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Alexithymia, Interoceptive Awareness, and Autonomic Indices: A Machine-Learning Approach to Psychosomatic Vulnerability

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A B S T R A C T

This study aims to predict psychosomatic vulnerability by integrating self-reported measures of alexithymia and interoceptive awareness with objective autonomic indices using a machine-learning approach. This cross-sectional observational study included 485healthy adult participants (aged 18to 65years) recruited from urban centers in Colombia. Self-reported psychological and somatic data were collected using the Toronto Alexithymia Scale (TAS-20), Multidimensional Assessment of Interoceptive Awareness (MAIA), and Somatic Symptom Scale (SSS). Continuous objective physiological data, specifically electrocardiogram and electrodermal activity, were acquired at a sampling rate of 1000Hz during resting, stress induction, and recovery phases. Machine learning models, including Random Forest, Support Vector Machines, and Gradient Boosting, were developed using an 80/20 train/test data split and ten-fold cross-validation, with SHapley Additive exPlanations (SHAP) utilized to determine feature importance. The Gradient Boosting model yielded the highest predictive performance, achieving an accuracy of 81.4%and an Area Under the Curve (AUC) of 0.885on the test dataset. SHAP value analysis identified that the top predictors of psychosomatic vulnerability were the “difficulty identifying feelings” facet of the TAS-20, the “not-worrying” dimension of the MAIA, baseline root mean square of successive differences (RMSSD), and the low-frequency to high-frequency (LF/HF) power ratio during stress. Psychosomatic vulnerability can be highly accurately predicted by synergistically integrating subjective psychological traits and objective physiological markers through advanced machine learning algorithms.

Keywords: *Alexithymia, Interoceptive Awareness, Autonomic Nervous System, Psychosomatic Vulnerability*

1. Introduction

Psychosomatic vulnerability represents one of the most profound and persistent challenges in contemporary medical and psychological healthcare. It is broadly characterized by the manifestation of severe psychological distress through enduring, and often highly debilitating, somatic symptoms. Individuals suffering from psychosomatic presentations frequently report a massive burden of physical ailments that consistently lack a clear, singular organic etiology, leading to exhaustive and often inconclusive medical testing. The conceptualization of somatic symptom disorders has evolved significantly in recent years, shifting away from an exclusive focus on medically unexplained physical symptoms and moving toward a framework that deeply emphasizes the disproportionate cognitive, emotional, and behavioral responses to somatic sensations (Porcelli et al., 2020). This vital paradigm shift acknowledges that psychosomatic vulnerability is not merely defined by the presence of physical pain, but rather by a complex, interconnected psychophysiological web involving distorted illness perception, pervasive affective dysregulation, and heightened pain catastrophizing (Hooshmandi et al., 2024). Consequently, psychological and cognitive factors are increasingly recognized by clinicians and researchers as the primary drivers in the onset, exacerbation, and chronic maintenance of somatic complaints (Zimoglyad et al., 2023). Among the most critical and widely studied psychological traits implicated in this profound vulnerability is alexithymia, a multifaceted and deeply ingrained construct fundamentally associated with a severe inability to process, regulate, and articulate emotional states.

The psychological construct of alexithymia, which literally translates from its Greek origins to “no words for emotions,” has been extensively investigated to understand its precise mechanistic role in driving psychosomatic pathology. Current clinical conceptualizations of alexithymia emphasize its three core operational features: a profound difficulty identifying subjective feelings and distinguishing them from the bodily sensations of emotional arousal, a pervasive difficulty describing subjective feelings to others, and an externally oriented cognitive style that rigidly favors concrete, external realities over internal psychological introspection (Taylor & Bagby, 2020). In the absence of adequate cognitive and emotional processing capabilities, individuals possessing elevated alexithymic traits are uniquely prone to misinterpret standard states of emotional arousal as severe signs of physical illness, a dangerous cognitive-affective phenomenon closely tied to the concept of somatosensory amplification (Nakao & Takeuchi, 2018). This cognitive-affective deficit effectively blocks the normative psychological resolution of stress, forcing the unresolved psychological tension to be forcefully discharged through physiological channels, ultimately culminating in diverse and painful physical outcomes (Myles, 2021). The pervasive, systemic impact of alexithymia is glaringly evident across various psychopathological manifestations centered on the physical body, encompassing not only classical somatization disorders but also extending to self-harm behaviors, which often act as rudimentary, physical emotion regulation strategies when cognitive strategies fail (Gatta et al., 2022). Furthermore, the systemic physiological dysregulation inherently associated with chronic alexithymia has been consistently and robustly linked to the severity and progression of complex chronic autoimmune and inflammatory conditions, such as inflammatory bowel disease, highlighting its role not merely as a psychological quirk, but as a pervasive, dangerous somatic risk factor (Martino et al., 2020).

The genesis, development, and chronic maintenance of alexithymia are deeply embedded in adverse environmental, developmental, and systemic contexts. Severe childhood trauma and early maltreatment represent profound developmental risk factors, fundamentally disrupting the normative acquisition of emotion regulation skills and directly predicting severe somatic symptoms later in adult life; notably, this effect is substantially mediated by the early emergence of emotional alexithymia (Adamowicz et al., 2024). Furthermore, comprehensive structural equation modeling has confirmed that childhood trauma strongly predicts somatic symptoms through the mediating pathways of emotional alexithymia and diminished perceived social support (Mohammadi Begi, 2023). This intergenerational transmission of emotional illiteracy is frequently observed within tightly knit family units, where children and adolescents growing up in what are termed “psychosomatic families” adopt severely maladaptive communication patterns that stifle healthy emotional expression and instead actively promote and reward physical symptom reporting (O’Malley, 2023). Such familial and environmental stressors were acutely exacerbated during unprecedented global crises, most notably the $COVID-19$pandemic, during which the interacting alexithymic traits of both parents and children synergistically amplified behavioral and somatic

JPPR
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symptomatology in vulnerable youth (Renzi et al., 2022). Particularly in adolescent girls, the complex interaction between high alexithymia, profound feelings of chronic loneliness, and generally diminished psychological well-being forms a highly potent catalyst for the development of severe psychosomatic problems (Saffarian Toosi & Khadivi Rofugar, 2020). In adult populations, alexithymia remains a crucial, heavily weighted moderator determining clinical and occupational outcomes. For example, in demanding occupational settings, the toxic combination of alexithymia and experiential avoidance strongly and reliably predicts the widespread development of psychosomatic disorders among corporate employees (pardh et al., 2022). Similarly, alexithymia heavily moderates how perceived social support impacts the frequency of somatic complaints, a dynamic particularly evident in populations of depressed women (Mohammadi & Jafari, 2020). Furthermore, its persistent presence not only directly exacerbates objective somatic symptoms but also significantly dampens psychotherapeutic treatment expectations and severely blunts positive outcomes in complex interdisciplinary chronic pain management programs (Blaettler et al., 2019). Unsurprisingly, broad meta-analytic data reveals that alexithymia is a prominent, deeply ingrained, and nearly ubiquitous feature across the entire clinical spectrum of eating disorders (Westwood et al., 2017).

Operating parallel to the emotional processing deficits characterized by alexithymia are profound disruptions in interoceptive awareness, which is defined as the central nervous system's capacity to perceive, appraise, and integrate sensory signals originating from within the visceral body. These interoceptive disruptions have rapidly emerged as a central, driving pillar of psychosomatic vulnerability. Interoception is not a simple, unitary construct; rather, it encompasses multiple, distinct dimensions, ranging from basic bodily noticing and attention regulation to emotional awareness and the subjective trusting of bodily signals (Todd et al., 2019). The ability to accurately and reliably assess these multidimensional facets, particularly in youth aged $7-17$years, is vital for understanding early developmental trajectories of psychological and somatic risk (Jones et al., 2020). When individuals lack precise, reliable interoceptive awareness, they exhibit significant, often dangerous difficulty discriminating between normal homeostatic physiological fluctuations and genuine signs of pathological bodily threat. This specific interoceptive failure profoundly predicts future psychosomatic symptoms and massively heightens the longitudinal risk for developing eating disorders, a risk trajectory that is especially pronounced in female adolescents (Riboli, 2022). Moreover, maladaptive cognitive coping mechanisms, such as rigid cognitive avoidance, frequently exacerbate somatic complaints precisely by disrupting and short-circuiting the protective, mediating function of healthy interoceptive awareness (Zulkifli et al., 2025).

The physiological and psychological consequences of blunted, distorted, or completely suppressed interoceptive awareness are particularly pronounced in clinical conditions characterized by a fundamental, deep-seated disconnect from the physical self. Extensive cross-sectional and longitudinal research indicates that an internalized sense of body mistrust serves as a crucial, load-bearing bridge linking impaired interoceptive awareness to the severe, life-threatening symptomology observed in clinical eating disorders (Brown et al., 2020). This somatocognitive disconnect is similarly evident in non-clinical but highly vulnerable populations, such as high-stress college women, where measured deficits in both general emotional awareness and specific interoceptive sensitivity to normative appetite cues heavily drive compulsive emotional eating behaviors (Bullock & Goldbacher, 2023). Furthermore, within the complex physiological context of moderate and severe obesity, profound difficulties in adaptive emotion regulation are intrinsically tethered to severe, measurable deficits in interoceptive awareness, thereby creating a highly destructive, self-perpetuating feedback loop of emotional dysregulation and somatic distress (Willem et al., 2019). In-depth qualitative investigations of hospitalized adolescent girls diagnosed with severe obesity further underscore this phenomenon, revealing that a profoundly disrupted, untrusted, and alien sense of the internal body is a central phenomenological experience in severe metabolic and somatic conditions (Liné et al., 2022). This pervasive somatic alienation is further compounded in adolescent populations when pre-existing interoceptive awareness deficits dangerously interact with a high psychological intolerance of uncertainty, thereby generating intolerable, terrifying feelings within the body that directly and forcefully fuel severe body dissatisfaction (Bijsterbosch et al., 2023).

Recognizing the immense, synergistic detrimental impact of these interacting psychological deficits, contemporary evidence-based therapeutic frameworks have increasingly shifted to simultaneously target both alexithymia and interoceptive awareness to holistically alleviate psychosomatic distress. Mindfulness-based cognitive

JPPR
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therapy has proven highly effective in directly addressing and neutralizing psychosomatic symptom distress, operating largely through the targeted therapeutic enhancement of self-compassion and the subsequent, measurable reduction of rigid alexithymic traits (Xu & Shi, 2024). Rigorous randomized controlled trials have further validated this specialized approach, firmly demonstrating that mindfulness-based interventions can significantly reduce alexithymia and tangibly improve objective physical outcomes in chronic, severe somatic conditions, such as widespread fibromyalgia (Lundberg, 2023). Beyond traditional mindfulness paradigms, highly targeted online emotional skills training programs have shown considerable, scalable success in simultaneously improving broad emotional awareness, interoceptive sensitivity, and interpersonal emotion management, thereby dynamically strengthening the individual's psychological defenses against involuntary somatization (Smith et al., 2024). In younger, highly vulnerable populations, particularly adolescent girls currently suffering from complex, medically unexplained psychosomatic disorders, intensive emotion-based group family therapy has been shown to effectively enhance psychological self-differentiation and substantially lower clinically elevated alexithymia scores, thereby systematically addressing the systemic familial roots of their ongoing physical distress (Ghavanati et al., 2025).

Despite the remarkably clear theoretical, empirical, and clinical links firmly established between alexithymia, disrupted interoceptive awareness, and somatic symptomology, a vast, critical gap remains in the modern literature regarding the direct linkage of these subjective psychological constructs with objective, continuously recorded physiological biomarkers. Psychosomatic vulnerability fundamentally, by its very definition, involves the dysregulation of the autonomic nervous system; yet, the vast majority of existing psychological literature relies almost exclusively on subjective self-report questionnaires, which are inherently vulnerable to the exact cognitive blind spots they aim to measure. To truly, scientifically capture the invisible biological translation of emotional illiteracy into tangible physical symptoms, it is absolutely essential to dynamically incorporate continuous autonomic indices, such as high-frequency heart rate variability and phasic electrodermal activity. These highly specific physiological markers provide an objective, real-time, unfiltered window into the precise sympathetic hyperarousal and parasympathetic withdrawal that biophysiologically characterize the psychosomatic stress response.

Furthermore, the statistical and methodological approaches historically employed to investigate these multidimensional relationships have predominantly relied on traditional, rigid linear regression models. However, human psychophysiology and the etiology of psychosomatic pathology are inherently complex, highly interactive, and fundamentally non-linear in nature. The synergistic, compounding interactions between highly specific facets of alexithymia, nuanced dimensions of interoceptive awareness, and dynamic, millisecond-by-millisecond changes in autonomic indices cannot be fully or accurately elucidated through simple, additive statistical models. Machine learning techniques, particularly advanced, supervised non-linear classification algorithms, offer a remarkably robust, highly sensitive alternative. These advanced computational algorithms possess the mathematical capacity to model highly complex, multi-dimensional data arrays, automatically identifying hidden, non-linear patterns and multi-variable interaction effects that traditional, standard statistics almost invariably miss. By directly integrating self-reported psychometric data with objective, high-resolution physiological signals within an advanced machine learning framework, it becomes computationally possible to construct highly accurate, interpretable predictive models of psychosomatic vulnerability, thereby paving the way for far more precise early identification and the subsequent deployment of highly personalized clinical interventions. Therefore, the primary aim of this study is to utilize a supervised machine-learning approach to predict psychosomatic vulnerability by integrating self-reported measures of alexithymia and interoceptive awareness with objective, continuous autonomic indices.

2. Methods and Materials

2.1. Study Design and Participants

The present research employed a cross-sectional observational study design to investigate the complex interplay between alexithymia, interoceptive awareness, and autonomic indices as predictors of psychosomatic vulnerability. The target population comprised a community-based sample drawn from several major urban centers in Colombia. A total of exactly 485healthy adult participants were recruited through a combination of stratified random sampling and targeted social media advertising to ensure a diverse representation of socioeconomic backgrounds. Inclusion criteria required

JPPR
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participants to be between the ages of 18and 65years, fluent in Spanish, and possessing normal or corrected-to-normal vision and hearing. Individuals were excluded if they reported a history of severe neurological disorders, current substance abuse, or were currently undergoing pharmacological treatment with medications known to significantly alter autonomic nervous system functioning, such as beta-blockers or psychotropic drugs.

2.2. *Measures*

To comprehensively assess the variables of interest, a multi-modal data collection approach was utilized, incorporating both validated psychological self-report measures and objective physiological recordings. Alexithymia was quantified using the Spanish-validated version of the Toronto Alexithymia Scale, a widely recognized instrument that assesses difficulty identifying feelings, difficulty describing feelings, and externally oriented thinking. Interoceptive awareness was evaluated via the Multidimensional Assessment of Interoceptive Awareness questionnaire, which captures distinct facets of body awareness, including noticing, not-distracting, not-worrying, attention regulation, emotional awareness, self-regulation, body listening, and trusting. Psychosomatic vulnerability was measured using the Somatic Symptom Scale, which records the burden of physical symptoms. In addition to these psychometric tools, continuous physiological data were acquired to compute autonomic indices. Participants were seated in a temperature-controlled, sound-attenuated laboratory room where a standard three-lead electrocardiogram was attached to record cardiac activity. Electrodermal activity was simultaneously recorded using Ag/AgCl electrodes attached to the medial phalanges of the non-dominant index and middle fingers. The physiological recording session consisted of a ten-minute baseline resting state, followed by a standardized stress-induction paradigm and a subsequent ten-minute recovery period. The electrocardiogram and electrodermal activity signals were digitized at a sampling rate of 1000Hz using a high-performance data acquisition system, allowing for the precise extraction of heart rate variability metrics and skin conductance responses.

2.3. *Data Analysis*

The data analysis pipeline was purposefully designed to leverage advanced machine learning techniques for the prediction of psychosomatic vulnerability based on the integration of psychological and physiological features. Initially, the raw physiological signals underwent rigorous preprocessing. Electrocardiogram data were filtered to remove noise and artifacts, and R-peaks were detected to calculate time-domain and frequency-domain heart rate variability parameters, such as the root mean square of successive differences and the ratio of low-frequency to high-frequency power. Electrodermal activity data were decomposed into tonic and phasic components to extract the frequency and amplitude of non-specific skin conductance responses. Following feature extraction, a comprehensive feature dataset was constructed by concatenating the psychometric scores and the autonomic indices. Missing data were handled using a K-nearest neighbors imputation algorithm. The predictive modeling phase utilized a supervised machine learning framework, specifically employing Random Forest, Support Vector Machines, and Gradient Boosting algorithms. The dataset was randomly partitioned into a training set comprising 80%of the sample and a hold-out test set containing the remaining 20%. To prevent overfitting and optimize hyperparameters, a ten-fold cross-validation procedure was implemented on the training data. The models' predictive performance was evaluated using standard metrics including accuracy, precision, recall, and the area under the receiver operating characteristic curve, denoted as AUC. Furthermore, SHapley Additive exPlanations values were calculated to ensure model interpretability, allowing for the quantification of the specific contribution of each psychological and autonomic feature to the overall prediction of psychosomatic vulnerability. Statistical significance for all relevant comparative tests was established at a threshold of $p < 0.05$.

3. Findings and Results

The data analysis yielded comprehensive insights into the baseline characteristics of the Colombian sample and the predictive utility of integrating psychological and physiological features to model psychosomatic vulnerability. Preliminary analyses were conducted to ensure the assumptions of normality and linearity were met for parametric testing where applicable. The final sample consisted of $N = 485$participants, comprising 256females (52.8%) and 229males (47.2%), with a mean age of $M = 34.6$years ($SD = 11.2$). Standard descriptive statistics and bivariate Pearson correlations were computed to examine the fundamental relationships between the primary psychometric scores and autonomic indices. The analysis

JPPR
E-ISSN: 3041-8542

revealed a significant positive correlation between the total score of the Toronto Alexithymia Scale and the Somatic Symptom Scale ($r = .46$, $p < .001$), indicating that higher levels of alexithymia were associated with a greater burden of psychosomatic symptoms. Conversely, a significant negative correlation was observed between the Multidimensional Assessment of Interoceptive Awareness total score and somatic symptoms ($r = -.38$, $p < .001$). Regarding the physiological parameters, resting heart rate variability, specifically the root mean square of successive differences (RMSSD), demonstrated a modest but significant negative correlation with psychosomatic vulnerability ($r = -.29$, $p < .01$), suggesting that lower parasympathetic tone is linked to higher symptom reporting. These descriptive and correlational data are summarized in Table 1.

Table 1

Descriptive Statistics and Bivariate Correlations of Primary Study Variables

Variable	***M***	***SD***	**1**	**2**	**3**	**4**
1. Somatic Symptom Scale (SSS)	12.45	4.82	–			
2. Toronto Alexithymia Scale (TAS-20)	48.31	10.15	$.46^{**}$	–		
3. Interoceptive Awareness (MAIA)	112.60	18.44	$-.38^{**}$	$-.51^{**}$	–	
4. Heart Rate Variability (RMSSD in ***ms***)	41.20	15.65	$-.29^{**}$	$-.22^{*}$	$.31^{**}$	–
5. Skin Conductance Responses (NS-SCR)	3.85	1.92	$.21^{*}$	$.18^{*}$	$-.15$	$-.42^{**}$

Following the initial descriptive assessment, the machine learning pipeline was executed to classify individuals into high versus low psychosomatic vulnerability categories. The target variable, derived from the Somatic Symptom Scale, was binarized using a median split ($Median = 12$) to facilitate supervised classification. The predictive models—Random Forest, Support Vector Machine (SVM), and Gradient Boosting—were trained on 80%of the data ($n = 388$) utilizing ten-fold cross-validation to optimize hyperparameters and mitigate overfitting. The final evaluation was conducted on the hold-out test set ($n = 97$). The comparative analysis of model performance revealed that tree-based ensemble methods outperformed the linear classification boundary established by the SVM. Specifically, the Gradient Boosting algorithm achieved the highest predictive accuracy at 81.4%, successfully identifying the complex, non-linear interactions between self-reported interoceptive deficits, alexithymia, and blunted autonomic reactivity. The Random Forest model performed marginally lower but still demonstrated robust predictive capacity. The SVM yielded the lowest sensitivity (Recall), suggesting it struggled to accurately identify true positive cases of high psychosomatic vulnerability without generating a high rate of false negatives. The complete performance metrics, including Accuracy, Precision, Recall, F1-Score, and the Area Under the Receiver Operating Characteristic Curve (AUC), are detailed in Table 2.

Table 2

Performance Metrics of Machine Learning Models Predicting Psychosomatic Vulnerability on the Test Set

Model	Accuracy	Precision	Recall	F1-Score	***AUC***
Gradient Boosting	.814	.821	.804	.812	.885
Random Forest	.793	.787	.804	.795	.862
Support Vector Machine	.731	.744	.695	.718	.780

To elucidate the inner workings of the best-performing Gradient Boosting model and establish clinical interpretability, SHapley Additive exPlanations (SHAP) values were computed. This approach permitted the ranking of both psychological and physiological features based on their absolute contribution to the model's predictions. The analysis revealed that the "Difficulty Identifying Feelings" subscale of the TAS-20 emerged as the single most critical predictor of psychosomatic vulnerability, exhibiting the highest mean absolute SHAP value. Interestingly, physiological indices were highly represented among the top predictors, with baseline Heart Rate Variability (RMSSD) and the ratio of low-frequency to high-frequency power (LF/HF ratio) during the stress-induction paradigm ranking third and fifth, respectively. Furthermore, the "Not-Worrying" and "Attention Regulation" facets of the MAIA

JPPR
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were identified as significant protective features; higher scores on these domains strongly influenced the model toward predicting low psychosomatic vulnerability. Skin conductance reactivity during the recovery phase also contributed significantly, indicating that delayed autonomic recovery is an important physiological marker. Table 3 presents the top ten features ranked by their mean absolute SHAP values, illustrating the synergistic importance of combining subjective psychological traits with objective autonomic indices in psychosomatic risk profiling.

Table 3

Top Ten Features Predicting Psychosomatic Vulnerability Ranked by Mean Absolute SHAP Values

Rank	Feature	Category	Mean SHAP Value
1	Difficulty Identifying Feelings (TAS-20)	Psychological	0.842
2	Not-Worrying (MAIA)	Psychological	0.715
3	Baseline RMSSD	Physiological (Cardiac)	0.658
4	Difficulty Describing Feelings (TAS-20)	Psychological	0.590
5	LF/HF Ratio (Stress Phase)	Physiological (Cardiac)	0.512
6	Attention Regulation (MAIA)	Psychological	0.485
7	Emotional Awareness (MAIA)	Psychological	0.420
8	EDA Recovery Rate (Phasic)	Physiological (Electrodermal)	0.395
9	Externally Oriented Thinking (TAS-20)	Psychological	0.310
10	Baseline NS-SCR Amplitude	Physiological (Electrodermal)	0.275

4. Discussion and Conclusion

The primary aim of the present study was to utilize a sophisticated machine-learning approach to predict psychosomatic vulnerability by comprehensively integrating self-reported measures of alexithymia and interoceptive awareness with objective, continuous autonomic indices. The findings demonstrated that tree-based ensemble methods, specifically the Gradient Boosting algorithm, achieved a robust predictive accuracy of 81.4%and an impressive area under the receiver operating characteristic curve of $AUC = .885$. By employing SHapley Additive exPlanations values to ensure model interpretability, the analysis revealed that psychosomatic vulnerability is not solely dictated by either psychological traits or physiological baselines in isolation, but rather by their complex, non-linear interactions. The single most critical predictor identified by the model was the "Difficulty Identifying Feelings" facet of the Toronto Alexithymia Scale. This subjective emotional deficit was closely followed by specific protective dimensions of interoceptive awareness, namely "Not-Worrying" and "Attention Regulation." Crucially, physiological parameters, including baseline root mean square of successive differences and the ratio of low-frequency to high-frequency power during stress, ranked among the top five most impactful features. These results underscore the multidimensional nature of psychosomatic symptomology, powerfully suggesting that an individual's inability to cognitively interpret emotions and calmly attend to bodily sensations acts in tandem with inherent autonomic dysregulation to drive profound physical distress.

The prominent emergence of alexithymia, specifically the profound difficulty in identifying feelings, as the leading predictor of psychosomatic vulnerability aligns robustly with the foundational theories of emotional processing deficits and somatization. The established conceptualization of alexithymia emphasizes that the inability to distinguish between subjective affective states and the physiological arousal of emotions forces unresolved psychological distress to manifest as medically unexplained physical symptoms (Taylor & Bagby, 2020). In the absence of an emotional vocabulary, individuals misinterpret normative physiological arousal as pathological bodily threat, a cognitive error conceptually related to somatosensory amplification (Nakao & Takeuchi, 2018). This phenomenon effectively short-circuits the psychological resolution of stress, discharging tension forcefully through somatic channels (Myles, 2021). The pervasive impact of such emotional illiteracy has been consistently observed across a wide spectrum of psychopathological and physical conditions, ranging from traditional somatization and self-harm (Gatta et al., 2022) to severe, chronic inflammatory diseases (Martino et al., 2020). The developmental trajectory of this vulnerability is often deeply rooted in early adverse experiences; severe childhood trauma fundamentally disrupts emotion regulation, predicting somatic symptoms in adulthood primarily through the mediation of early

JPPR
E-ISSN: 3041-8542

emotional alexithymia (Adamowicz et al., 2024). Structural modeling further confirms that such early trauma acts through alexithymia and diminished social support to crystallize somatic complaints (Mohammadi Begi, 2023). This risk is notably amplified within dysfunctional familial environments, where "psychosomatic families" actively suppress healthy emotional expression and reinforce physical symptom reporting (O'Malley, 2023). The exacerbating nature of alexithymia was particularly evident during the acute stress of the pandemic, synergistically amplifying somatic symptoms in vulnerable youth (Renzi et al., 2022). Furthermore, demographic factors such as being a female adolescent struggling with loneliness (Saffarian Toosi & Khadivi Rofugar, 2020), or facing high occupational stress coupled with experiential avoidance (pardh et al., 2022), dramatically compound the somatizing effects of alexithymia. It is also a well-documented moderator determining the severity of somatic complaints in depressed populations (Mohammadi & Jafari, 2020) and a critical barrier to positive outcomes in chronic pain treatments (Blaettler et al., 2019), cementing its role as a fundamental driver of widespread physical vulnerability (Zimoglyad et al., 2023).

Operating in tandem with emotional deficits, our findings highlighted the critical protective role of specific facets of interoceptive awareness, notably the capacity to not worry about physical sensations. Interoception encompasses multiple dimensions of perceiving and integrating visceral signals (Todd et al., 2019), and assessing these facets is crucial for predicting clinical risk (Jones et al., 2020). The machine learning model clearly indicated that individuals who lacked the ability to calmly attend to their bodily sensations without cognitive distraction or catastrophic worry were significantly more likely to be classified as highly psychosomatically vulnerable. This directly supports the growing consensus that distorted interoceptive appraisal is a central pillar of somatic disorders (Hooshmandi et al., 2024). When individuals exhibit profound interoceptive failures, they display a dangerous inability to discriminate between normal homeostatic shifts and genuine pathology, heavily predicting longitudinal somatic risk and severe eating disorder symptomology (Riboli, 2022). This profound disconnect and internalized sense of body mistrust bridges impaired interoception with severe clinical outcomes (Brown et al., 2020). Such somatocognitive alienation heavily drives compulsive emotional behaviors under stress (Bullock & Goldbacher, 2023) and forms a self-perpetuating cycle of emotional and somatic distress in conditions like severe obesity (Willem et al., 2019), a phenomenon qualitatively confirmed as a deeply alienating physical experience (Liné et al., 2022). Furthermore, the interaction of interoceptive deficits with a high intolerance of uncertainty generates intolerable bodily feelings that directly fuel physical distress (Bijsterbosch et al., 2023), while maladaptive strategies like cognitive avoidance actively exacerbate this process by disrupting the protective functions of healthy interoception (Zulkifli et al., 2025).

The significant predictive power of objective autonomic markers, such as heart rate variability and electrodermal reactivity, solidifies the biophysiological mechanisms underpinning psychosomatic distress. While modern frameworks of somatic symptom disorders emphasize cognitive and emotional responses (Porcelli et al., 2020), our machine learning model demonstrates that these psychological traits are fundamentally intertwined with measurable biological dysregulation. The prominence of baseline root mean square of successive differences and the low-frequency to high-frequency power ratio indicates that lower parasympathetic tone and heightened sympathetic hyperarousal are not just correlates, but powerful non-linear predictors of somatic vulnerability. This aligns with therapeutic interventions showing that modifying psychological traits inevitably alters physiological states. For instance, mindfulness-based cognitive therapy effectively neutralizes somatic distress by specifically targeting self-compassion and alexithymia (Xu & Shi, 2024), leading to tangible physical improvements in chronic pain conditions (Lundberg, 2023). Similarly, targeted emotional skills training simultaneously enhances interoceptive sensitivity and physiological regulation (Smith et al., 2024), just as family-based emotion therapies lower somatic distress by addressing both systemic emotional literacy and the associated physiological tension (Ghavanati et al., 2025). The widespread presence of alexithymia across somatic and eating disorders (Westwood et al., 2017) can thus be partially explained by this shared, underlying autonomic rigidity.

In conclusion, the present study successfully demonstrates that psychosomatic vulnerability is a deeply complex, multifaceted phenomenon that can be highly accurately predicted using advanced machine learning techniques. By moving beyond simple linear models and isolated self-report questionnaires, this research illuminates the profound, synergistic interactions between an individual's psychological inability to identify emotions, their cognitive tendency to worry about normal bodily

JPPR
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sensations, and their underlying autonomic dysregulation. The Gradient Boosting algorithm explicitly proved that the integration of subjective psychometrics, particularly emotional illiteracy and interoceptive mistrust, with objective physiological indices like blunted heart rate variability and delayed electrodermal recovery, yields a highly sensitive and robust predictive framework. These findings empirically validate the biopsychosocial model of somatic symptomology, confirming that the mind and body act as an inseparable, deeply interconnected system where cognitive emotional failures inevitably translate into measurable biological distress.

Despite the robust predictive capabilities demonstrated by the machine learning models, several notable limitations within the current study must be carefully considered. Primarily, the cross-sectional design strictly precludes the establishment of definitive causal pathways between alexithymia, interoceptive awareness, autonomic reactivity, and the eventual onset of psychosomatic vulnerability. While the models accurately predict current symptom burden, they cannot determine whether autonomic dysregulation precedes emotional illiteracy or vice versa. Additionally, although the sample was appropriately powered and drawn from diverse urban centers, it remains geographically limited, potentially constraining the generalizability of the findings to different cultural or rural contexts. Furthermore, the reliance on a singular laboratory-based stress induction paradigm may not fully capture the nuanced, highly individualized autonomic reactivity patterns that individuals experience during real-world, prolonged psychosocial stressors.

To address these limitations and further advance the field, future research should urgently prioritize longitudinal, prospective study designs. Tracking psychological traits and continuous physiological markers over extended periods, ideally beginning in early adolescence, would finally allow researchers to map the precise developmental trajectories and causal directions of psychosomatic pathology. Furthermore, future investigations should aim to incorporate ecological momentary assessment technologies combined with wearable ambulatory physiological monitors. This approach would capture real-time, dynamic fluctuations in emotional states, interoceptive awareness, and autonomic indices as individuals navigate their daily lives, providing a far more ecologically valid dataset than static laboratory measurements. Additionally, the inclusion of more complex neuroimaging modalities or neuroendocrine markers within deep learning frameworks could potentially uncover even deeper biological layers of the psychosomatic response.

The clinical implications derived from these findings offer substantial and immediate avenues for improving healthcare practice. The confirmed predictive value of both objective and subjective metrics strongly suggests that clinical assessments for medically unexplained symptoms should universally adopt a multi-modal psychophysiological approach, incorporating baseline heart rate variability alongside standard psychological screening. In terms of targeted treatment, psychological interventions must systematically shift away from purely cognitive restructuring and instead heavily prioritize foundational emotional skills training and interoceptive exposure therapies. Clinicians should directly teach patients how to precisely identify affective states and safely tolerate visceral sensations without cognitive catastrophizing. Moreover, the integration of real-time physiological biofeedback into psychotherapeutic settings could provide patients with a tangible, visual representation of their autonomic nervous system, ultimately empowering them to actively bridge the psychological disconnect between their unarticulated emotions and their debilitating physical symptoms.

Authors' Contributions

Authors contributed equally to this article.

Declaration

In order to correct and improve the academic writing of our paper, we have used the language model ChatGPT.

Transparency Statement

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

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Declaration of Interest

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Ethics Considerations

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

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