicated that the model depended more strongly on that predictor. The permutation procedure was repeated to reduce random variation. Because correlated predictors can distribute importance across related variables, feature-importance results were interpreted together with bivariate associations, construct content, and supplementary analyses rather than as direct evidence of causality. A fixed random seed was used for data partitioning, cross-validation, hyperparameter optimization, bootstrap estimation, and permutation analysis to support computational reproducibility. All conventional statistical tests were two-tailed, with the significance level set at $p < .05$. Because the study used a cross-sectional design, the resulting model was interpreted as a tool for classifying concurrent panic-symptom risk and not as evidence that the predictor variables caused the development of panic symptoms.

3. Findings and Results

Of the 556 Taiwanese youths invited to participate, 529 returned the study questionnaires, corresponding to an initial response rate of 95.1%. Seventeen questionnaires were excluded because they contained more than 10% missing data, demonstrated repetitive or indiscriminate response patterns, or were completed in an implausibly short period. The final analytic sample therefore consisted of 512 participants, representing 92.1% of all invited youths. The participants ranged in age from 15 to 24 years, with a mean age of 19.42 years and a standard deviation of 2.58 years. A total of 278 participants were female, representing 54.3% of the sample, 230 were male, representing 44.9%, and four participants, representing 0.8%, identified with another gender identity or preferred not to report their gender.

Regarding educational and recruitment status, 221 participants, representing 43.2% of the sample, were enrolled in senior high schools or vocational schools, 254 participants, representing 49.6%, were university or college students, and 37 participants, representing 7.2%, were recruited through community youth centers. Geographically, 198 participants, representing 38.7% of the sample, resided in northern Taiwan, 161 participants, representing 31.4%, resided in central Taiwan, and 153 participants, representing 29.9%, resided in southern Taiwan. Most participants lived with their parents or immediate family members, accounting for 397 individuals or 77.5% of the sample. Eighty participants, representing 15.6%, lived in student accommodations or with relatives, while 35 participants, representing 6.8%, lived independently.

Ninety-three participants, representing 18.2% of the sample, reported having previously received psychological counseling. Forty-six participants, representing 9.0%, reported a history of psychiatric treatment, and 30 participants, representing 5.9%, reported current or previous use of psychiatric medication. A history of at least one self-identified panic attack was reported by 118 participants, representing 23.0% of the total sample. The mean Panic Disorder Severity Scale–Self-Report score was 5.85, with a standard deviation of 4.68 and an observed range from 0 to 23. Based on the predetermined cutoff score of 8, 139 participants, representing 27.1% of the sample, were classified as having elevated panic-symptom risk, whereas 373 participants, representing 72.9%, were classified as having low panic-symptom risk.

The elevated-risk and low-risk groups did not differ significantly in mean age, $t(510) = 0.82$, $p = .413$, gender

distribution, $\chi^2(2) = 2.06$, $p = .357$, educational category, $\chi^2(2) = 3.14$, $p = .208$, geographical region, $\chi^2(2) = 1.29$, $p = .525$, or living arrangement, $\chi^2(2) = 2.86$, $p = .240$. These results suggested that the classification groups were demographically comparable. However, previous use of mental health services was significantly more common among participants in the elevated-risk group. Psychological counseling had been received by 45 elevated-risk participants, representing 32.4% of that group, compared with 48 low-risk participants, representing 12.9% of the low-risk group, $\chi^2(1) = 25.92$, $p < .001$. A history of psychiatric treatment was reported by 24 elevated-risk participants, representing 17.3%, and 22 low-risk participants, representing 5.9%, $\chi^2(1) = 16.00$, $p < .001$. Psychiatric medication use was reported by 16 elevated-risk participants, representing 11.5%, compared with 14 low-risk participants, representing 3.8%, $\chi^2(1) = 11.05$, $p = .001$. A previous panic attack was reported by 69 participants in the elevated-risk group, representing 49.6%, compared with 49 participants in the low-risk group, representing 13.1%, $\chi^2(1) = 76.08$, $p < .001$.

Item-level missingness among the 512 retained cases was low, accounting for 0.68% of all expected responses. Missing values were distributed across participants and measures without evidence of concentration in a particular risk group. Median imputation was therefore performed within the machine-learning pipeline, with all imputation

parameters estimated from the training data only. Examination of skewness, kurtosis, histograms, and standardized residuals did not indicate extreme distributional abnormalities in the principal predictor variables. No predictor demonstrated variance inflation sufficient to warrant removal, although theoretically related dimensions of interoceptive awareness were moderately correlated. Internal-consistency coefficients for all principal scales and subscales were acceptable to excellent, with Cronbach's alpha coefficients ranging from .72 to .94 and McDonald's omega coefficients ranging from .73 to .94.

The stratified data-partitioning procedure allocated 410 participants to the training dataset and 102 participants to the independent testing dataset. The training dataset included 111 participants with elevated panic-symptom risk and 299 participants with low panic-symptom risk. The independent testing dataset included 28 participants with elevated risk and 74 participants with low risk. The prevalence of elevated panic-symptom risk was therefore 27.1% in the training dataset and 27.5% in the testing dataset. No statistically significant differences were found between the training and testing datasets in age, gender distribution, educational status, risk-group prevalence, or any of the 11 psychological predictor variables, with all p values greater than .05. These findings indicated that the stratified partitioning procedure produced comparable training and testing samples.

Table 1

Descriptive Statistics, Internal Consistency, and Comparisons of Psychological Predictors by Panic-Symptom Risk

Variable	Possible range	Cronbach's α	McDonald's ω	Total sample M (SD)	Low-risk group M (SD)	Elevated-risk group M (SD)	t	p	Cohen's d
Anxiety sensitivity	0–72	.94	.94	22.76 (12.61)	17.65 (9.14)	36.48 (10.15)	19.17	< .001	2.00
Interoceptive noticing	0–5	.76	.77	3.28 (0.77)	3.18 (0.76)	3.56 (0.71)	5.28	< .001	0.51
Interoceptive not-distracting	0–5	.72	.73	2.65 (0.74)	2.78 (0.70)	2.31 (0.73)	–6.55	< .001	0.66
Interoceptive not-worrying	0–5	.79	.80	2.62 (0.80)	2.87 (0.69)	1.94 (0.65)	–14.16	< .001	1.37
Attention regulation	0–5	.86	.87	3.08 (0.76)	3.25 (0.70)	2.62 (0.72)	–8.87	< .001	0.89
Emotional awareness	0–5	.82	.83	3.40 (0.72)	3.30 (0.71)	3.67 (0.66)	5.52	< .001	0.53
Interoceptive self-regulation	0–5	.84	.85	2.91 (0.79)	3.11 (0.73)	2.36 (0.68)	–10.88	< .001	1.05
Body listening	0–5	.81	.82	2.90 (0.80)	3.05 (0.77)	2.48 (0.74)	–7.67	< .001	0.75
Body trusting	0–5	.88	.89	2.91 (0.87)	3.21 (0.72)	2.09 (0.70)	–15.98	< .001	1.57
Sleep disturbance	0–21	.83	.84	6.87 (3.44)	5.81 (2.89)	9.72 (3.16)	12.74	< .001	1.32
Perceived stress	0–40	.89	.90	18.91 (7.00)	16.32 (5.62)	25.86 (5.41)	17.56	< .001	1.71

As shown in Table 1, statistically significant differences between the elevated-risk and low-risk groups were observed for all psychological predictor variables. The largest difference was found for anxiety sensitivity, with the elevated-risk group reporting a mean score of 36.48 compared with 17.65 in the low-risk group. The standardized mean difference of $d = 2.00$ represented an exceptionally large effect and indicated that fear of anxiety-related physical, cognitive, and social sensations was substantially greater among youths classified as being at elevated panic-symptom risk. Perceived stress also showed a very large group difference, $d = 1.71$, with elevated-risk participants reporting substantially greater perceptions of unpredictability, uncontrollability, and psychological overload. Body trusting demonstrated the strongest interoceptive difference, $d = 1.57$, indicating that elevated-risk participants were considerably less likely to experience their bodily sensations as safe, dependable, and worthy of trust. Sleep disturbance was also substantially greater in the elevated-risk group, $d = 1.32$, suggesting that difficulties involving sleep quality, sleep initiation, sleep continuity, sleep efficiency, and daytime functioning were strongly associated with panic-symptom risk. The not-worrying dimension produced another large difference, $d = 1.37$, because elevated-risk participants were markedly less able to experience unpleasant bodily sensations without responding with worry or emotional distress. Interoceptive self-regulation, attention regulation, body listening, and not-distracting were also significantly lower among elevated-

risk participants, with effect sizes ranging from moderate to large. In contrast, the elevated-risk group obtained higher scores for noticing bodily sensations and emotional awareness. These differences were moderate in magnitude and suggested that elevated-risk youths were not necessarily deficient in detecting internal sensations. Rather, they appeared to notice bodily and emotional changes more readily while simultaneously demonstrating lower body trust, greater worry about sensations, and weaker capacity to regulate distress through adaptive attention to bodily experiences. This pattern supported the conceptual distinction between awareness of internal sensations and the ability to interpret and regulate those sensations adaptively.

The support vector machine was developed using the 410-participant training dataset. Hyperparameter optimization within repeated stratified 10-fold cross-validation selected a radial basis function kernel with a penalty parameter of $C = 10$ and a kernel coefficient of $\gamma = .05$. Because elevated-risk participants constituted the smaller outcome category, inverse-frequency class weighting was used. The resulting relative class weight was 1.00 for the low-risk category and 2.69 for the elevated-risk category. Probability calibration and decision-threshold selection were performed using cross-validated training predictions. The final probability threshold was set at .41, rather than the conventional .50 threshold, because this value provided the most favorable balance between sensitivity and specificity while preserving sensitivity as a priority for risk-screening purposes.

Table 2

Cross-Validated and Independent Testing Performance of the Support Vector Machine

Performance measure	Repeated 10-fold cross-validation M (SD)	Independent testing estimate	Bootstrap 95% CI
Accuracy	.856 (.037)	.882	[.814, .941]
Balanced accuracy	.849 (.044)	.875	[.793, .939]
Sensitivity	.829 (.071)	.857	[.714, .964]
Specificity	.869 (.048)	.892	[.811, .959]
Positive predictive value	.711 (.079)	.750	[.607, .875]
Negative predictive value	.931 (.029)	.943	[.881, .986]
F1 score	.764 (.061)	.800	[.667, .897]
Area under the ROC curve	.915 (.031)	.928	[.872, .973]
Area under the precision–recall curve	.809 (.052)	.836	[.738, .918]
Brier score	.110 (.017)	.104	[.076, .139]

The results presented in Table 2 showed that the support vector machine maintained strong and relatively stable performance across the internal cross-validation and independent testing procedures. Within repeated 10-fold cross-validation, the model achieved a mean accuracy of

.856 and a mean balanced accuracy of .849. The similarity between these measures indicated that the model's apparent performance was not primarily attributable to the larger number of low-risk participants. Cross-validated sensitivity was .829, indicating that approximately 83% of elevated-risk

cases were correctly identified during model development, while cross-validated specificity was .869, indicating that approximately 87% of low-risk cases were correctly classified. The mean cross-validated area under the receiver operating characteristic curve was .915, demonstrating excellent discrimination across possible classification thresholds. The mean area under the precision–recall curve was .809, which was substantially higher than the elevated-risk prevalence of .271 and therefore indicated meaningful identification of the less frequent risk category.

When applied to the completely isolated testing dataset, the support vector machine correctly classified 90 of the 102 participants, producing an accuracy of .882. Of the 28 elevated-risk participants, 24 were correctly identified and four were incorrectly classified as low risk. The resulting sensitivity was .857. Of the 74 low-risk participants, 66 were correctly classified and eight were incorrectly identified as elevated risk, resulting in a specificity of .892. The confusion matrix therefore contained 24 true-positive classifications, 66 true-negative classifications, eight false-positive classifications, and four false-negative classifications. Balanced accuracy was .875, confirming that the model performed consistently across both risk categories. The positive predictive value was .750, indicating that three-quarters of participants classified by the model as elevated risk actually met the panic-symptom risk criterion. The negative predictive value was .943, indicating that participants classified as low risk had a 94.3% probability of belonging to the observed low-risk group. The F1 score of .800 demonstrated a strong balance between the precision and sensitivity of elevated-risk classification.

The independent testing area under the receiver operating characteristic curve was .928, with a 95% bootstrap

confidence interval ranging from .872 to .973. This result indicated that when one elevated-risk participant and one low-risk participant were selected at random, the model had an estimated 92.8% probability of assigning a higher risk score to the elevated-risk participant. The area under the precision–recall curve was .836, further demonstrating effective performance in identifying elevated-risk cases despite the unequal group sizes. The Brier score of .104 indicated a relatively small average discrepancy between the model’s predicted probabilities and the participants’ observed classifications. Examination of the calibration curve showed that predicted risk probabilities closely corresponded to observed risk proportions across most probability intervals. The calibration intercept was .03 and the calibration slope was .94, suggesting little systematic overestimation or underestimation and only limited extremity in the predicted probabilities. Collectively, the results indicated that the support vector machine generalized effectively from the training data to previously unseen participants.

Permutation importance was calculated using the independent testing dataset to examine the contribution of each predictor to the discriminative performance of the final model. Each predictor was randomly permuted while all other variables were left unchanged, and the resulting reduction in the area under the receiver operating characteristic curve was recorded. The procedure was repeated 1,000 times for each predictor. A larger reduction in the area under the curve indicated that disruption of the predictor produced a greater loss of model performance and that the classifier relied more strongly on that variable.

Table 3

Permutation Importance of Predictors in the Independent Testing Dataset

Rank	Predictor	Mean decrease in ROC AUC	95% CI	Direction associated with elevated risk
1	Anxiety sensitivity	.089	[.061, .121]	Higher scores
2	Perceived stress	.067	[.044, .092]	Higher scores
3	Body trusting	.051	[.031, .075]	Lower scores
4	Sleep disturbance	.044	[.026, .066]	Higher scores
5	Interoceptive not-worrying	.031	[.016, .050]	Lower scores
6	Interoceptive self-regulation	.026	[.012, .043]	Lower scores
7	Attention regulation	.018	[.007, .033]	Lower scores
8	Body listening	.012	[.003, .025]	Lower scores
9	Interoceptive not-distracting	.010	[.002, .023]	Lower scores
10	Emotional awareness	.007	[.001, .017]	Higher scores
11	Interoceptive noticing	.005	[.000, .014]	Higher scores

As reported in Table 3, anxiety sensitivity was the most influential predictor in the final support vector machine. Randomly disrupting anxiety-sensitivity scores reduced the testing area under the receiver operating characteristic curve by an average of .089, which was the largest reduction observed for any predictor. This finding indicated that the model relied strongly on individual differences in the tendency to fear anxiety-related sensations and interpret them as physically dangerous, cognitively harmful, or socially threatening. Perceived stress was the second most important predictor, producing a mean reduction of .067 in the area under the curve. The model therefore appeared to use subjective experiences of uncontrollability and overload as a major source of information when distinguishing elevated-risk from low-risk participants. Body trusting was the most influential interoceptive dimension and the third most important predictor overall. Lower trust in bodily sensations was associated with elevated risk, and permutation of this variable reduced the area under the curve by .051. Sleep disturbance ranked fourth, with a mean importance value of .044, demonstrating that sleep-related impairment provided classification information beyond anxiety sensitivity and perceived stress.

The not-worrying and self-regulation dimensions of interoceptive awareness ranked fifth and sixth, respectively. Lower not-worrying scores indicated a stronger tendency to become distressed by uncomfortable physical sensations, while lower self-regulation scores indicated reduced ability to calm psychological distress by attending constructively to bodily experience. Attention regulation, body listening, and not-distracting made smaller but still measurable contributions to model performance. Emotional awareness and bodily noticing had the lowest permutation-importance values. Although elevated-risk participants reported greater noticing and emotional awareness in the descriptive comparisons, these variables provided relatively limited unique information after the model simultaneously considered anxiety sensitivity, stress, sleep disturbance, body trust, and regulatory dimensions of interoception. The combined importance pattern suggested that panic-symptom risk was not primarily characterized by an absence of awareness of internal sensations. Instead, risk classification depended more strongly on whether bodily sensations were feared, distrusted, experienced with worry, and accompanied by difficulty regulating arousal and stress.

Figure 1

Receiver Operating Characteristic Curves for the Support Vector Machine, Penalized Logistic Regression, and Majority-Class Classifier in the Independent Testing Dataset

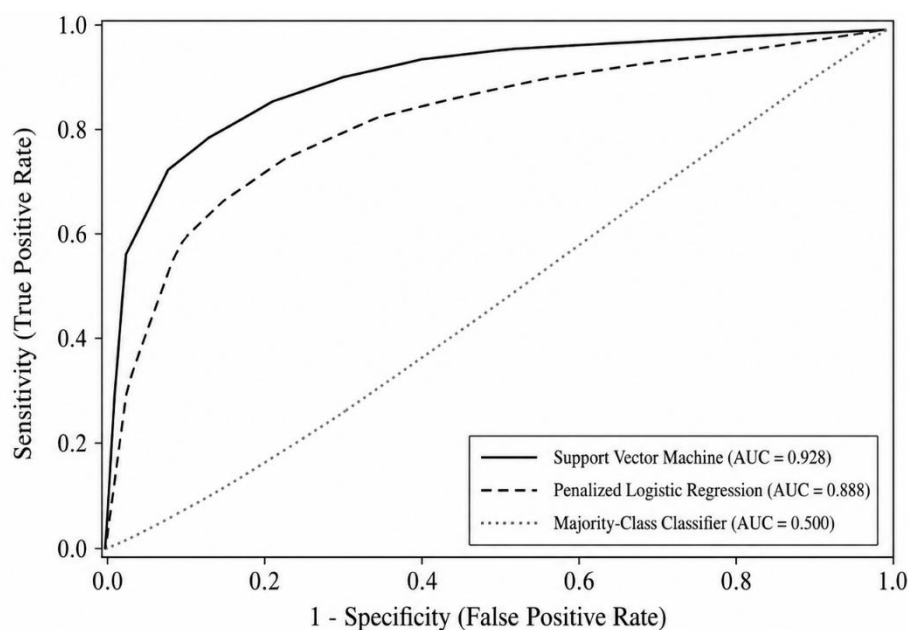


Figure 1 illustrates the discriminative performance of the support vector machine in comparison with a penalized

logistic regression model and a majority-class reference classifier. The support vector machine produced the largest

area under the receiver operating characteristic curve, with an AUC of .928. The penalized logistic regression model produced an AUC of .888, while the majority-class classifier produced the chance-level value of .500. At its locked decision threshold, the penalized logistic regression model correctly classified 86 of the 102 testing participants and achieved an accuracy of .843, balanced accuracy of .825, sensitivity of .786, specificity of .865, positive predictive value of .688, negative predictive value of .914, and an F1 score of .733. The support vector machine exceeded the logistic regression model in each of these principal classification measures, particularly in its identification of elevated-risk participants. The majority-class classifier labeled every participant as low risk and consequently achieved an apparently moderate overall accuracy of .725 because low-risk participants represented the majority of the testing sample. However, its sensitivity was zero, its balanced accuracy was .500, and it failed to identify any participant with elevated panic-symptom risk. The receiver operating characteristic curves therefore demonstrated that ordinary accuracy alone would have provided a misleading evaluation in the presence of unequal group sizes. The superior balanced accuracy, sensitivity, F1 score, and area under the curve obtained by the support vector machine indicated that its performance reflected meaningful discrimination rather than reliance on the majority category. The improvement over penalized logistic regression also suggested that nonlinear relationships and interactions among anxiety sensitivity, interoceptive functioning, sleep disturbance, and perceived stress contributed to the classification of panic-symptom risk.

4. Discussion

The present study developed and internally validated a support vector machine model for classifying elevated panic-symptom risk among Taiwanese youth based on anxiety sensitivity, multidimensional interoceptive awareness, sleep disturbance, and perceived stress. The findings showed that the elevated-risk group differed significantly from the low-risk group across all psychological predictors. Anxiety sensitivity, perceived stress, sleep disturbance, reduced body trusting, lower interoceptive not-worrying, and weaker interoceptive self-regulation produced the largest group differences. The support vector machine demonstrated strong discriminative performance in both repeated cross-validation and the independent testing dataset. In the testing sample, the model

achieved an accuracy of .882, balanced accuracy of .875, sensitivity of .857, specificity of .892, and an area under the receiver operating characteristic curve of .928. Anxiety sensitivity was the most influential predictor, followed by perceived stress, body trusting, sleep disturbance, interoceptive not-worrying, and interoceptive self-regulation. Moreover, the support vector machine outperformed penalized logistic regression and the majority-class classifier, suggesting that panic-symptom risk was better represented by a nonlinear multivariable pattern than by a simple linear combination of predictors.

The strongest finding was the prominent role of anxiety sensitivity. Youths in the elevated-risk group reported substantially greater fear of anxiety-related physical, cognitive, and social sensations, and anxiety sensitivity produced the largest decrease in model performance when permuted. This result is consistent with theoretical accounts in which panic symptoms develop when benign bodily sensations are interpreted as dangerous, uncontrollable, or socially threatening. Anxiety sensitivity can intensify ordinary experiences such as palpitations, dizziness, breathlessness, trembling, or mental confusion by transforming them into signals of imminent catastrophe. Once these sensations are feared, attention becomes increasingly focused on the body, which may further increase physiological arousal and confirm the individual's belief that something dangerous is occurring. Interoceptive anxiety-related processes have previously been identified as central mechanisms linking bodily sensations to anxiety and maladaptive coping, particularly during periods of uncertainty and heightened health concern (Zvolensky et al., 2022). The current findings extend this perspective to Taiwanese youth by showing that anxiety sensitivity is not only associated with panic symptoms at the group level but also provides the greatest unique contribution to individual risk classification.

The importance of anxiety sensitivity is also compatible with evidence supporting interoceptive exposure as a treatment strategy. Interoceptive exposure deliberately evokes feared physical sensations so that individuals can learn that bodily discomfort is temporary, tolerable, and not necessarily dangerous. A comprehensive scoping review concluded that interoceptive exposure has broad relevance across mental and physical health conditions characterized by fear and avoidance of internal sensations (Farris et al., 2025). The strong contribution of anxiety sensitivity in the present model suggests that youths classified as elevated risk may benefit from interventions that directly modify

catastrophic beliefs about bodily arousal. This interpretation is also consistent with the effectiveness of cognitive-behavioral treatments for panic disorder, including self-guided virtual reality approaches that combine exposure, cognitive restructuring, and repeated practice with feared sensations and situations (Shin et al., 2021). Thus, anxiety sensitivity may function both as a classification marker and as a modifiable intervention target.

Perceived stress was the second most influential predictor and showed a very large difference between the elevated-risk and low-risk groups. Elevated-risk youths experienced their lives as more unpredictable, uncontrollable, and overwhelming. This result suggests that panic symptoms may arise not only from fear of bodily sensations but also from the broader psychological context in which those sensations are experienced. Persistent stress can increase baseline arousal, reduce attentional flexibility, intensify repetitive negative thinking, and impair the ability to reinterpret ambiguous sensations. Under these conditions, ordinary bodily changes may be more likely to be perceived as threatening. Evidence from transdiagnostic exercise research indicates that reductions in repetitive negative thinking and stress perception can mediate improvements in psychological symptoms (Frei et al., 2026). This supports the possibility that perceived stress contributes to panic risk partly by maintaining cognitive and physiological activation.

The importance of perceived stress is particularly relevant to youth populations exposed to academic pressure, uncertainty about future employment, changing family expectations, and social adjustment. Research among Chinese college students following the Shanghai lockdown documented continuing psychological and physical health concerns after prolonged environmental disruption (Sun & Cicchella, 2025). Although the context differs from the present study, such findings illustrate how sustained uncertainty may affect young people's emotional and somatic functioning. Individual physiological factors may also shape the effects of stress on mental states, as the relationship between inflammation and psychophysiological functioning appears to vary according to personal characteristics (Yamaoka et al., 2025). The current results therefore support a biopsychosocial interpretation in which perceived stress heightens vulnerability to panic symptoms by increasing arousal and reducing regulatory capacity.

The findings concerning interoceptive awareness were more differentiated and demonstrated the importance of treating interoception as a multidimensional construct. Elevated-risk youths reported greater noticing of bodily

sensations and greater emotional awareness, yet they also reported substantially lower body trusting, not-worrying, self-regulation, attention regulation, body listening, and not-distracting. This pattern indicates that heightened awareness of internal states is not necessarily protective. Youths at elevated risk appeared able to notice bodily and emotional changes, but they were less likely to experience those changes as safe, manageable, or informative. The clinically relevant problem may therefore be the interpretation and regulation of sensations rather than the simple detection of bodily signals.

This interpretation aligns with contemporary models distinguishing objective interoceptive performance from subjective interoceptive beliefs and regulatory capacities. Interoception includes multiple processes, such as detecting bodily signals, attending to them, evaluating their meaning, and regulating the emotional response they produce (Nayok et al., 2023; Nord & Garfinkel, 2022). Evidence from a large multidomain psychophysical study found that objective interoceptive performance was not consistently related to mental health symptoms, suggesting that accurate bodily detection alone may not explain psychological distress (Banellis et al., 2025). The present findings are consistent with this conclusion. Bodily noticing and emotional awareness made relatively small unique contributions to the classification model, whereas body trusting and not-worrying were among the most important predictors. Thus, panic-symptom risk appears to depend less on whether youths perceive bodily sensations and more on whether they interpret those sensations with fear and distrust.

Body trusting was the most influential interoceptive dimension and the third most important predictor overall. Youths in the elevated-risk group were markedly less likely to regard their bodies as safe and dependable. Low body trust may create a persistent state of uncertainty in which internal sensations are treated as unreliable or potentially dangerous. This may be especially relevant to panic symptoms because episodes often involve a perceived betrayal of bodily control, such as the belief that the heart, breathing, balance, or consciousness may suddenly fail. Transdiagnostic accounts have proposed that altered interoceptive processing is shared across anxiety and affective disorders, particularly when bodily sensations are interpreted negatively or integrated poorly with emotional information (Saltafossi et al., 2024, 2025). Neurobiological findings also indicate altered activity in regions involved in salience detection, bodily representation, and regulatory control among individuals with anxiety and depressive disorders (Bednarek

et al., 2026). Heartbeat-evoked potentials have similarly been proposed as markers of dysfunctional cortical processing of internal cardiac signals (Wang, 2026). These findings support the interpretation that reduced body trust may reflect both psychological beliefs and altered processing of internal signals.

The lower not-worrying scores observed among elevated-risk youths further suggest that unpleasant sensations triggered stronger emotional alarm. This pattern resembles body vigilance, in which individuals closely monitor bodily changes and become increasingly concerned about their meaning. The psychometric evaluation of the Body Vigilance Scale in a non-Western context reflects the importance of measuring sustained somatic monitoring across cultures (Chahine et al., 2025). However, bodily attention alone is not necessarily maladaptive. Research involving women with and without histories of intimate partner violence showed that associations between interoceptive abilities and somatic complaints depend on psychological context and prior experience (Machorrinho et al., 2025). In the present study, heightened noticing became clinically relevant when combined with worry, distrust, and reduced regulation. Therefore, interventions should not simply encourage greater attention to the body; they should cultivate non-catastrophic, flexible, and accepting attention.

Interoceptive self-regulation and attention regulation also contributed meaningfully to classification. Elevated-risk youths appeared less able to use attention to bodily sensations as a means of calming distress and less able to shift or sustain attention adaptively. These deficits may allow arousal to escalate once panic-related sensations emerge. Psychological interventions targeting interoception have shown that bodily awareness can be modified and may contribute to improvement across mental health disorders (Heim et al., 2023). Mindfulness-based interventions may be particularly relevant because they train individuals to observe sensations without immediate judgment or avoidance. Preliminary evidence has indicated benefits of mindfulness-based interventions in conditions characterized by distressing bodily experiences, including psychogenic non-epileptic seizures and chronic pain (Ciacchini et al., 2025; Ciacchini et al., 2024). Mindfulness-based cognitive therapy has also been proposed for anxiety disorders that do not respond adequately to pharmacotherapy (Sado et al., 2021, 2022). The present findings suggest that such approaches may be helpful when panic risk is characterized by low body trust and poor interoceptive regulation.

Sleep disturbance was another major predictor and was substantially more severe in the elevated-risk group. Poor sleep may increase panic vulnerability through several interconnected pathways, including autonomic activation, emotional instability, cognitive fatigue, and increased sensitivity to ambiguous physical sensations. Insomnia has been conceptualized as a systemic condition rather than an isolated sleep complaint because it affects emotional, neurological, metabolic, and physiological functioning (Yun & Jo, 2021). Neurofunctional alterations have also been observed in individuals with insomnia symptoms in clinically vulnerable populations (White et al., 2024). In youth, sleep deprivation may produce dizziness, palpitations, concentration difficulties, derealization, and fatigue, all of which may be misinterpreted as signs of danger by individuals with elevated anxiety sensitivity.

The relationship between sleep and interoception may also be bidirectional. Research examining sleep and interoception across adulthood has suggested that sleep quality is related to how internal bodily states are perceived and processed (Seo et al., 2025). Poor sleep may intensify bodily sensations and reduce the capacity to regulate attention, whereas heightened vigilance to heartbeat, breathing, or physical discomfort may interfere with sleep onset and maintenance. The present findings support an interactive model in which sleep disturbance does not operate independently but amplifies the effects of anxiety sensitivity, stress, and maladaptive interoceptive appraisal. This may partly explain why the nonlinear support vector machine outperformed logistic regression.

The strong performance of the support vector machine indicates that panic-symptom risk can be classified effectively from a relatively small set of theoretically grounded psychological variables. The model's high sensitivity is especially important for screening because failure to identify an elevated-risk youth may delay assessment and intervention. At the same time, the strong specificity and negative predictive value indicate that the model did not achieve sensitivity merely by labeling large numbers of participants as high risk. Its superiority over the linear logistic model suggests that the relationships among predictors were not entirely additive. For example, high bodily noticing may be benign when body trust is high but may become clinically significant when accompanied by high anxiety sensitivity, poor sleep, and elevated stress.

The model's findings are also relevant to treatment heterogeneity. Recent work has emphasized that non-response to psychotherapy for anxiety disorders may reflect

different maintenance mechanisms rather than a single form of treatment failure (Sasin et al., 2026). The current predictor pattern suggests that youths with similar panic-symptom severity may have different underlying profiles. Some may be primarily characterized by anxiety sensitivity, others by stress and sleep disturbance, and others by distrust of bodily sensations and poor interoceptive regulation. This heterogeneity may help explain why one intervention is not equally effective for all individuals. Complementary interventions such as respiration training, heart rate variability biofeedback, exercise, mindfulness, and mind-body programs may address different components of the risk profile (Balban et al., 2023; Dolgilevica et al., 2025; Kwon & Lee, 2022; Strehli et al., 2022; Sumińska & Rynkiewicz, 2025). Physiological responses during exercise have also been associated with cognitive-behavioral treatment outcomes in panic disorder, reinforcing the value of integrating psychological and bodily mechanisms (Wintermann et al., 2022).

5. Conclusion

The findings should nevertheless be interpreted within a broader medical context. Bodily sensations associated with panic may overlap with genuine physical conditions, nutritional abnormalities, or trauma-related responses. Vitamin B12 deficiency, for example, can present with neurological symptoms that may be confused with anxiety-related complaints (Zhou et al., 2024). Emerging psychobiotic research also points to complex interactions among the gut microbiome, metabolites, and mood regulation (Garzone et al., 2025). In medically vulnerable individuals, such as those with congenital heart disease, real cardiac sensations may interact with trauma-related fear and require carefully integrated assessment (Callus, 2025). Therefore, the model should be understood as a psychological risk-classification tool and not as a substitute for diagnostic or medical evaluation.

6. Limitations & Suggestions

This study had several limitations. Its cross-sectional design prevented conclusions about the temporal or causal relationships among anxiety sensitivity, interoceptive awareness, sleep disturbance, perceived stress, and panic symptoms. All principal variables were measured using self-report instruments, which may have been influenced by recall bias, response style, and shared method variance. Although the sample included youths from several regions

and educational settings in Taiwan, it may not fully represent adolescents and young adults who are not enrolled in education, live in rural areas, or have severe psychiatric conditions. Panic-symptom risk was defined using a screening cutoff rather than a structured clinical interview, and the resulting categories should not be interpreted as confirmed diagnoses of panic disorder. The model was internally validated using a held-out testing sample, but it was not externally validated in a separate population. In addition, the relatively small number of elevated-risk cases may have limited the precision of some performance estimates. Finally, permutation importance indicates the model's reliance on variables but does not establish causal importance, and correlations among interoceptive dimensions may have distributed predictive importance across related features.

Future studies should use longitudinal designs to determine whether the identified variables predict the onset, persistence, or remission of panic symptoms over time. External validation should be conducted in independent Taiwanese samples and in youth populations from other cultural and linguistic settings. Clinical interviews could be added to distinguish transient panic symptoms, recurrent panic attacks, and diagnosed panic disorder. Future models should also incorporate objective sleep measures, physiological recordings, behavioral interoception tasks, and digital indicators of stress or activity. Larger samples would permit subgroup analyses by age, gender, educational stage, treatment history, and symptom profile. Comparative research should evaluate additional machine-learning algorithms and assess whether simpler models can achieve similar performance with fewer predictors. Prospective intervention studies could also examine whether changes in anxiety sensitivity, body trust, sleep quality, and perceived stress correspond to changes in model-estimated risk.

Schools, universities, youth counseling centers, and community mental health services should consider screening panic-symptom risk using a combination of bodily fear, stress, sleep, and interoceptive-regulation indicators rather than relying on panic symptoms alone. Youths identified as elevated risk should receive a comprehensive assessment that includes medical, psychological, and contextual factors. Preventive programs may combine psychoeducation about benign bodily arousal, cognitive restructuring of catastrophic interpretations, interoceptive exposure, stress-management training, sleep-hygiene support, and exercises that strengthen body trust and emotional regulation. Digital screening tools based on the model may improve access, but

results should be reviewed by qualified professionals and should never be presented as definitive diagnoses. Intervention planning should also be individualized because similar panic-symptom levels may arise from different combinations of anxiety sensitivity, stress, sleep disturbance, and interoceptive difficulties.

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Declaration of Interest

The authors of this article declared no conflict of interest.

Ethical Considerations

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

Transparency of Data

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

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Authors' Contributions

All authors equally contributed to this article.

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