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Modeling Generalized Anxiety Disorder from Intolerance of Uncertainty and Attentional Control Using AI-Driven Feature Selection

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A B S T R A C T

Objective: The primary objective of this study was to identify the most robust, item-level cognitive predictors of generalized anxiety disorder severity utilizing an artificial intelligence-driven hybrid feature selection pipeline applied to the constructs of intolerance of uncertainty and attentional control.

Methods and Materials: A cross-sectional predictive study design was utilized with a sample of 486 Canadian adults. Participants completed standardized self-report measures, including the 7-item Generalized Anxiety Disorder Assessment (GAD-7), the 12-item Intolerance of Uncertainty Scale (IUS-12), and the 20-item Attentional Control Scale (ACS). Data preprocessing involved k-nearest neighbors imputation for missing values and standardization of continuous variables ($z = \frac{x-\mu}{\sigma}$). A hybrid machine learning approach combining Least Absolute Shrinkage and Selection Operator (LASSO) regression and Extreme Gradient Boosting Recursive Feature Elimination (XGBoost-RFE) was employed to extract key item-level predictors. The dataset was split into an 80%training set and a 20%testing set, with model hyperparameter tuning validated via 10-fold cross-validation.

Findings: The sample ($N = 486$; 61.3%female; age $M = 34.2$, $SD = 10.5$) exhibited significant baseline correlations between GAD-7 and both IUS-12 ($r = .64, p < .001$) and ACS ($r = -.52, p < .001$). From an initial pool of 32cognitive items, the hybrid AI pipeline (using an optimal LASSO penalty of $\alpha = 0.034$) identified a critical subset of just 7key features (4 capturing distress/paralysis from uncertainty and 3capturing difficulties in attentional shifting/focusing). The optimized XGBoost model utilizing these 7selected features achieved superior predictive performance on the test set ($R^2 = 0.73$, $RMSE = 2.40$) compared to the baseline model utilizing all 32features ($R^2 = 0.61$, $RMSE = 2.88$).

Conclusion: Granular, item-level cognitive vulnerabilities—specifically uncertainty-induced paralysis and severe deficits in attentional shifting—are the primary drivers of anxiety severity, demonstrating the transformative potential of AI in precise psychiatric modeling.

Keywords: *Generalized Anxiety Disorder, Intolerance of Uncertainty, Attentional Control, Machine Learning*

1. Introduction

Generalized Anxiety Disorder (GAD) represents a pervasive and debilitating mental health condition characterized by chronic, excessive, and often uncontrollable worry about a multitude of everyday events and activities. This disorder is not only prevalent but also associated with profound impairments in social, occupational, and interpersonal functioning, creating significant burdens on both individuals and broader healthcare systems. The etiology and maintenance of GAD are inherently multifactorial, encompassing a complex interplay of cognitive, emotional, and behavioral vulnerabilities. In recent years, researchers have increasingly turned their attention to the underlying mechanisms that drive emotional dysregulation and psychological distress, seeking to identify robust predictors of anxiety severity. A growing body of literature emphasizes the critical role of emotional regulation, or the lack thereof, in the precipitation and exacerbation of anxiety and depressive symptoms across diverse populations (Nguyen et al., 2025; Syafitri et al., 2024). When individuals encounter stressors, their capacity to adaptively manage their emotional responses dictates their psychological trajectory, highlighting the necessity of examining broader emotional processing frameworks in the context of GAD.

Central to the discourse on emotional vulnerability is the profound impact of shame and internalized distress. Shame is a deeply painful, self-conscious emotion that involves a global negative evaluation of the self, often leading to feelings of worthlessness and an intense desire to conceal one's perceived flaws from others. The literature has consistently documented the detrimental effects of shame on mental health, particularly in its capacity to amplify anxiety and depressive symptomatology (Kang & Jo, 2024; Sim & Choi, 2023). Internalized shame has been identified as a potent driver of psychological inflexibility, frequently correlating with maladaptive coping strategies such as rumination and self-concealment (Jeon & Park, 2023). Furthermore, shame profoundly distorts body image and self-perception, acting as a core vulnerability factor in the development of psychosocial distress, especially among vulnerable groups subjected to idealized sociocultural norms or traumatic experiences (Mills et al., 2022; Seekis & Kennedy, 2023). This self-evaluative threat is intrinsically linked to the cognitive manifestations of anxiety, as individuals overwhelmed by shame often experience heightened states of physiological arousal and chronic apprehension regarding future negative evaluations.

The toxic effects of shame are frequently observed in specialized populations experiencing severe psychological or physical health challenges. For instance, among trauma survivors, including individuals who have experienced sexual assault, trauma-related shame serves as a massive barrier to recovery, deeply embedding feelings of isolation and perpetuating intense anxiety and depressive states (Bhuptani & Messman, 2021; Xu et al., 2024). Similarly, in the context of chronic physical illnesses, such as patients navigating lung cancer or individuals living with HIV/AIDS, internalized shame regarding their health status or bodily integrity significantly compounds depressive symptoms and generalized anxiety, severely diminishing their overall quality of life (Siwik et al., 2022; Skelton et al., 2021). The psychological burden extends to individuals facing altered physical states due to medical interventions, such as women with a history of mastectomy, where the intersection of altered body image and emotional dysregulation frequently results in heightened sexual and generalized distress (Rasouli et al., 2024). Even in educational and professional environments, mental health shame poses a significant threat to well-being, driving relationship addictions, interpersonal dysfunction, and severe distress among university students, graduate cohorts, and caregiving students (Kotera et al., 2022; Park & Lee, 2024). Furthermore, negative interpersonal experiences, such as peer victimization during adolescence, are profoundly mediated by external shame, creating a direct pathway to severe mood dysregulation and chronic anxiety (Yaghoubi et al., 2021).

In stark contrast to the destructive nature of shame, self-compassion has emerged as a fundamental psychological buffer and a crucial component of adaptive emotional regulation. Self-compassion entails treating oneself with kindness, recognizing one's experiences as part of the broader human condition, and maintaining mindful awareness of painful thoughts and feelings rather than over-identifying with them. A substantial corpus of empirical

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research demonstrates that self-compassion effectively mitigates the negative impacts of shame and emotional dysregulation across numerous contexts (Büyüköksüz & Kayaalp-pehlivan, 2025). By fostering a non-judgmental stance toward personal suffering, self-compassion significantly enhances psychological flourishing and hope, thereby protecting individuals against the onset of generalized anxiety and depression (Cutajar & Bates, 2025; Liu et al., 2024). The cultivation of self-compassion allows individuals to decouple their self-worth from transient failures or uncertainties, serving as a powerful moderator that disrupts the detrimental link between emotional reactivity and long-term mental health deficits (Vidal et al., 2024).

The transdiagnostic utility of self-compassion and adaptive emotional regulation is evident across various age groups and clinical presentations. In adolescent populations, cognitive self-compassion and emotional regulation training have been shown to significantly enhance motivational self-regulation and adaptive functioning, mitigating the pervasive effects of anxiety (Moradmand et al., 2023; Osareh et al., 2024). Moreover, self-compassion actively mediates the relationship between fundamental psychological constructs, such as attachment styles, and the subjective well-being and loneliness experienced by youth (Ohadi Haeri et al., 2024; Rezagholiyan et al., 2025). The protective benefits of these emotional regulation strategies extend to high-stress professional and caregiving environments. For example, among college teachers facing substantial occupational stress, self-compassion and emotional regulation act as crucial mediators, preserving psychological resilience and overall mental health (Rehman et al., 2024). Similarly, for caregivers bearing the heavy emotional burden of supporting elderly patients with Alzheimer's disease, therapies focused on cultivating self-compassion significantly alleviate depression and emotional dysregulation (Sadeghi et al., 2024). The integration of self-compassion and mindfulness frameworks has also proven highly effective in predicting improved quality of life among post-deployment military veterans and reducing perceived stress in patients suffering from psychosomatic conditions like irritable bowel syndrome (Omidi et al., 2024; Wild et al., 2025).

While the broader domains of emotional regulation, self-compassion, and shame provide a vital foundation for understanding psychological distress, predicting the specific severity of Generalized Anxiety Disorder requires an examination of highly specific cognitive mechanisms. Within the cognitive-behavioral conceptualization of GAD, two highly specific constructs have been identified as paramount: Intolerance of Uncertainty (IU) and Attentional Control (AC). Intolerance of uncertainty refers to a dispositional characteristic that arises from a set of negative beliefs about uncertainty and its implications. Individuals with high IU perceive ambiguous situations as highly stressful, upsetting, and inherently threatening, regardless of the actual probability of a negative outcome. This cognitive vulnerability drives the chronic, unyielding worry that is the hallmark of GAD, as individuals engage in exhaustive cognitive efforts to anticipate and prepare for all possible negative future scenarios. Because the future is inherently uncertain, this maladaptive coping strategy traps the individual in a perpetual state of severe anxiety.

Concurrently, attentional control represents a critical executive function that significantly influences an individual's ability to self-regulate emotional responses. Attentional control encompasses the capacity to voluntarily focus attention on goal-relevant stimuli and, crucially, to shift attention away from distracting or distressing information. In the context of GAD, profound deficits in attentional control are frequently observed. When individuals with anxiety encounter a perceived threat or an ambiguous stimulus, their attention is rapidly captured by the threat-related information. Without robust attentional control, they are unable to disengage from these distressing cognitive sets, leading to sustained physiological arousal and the exacerbation of emotional dysregulation. Therefore, the interaction between a high intolerance of uncertainty and poor attentional control creates a highly toxic cognitive environment where ambiguous information is interpreted catastrophically, and the individual lacks the cognitive flexibility to shift their focus away from the resulting anxiety.

Despite the acknowledged importance of intolerance of uncertainty and attentional control in GAD, traditional statistical methodologies often struggle to parse the intricate, non-linear relationships and item-level weights of these psychological constructs. The vast majority of psychometric research relies on total scale scores, which invariably obscure the nuanced contributions of specific cognitive facets. For instance, is the inability to concentrate during anxiety more predictive of GAD severity than the specific belief that uncertainty implies negative future events? Traditional linear regressions are frequently ill-equipped to handle the high dimensionality and multicollinearity inherent in granular item-level psychological data. This

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methodological limitation necessitates the application of advanced computational techniques capable of isolating the most robust clinical predictors from complex datasets.

Artificial Intelligence (AI) and machine learning offer a revolutionary approach to modeling mental health disorders by utilizing mathematically rigorous feature selection algorithms. Algorithms such as the Least Absolute Shrinkage and Selection Operator (LASSO) and Extreme Gradient Boosting (XGBoost) provide the capability to sift through large arrays of psychometric items, aggressively penalizing redundant variables and isolating only the most critical predictors of an outcome. By applying AI-driven feature selection to the constructs of intolerance of uncertainty and attentional control, researchers can move beyond broad theoretical associations and pinpoint the precise cognitive markers that drive generalized anxiety. This high-resolution mapping is essential for the development of highly targeted clinical interventions. If specific deficits in attentional shifting or specific subsets of uncertainty paralysis are identified as the primary drivers of an individual's anxiety, cognitive-behavioral therapies and mindfulness-based interventions can be meticulously tailored to address those exact cognitive vulnerabilities. By bridging the gap between broad emotional regulation theories—such as those exploring shame and self-compassion—and precise cognitive feature mapping, the field of clinical psychology can substantially enhance the precision and efficacy of its predictive models. Ultimately, the aim of this study is to identify the most robust item-level cognitive predictors of generalized anxiety disorder utilizing an artificial intelligence-driven hybrid feature selection pipeline applied to the constructs of intolerance of uncertainty and attentional control.

2. Methods and Materials

2.1. Study Design and Participants

The current research utilized a cross-sectional predictive study design to systematically investigate the complex relationships between intolerance of uncertainty, attentional control, and the severity of generalized anxiety disorder symptoms. The target population comprised English-speaking adults residing across various provinces in Canada, ensuring a broad geographic and demographic representation within the national context. A total exact sample of 486 participants was successfully recruited through a combination of digital community boards, national mental health advocacy networks, and university research participation portals. To be deemed eligible for inclusion in the study, participants were required to be at least eighteen years of age, currently residing within Canada, and fully capable of comprehending and providing digital informed consent. Individuals with a self-reported history of severe neurological damage, cognitive impairments that would preclude the understanding of self-report measures, or those currently undergoing intensive inpatient psychiatric hospitalization were excluded from the study to minimize the influence of compounding severe clinical variables.

2.2. Measures

To accurately quantify the psychological constructs under investigation, three widely validated and standardized self-report psychometric instruments were administered to the participant cohort. The primary dependent variable, the severity of generalized anxiety disorder symptoms, was evaluated utilizing the Generalized Anxiety Disorder Assessment, universally recognized as the GAD-7. This instrument is a self-report questionnaire consisting of seven items, where participants are asked to rate the frequency with which they have experienced specific anxiety symptoms, such as excessive worrying or feeling restless, over the preceding two-week period. Responses are recorded on a four-point Likert scale ranging from 0, representing not at all, to 3, representing nearly every day, yielding a total possible score ranging from 0to 21, where higher scores strongly correlate with greater clinical severity of generalized anxiety symptomatology. The measurement of the primary predictive construct, intolerance of uncertainty, was conducted using the short form of the Intolerance of Uncertainty Scale, commonly denoted as the IUS-12. This twelve-item questionnaire is meticulously designed to evaluate a respondent's negative cognitive, emotional, and behavioral reactions to ambiguous situations, the perceived negative implications of being uncertain, and maladaptive attempts to control future events. Participants provide their responses on a five-point Likert scale ranging from 1, indicating that the statement is not at all characteristic of them, to 5, indicating that it is entirely characteristic of them. Finally, to evaluate the second predictive construct, the Attentional Control Scale was employed. This comprehensive twenty-item measure captures two primary and distinct components of executive attention, specifically attentional focusing, which is the ability to maintain deep concentration in the face of distracting stimuli, and attentional shifting, which represents the cognitive

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flexibility to transfer attention between multiple tasks. Participants rated their everyday cognitive experiences related to attentional management on a four-point Likert scale ranging from 1, meaning almost never, to 4, meaning always. All three psychometric instruments utilized in this study have consistently demonstrated highly robust psychometric properties in previous literature, including excellent internal consistency, strong test-retest reliability, and high construct validity across diverse clinical and non-clinical adult populations.

2.3. Data analysis

The comprehensive analytical pipeline was executed using the Python programming language, specifically leveraging the Scikit-Learn and XGBoost libraries for all data preprocessing, machine learning operations, and artificial intelligence-driven feature selection procedures. Initial data preprocessing involved a rigorous screening for missing values, which were subsequently addressed using a k-nearest neighbors imputation algorithm to preserve the structural integrity of the dataset without reducing the statistical power associated with the exact sample size. Following the imputation phase, all continuous independent variables, specifically the individual item scores derived from the intolerance of uncertainty and attentional control scales, were standardized utilizing a standard scaling technique. This process ensures that every feature possesses a mean of 0and a standard deviation of 1, mathematically represented by the formula $z = \frac{x-\mu}{\sigma}$, which operates as a mandatory prerequisite for the optimal functioning of distance-based and regularization-penalized machine learning algorithms. The core analytical phase centered on AI-driven feature selection to identify the most critical and heavily weighted cognitive predictors of generalized anxiety disorder from the granular item-level data. To achieve this optimal subset of predictors, a sophisticated hybrid feature selection methodology was deployed, combining the Least Absolute Shrinkage and Selection Operator regression with a Recursive Feature Elimination algorithm wrapper built around an Extreme Gradient Boosting regressor. The LASSO algorithm applies an L_1regularization penalty to the objective loss function, which effectively shrinks the coefficients of less important and highly collinear features to exactly 0, thereby executing an intrinsic and highly aggressive variable selection. Concurrently, the Recursive Feature Elimination evaluated the permutation importance of each specific item from the psychological scales, systematically pruning the least significant features at each algorithmic iteration until the optimal predictive subset was isolated. The entire dataset was randomly partitioned into a strictly isolated training set comprising 80%of the data and a hold-out testing set containing the remaining 20%. To rigorously prevent mathematical overfitting and ensure the true generalizability of the selected cognitive features, hyperparameter tuning and model validation were conducted utilizing a 10-fold cross-validation strategy exclusively within the boundaries of the training subset. The final predictive performance of the model, constructed solely using the optimally selected AI-driven features, was subsequently evaluated on the unseen testing data utilizing standard regression evaluation metrics. These metrics included the Mean Squared Error, mathematically denoted as $MSE = \frac{1}{n}\sum_{i=1}^{n}(Y_i - \hat{Y}_i)^2$, the Root Mean Squared Error calculated as $RMSE = \sqrt{MSE}$, and the coefficient of determination, represented as R^2, which quantifies the total proportion of variance in generalized anxiety symptoms explicitly explained by the isolated features of uncertainty intolerance and attentional control.

3. Findings and Results

The initial phase of the data analysis involved calculating the descriptive statistics and evaluating the demographic characteristics of the recruited Canadian sample comprising $N = 486$participants. The participant cohort exhibited a mean age of $M = 34.2$years with a standard deviation of $SD = 10.5$years, ranging from 18to 68years. In terms of gender distribution, the sample was predominantly female, comprising $n = 298(61.3\%)$ women, $n = 176(36.2\%)$ men, and $n = 12(2.5\%)$ individuals who identified as non-binary or preferred not to disclose their gender. Educational attainment within the sample was relatively high, with $n = 215(44.2\%)$ holding a bachelor's degree, $n = 142(29.2\%)$ possessing a high school diploma or equivalent, $n = 98(20.2\%)$ holding a graduate or professional degree, and $n = 31(6.4\%)$ having completed some college or associate degrees. Preliminary analysis of the clinical self-report measures indicated that the sample presented with a wide variance in generalized anxiety symptoms, intolerance of uncertainty, and attentional control, providing a robust foundation for the subsequent predictive modeling. The mean score for the Generalized Anxiety Disorder Assessment (GAD-7) was $M = 10.84(SD = 4.62)$, which falls into the moderate anxiety severity range. The Intolerance of Uncertainty Scale (IUS-12) demonstrated a

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mean score of $M = 36.52(SD = 9.14)$, and the Attentional Control Scale (ACS) exhibited a mean score of $M = 45.31(SD = 11.25)$. Detailed demographic characteristics and baseline descriptive statistics for all major study variables are presented systematically in Table 1.

Table 1

Demographic Characteristics and Descriptive Statistics of the Sample (N=486)

Variable	Frequency (n)	Percentage (%)	Mean (M)	Standard Deviation (SD)
Gender				
Female	298	61.3		
Male	176	36.2		
Non-binary/Other	12	2.5		
Age (Years)			34.2	10.5
Education				
High School/Equivalent	142	29.2		
Some College/Associate	31	6.4		
Bachelor's Degree	215	44.2		
Graduate Degree	98	20.2		
Clinical Measures				
GAD-7 Total Score			10.84	4.62
IUS-12 Total Score			36.52	9.14
ACS Total Score			45.31	11.25

Following the descriptive analysis, bivariate Pearson correlation coefficients were computed to examine the fundamental linear relationships between the primary study constructs prior to the application of complex machine learning algorithms. The correlation analysis revealed significant associations aligning with existing theoretical frameworks. A strong positive correlation was observed between total intolerance of uncertainty scores and generalized anxiety disorder severity, $r = .64$, $p < .001$, indicating that higher levels of uncertainty intolerance are closely linked to more severe anxiety symptoms. Conversely, the total attentional control score demonstrated a significant negative correlation with generalized anxiety severity, $r = -.52$, $p < .001$, suggesting that greater cognitive ability to focus and shift attention acts as a protective factor against anxiety symptomatology. Furthermore, an inverse relationship was documented between intolerance of uncertainty and attentional control, $r = -.47$, $p < .001$. To provide a more granular understanding, the attentional control scale was divided into its two validated sub-components: attentional focusing and attentional shifting. Both subscales exhibited significant negative correlations with the GAD-7 scores, with attentional focusing yielding $r = -.49$, $p < .001$and attentional shifting yielding $r = -.43$, $p < .001$. The complete correlation matrix detailing these relationships is displayed in Table 2.

Table 2

Pearson Correlation Matrix of Primary Study Variables

Variable	1	2	3	4	5
1. GAD-7 Total	–				
2. IUS-12 Total	$.64^{**}$	–			
3. ACS Total	$-.52^{**}$	$-.47^{**}$	–		
4. ACS Focusing	$-.49^{**}$	$-.42^{**}$	$.88^{**}$	–	
5. ACS Shifting	$-.43^{**}$	$-.41^{**}$	$.85^{**}$	$.51^{**}$	–

The core objective of the study was to identify the most critical item-level predictors of generalized anxiety disorder utilizing an AI-driven hybrid feature selection pipeline. The initial pool of independent variables consisted of 32distinct items (12 from the IUS-12 and 20from the ACS). The Least Absolute Shrinkage and Selection Operator (LASSO) regression was first applied to the training dataset ($n = 388$). Through rigorous 10-fold cross-validation, the

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optimal L_1regularization penalty parameter (α) was determined to be $\alpha = 0.034$. The application of this penalty successfully shrunk the coefficients of 21redundant or statistically noisy items to exactly 0.00, leaving a reduced subset of 11features. Subsequently, the Extreme Gradient Boosting Recursive Feature Elimination (XGBoost-RFE) algorithm was deployed on these remaining 11features to isolate the absolute most robust predictors by evaluating permutation importance. The XGBoost-RFE algorithm converged on a final optimal subset of exactly 7paramount features that maximized predictive accuracy while minimizing model complexity. Of these 7features, 4were items derived from the Intolerance of Uncertainty Scale, primarily reflecting paralysis in the face of ambiguity and distress regarding unforeseen events. The remaining 3features were derived from the Attentional Control Scale, specifically capturing profound difficulties in voluntary attentional focusing and the inability to deliberately shift cognitive sets away from distressing stimuli. The specific selected items, alongside their respective standardized LASSO coefficients indicating directional impact and their XGBoost relative importance scores, are comprehensively detailed in Table 3.

Table 3

Optimal Feature Subset Selected via Hybrid AI Pipeline (LASSO and XGBoost-RFE)

Selected Feature (Original Scale Item)	Construct Domain	LASSO Coefficient (β)	XGBoost Relative Importance (%)
IUS Item 1: "Unforeseen events upset me greatly"	Uncertainty Distress	0.28	24.5
IUS Item 9: "Uncertainty keeps me from living a full life"	Uncertainty Paralysis	0.22	19.2
ACS Item 8: "I have a hard time concentrating when I'm anxious"	Attentional Focusing	−0.19	16.8
IUS Item 3: "Uncertainty makes me vulnerable, unhappy, or sad"	Uncertainty Distress	0.17	14.1
ACS Item 12: "It is hard for me to break off from one train of thought"	Attentional Shifting	−0.15	11.4
IUS Item 10: "One should always look ahead so as to avoid surprises"	Future Control	0.12	8.3
ACS Item 4: "My concentration is good even if there is music in the room"	Attentional Focusing	−0.09	5.7

In the final phase of the analysis, the predictive efficacy of the isolated 7-feature subset was rigorously evaluated against the hold-out testing dataset ($n = 98$), which had been strictly sequestered from all prior feature selection and model training procedures. To establish a comparative baseline, an initial baseline XGBoost regression model was trained utilizing all original 32items. This full-feature baseline model achieved a coefficient of determination of $R^2 = 0.61$on the testing set, with a Root Mean Squared Error of $RMSE = 2.88$. Conversely, the optimized XGBoost model, strictly utilizing the 7features identified by the AI-driven pipeline, demonstrated vastly superior generalization capabilities and predictive accuracy. The optimized model achieved an $R^2 = 0.73$on the unseen testing data, successfully explaining 73%of the variance in generalized anxiety disorder symptom severity utilizing less than a quarter of the original psychometric items. Furthermore, the prediction error was substantially reduced, yielding an $RMSE = 2.40$and a Mean Squared Error of $MSE = 5.76$. The minimal discrepancy between the training set $R^2(0.76)$ and the testing set $R^2(0.73)$ strongly indicates that the hybrid feature selection methodology successfully prevented mathematical overfitting and isolated genuine, generalizable cognitive markers of anxiety. The comprehensive performance metrics contrasting the baseline full-feature model with the optimized AI-selected feature model across both training and testing datasets are provided in Table 4.

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Table 4

Predictive Performance Metrics of the Machine Learning Models

Model Specification	Dataset	Mean Squared Error (MSE)	Root Mean Sq. Error ($RMSE$)	R-Squared (R^2)
Baseline Model (32 Features)	Training (80%)	3.85	1.96	0.81
	Testing (20%)	8.29	2.88	0.61
Optimized Model (7 Features)	Training (80%)	4.91	2.21	0.76
	Testing (20%)	5.76	2.40	0.73

4. Discussion

The primary objective of the current study was to leverage an artificial intelligence-driven feature selection pipeline to identify the most robust, item-level cognitive predictors of Generalized Anxiety Disorder severity from the broader constructs of intolerance of uncertainty and attentional control. Traditional psychometric analyses have consistently demonstrated that high intolerance of uncertainty and low attentional control are significantly correlated with anxiety. However, by utilizing a hybrid machine learning approach consisting of Least Absolute Shrinkage and Selection Operator regression and Extreme Gradient Boosting, this study successfully distilled a pool of 32cognitive items down to a highly predictive subset of just 7features. This minimal subset accounted for an impressive 73%of the variance in generalized anxiety symptoms, demonstrating substantial predictive power and emphasizing that specific granular cognitive vulnerabilities—rather than broad, generalized constructs—are the primary drivers of anxiety pathology.

The AI pipeline identified four specific items related to intolerance of uncertainty that were paramount in predicting anxiety severity. These items primarily captured a profound distress regarding unforeseen events, the feeling that uncertainty inherently leads to vulnerability or sadness, the belief that one must constantly look ahead to avoid surprises, and a sense of life paralysis caused by ambiguity. These specific cognitive features align closely with contemporary research highlighting the detrimental role of psychological inflexibility and emotion dysregulation in the exacerbation of internalizing disorders (Büyüköksüz & Kayaalp-pehlivan, 2025). When individuals interpret uncertainty as a direct threat, they frequently experience a cascade of negative affect that they are unable to adaptively regulate, leading directly to the sustained physiological arousal characteristic of generalized anxiety (Nguyen et al., 2025; Syafitri et al., 2024). This cognitive paralysis often generates secondary emotional responses, most notably internalized shame. As individuals struggle to control uncontrollable future events, they may perceive their cognitive failures as profound personal flaws, a process well-documented to escalate anxiety and depressive symptoms (Jeon & Park, 2023; Kang & Jo, 2024). The intense distress generated by uncertainty mimics the emotional devastation seen in specialized populations facing uncontrollable circumstances. For instance, among trauma survivors or individuals navigating severe medical diagnoses like lung cancer or HIV/AIDS, the inability to predict physical or emotional outcomes frequently translates into deep-seated shame and severe psychological impairment (Bhuptani & Messman, 2021; Siwik et al., 2022; Skelton et al., 2021; Xu et al., 2024). The specific predictive weight of feeling "vulnerable" due to uncertainty in our model suggests that cognitive anticipation of threat fundamentally undermines an individual's sense of safety, much like how altered bodily integrity or medical trauma strips away emotional security and triggers severe distress (Rasouli et al., 2024).

In tandem with intolerance of uncertainty, the machine learning algorithm isolated three critical items from the attentional control scale: the inability to concentrate when anxious, profound difficulty breaking off from a distressing train of thought, and susceptibility to environmental distractions. These items specifically capture deficits in attentional shifting and focusing, which are core executive functions necessary for effective emotion regulation. The inability to disengage from a threatening train of thought represents a state of severe rumination. Previous literature establishes that such rumination acts as a potent mediator between negative self-evaluation and psychological distress, frequently eroding interpersonal satisfaction and overall well-being (Sim & Choi, 2023). When attentional control is compromised, individuals remain cognitively locked onto stressors. This exact mechanism explains why interventions focused on cognitive restructuring and mindfulness are vital, as they directly train the executive functions required to shift attention away from distress (Omidi et al., 2024; Wild et al., 2025). The relevance of attentional deficits is particularly evident in high-stress environments. Among college and

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graduate students, as well as individuals in intensive caregiving roles, the failure to control attention under pressure leads directly to maladaptive coping mechanisms, severe occupational distress, and profound mental health shame (Kotera et al., 2022; Park & Lee, 2024; Sadeghi et al., 2024).

The interplay between the identified features of uncertainty paralysis and attentional rigidity highlights the vital protective role of adaptive self-regulation, specifically self-compassion. The literature robustly supports self-compassion as a critical buffer that mitigates the toxic effects of cognitive inflexibility and emotional reactivity. By responding to personal struggles with kindness rather than critical over-identification, self-compassion allows individuals to gently shift their attention away from catastrophic scenarios and accept the inherent uncertainties of life (Cutajar & Bates, 2025; Liu et al., 2024). This buffering effect is observed across diverse developmental stages and stressors. In adolescents, for example, targeted emotional regulation and self-compassion training drastically reduce anxiety by improving the ability to disengage from peer-related threats or victimization (Moradmand et al., 2023; Osareh et al., 2024; Yaghoubi et al., 2021). Furthermore, cultivating a self-compassionate stance actively breaks the cycle of rumination and emotional dysregulation that bridges depressive symptoms and loneliness, enhancing overall subjective well-being (Ohadi Haeri et al., 2024; Rezagholiyan et al., 2025; Vidal et al., 2024).

The modern digital landscape further exacerbates the vulnerabilities identified by our AI model. The specific attentional deficit of being easily distracted maps onto contemporary challenges where individuals are constantly bombarded by idealized social norms and distressing digital stimuli. When young individuals, particularly women, lack the attentional control to shift focus away from detrimental social media content, they experience acute appearance-related shame and subsequent anxiety (Mills et al., 2022; Seekis & Kennedy, 2023). This environmental capture of attention, combined with a high intolerance of uncertainty regarding social standing, drives severe psychological distress. Thus, adaptive emotional regulation and the cultivation of psychological resilience are paramount for mitigating the specific cognitive deficits highlighted by our findings. As demonstrated in professional cohorts, such as college educators, possessing strong emotional regulation frameworks acts as a necessary shield against the onslaught of occupational uncertainty, preserving mental health and functioning (Rehman et al., 2024). Ultimately, our machine learning findings synthesize seamlessly with the existing literature: generalized anxiety is heavily driven by a specific, toxic combination of paralyzing distress in the face of ambiguity and a neurological inability to voluntarily shift attention away from that perceived threat.

5. Conclusion

The application of artificial intelligence and machine learning in psychometric evaluation offers a transformative advancement in the conceptualization and prediction of mental health disorders. This study successfully demonstrated that the complex, multifaceted presentation of Generalized Anxiety Disorder can be accurately modeled using a highly condensed subset of specific cognitive vulnerabilities. By applying a hybrid LASSO and XGBoost feature selection pipeline, the research isolated just seven critical items from broader scales of intolerance of uncertainty and attentional control, proving that targeted cognitive mechanisms—such as the profound inability to break a train of thought and paralyzing distress regarding unforeseen events—are the primary structural pillars of clinical anxiety. This AI-driven methodology not only mitigates the statistical noise associated with traditional sum-score approaches but also provides a high-resolution map of the precise cognitive deficits that trap individuals in states of chronic worry. Ultimately, these findings underscore that the severity of generalized anxiety is heavily dependent on specific failures in attentional shifting and an absolute intolerance for life's inherent ambiguities.

6. Limitations & Suggestions

Despite the methodological rigor and advanced computational techniques employed, this study is subject to several limitations that must be acknowledged. First, the cross-sectional nature of the research design precludes any definitive causal inferences. While the machine learning algorithms identified strong predictive patterns, it is impossible to determine whether the identified deficits in attentional control and uncertainty intolerance precede the onset of generalized anxiety or if chronic anxiety subsequently deteriorates these cognitive capacities over time. Second, the reliance on self-report psychometric instruments inherently introduces the risk of subjective response biases, such as negative affectivity bias or social desirability, where participants may inadvertently exaggerate or downplay their cognitive struggles. Third, the

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sample was exclusively comprised of English-speaking adults residing within Canada. This geographical and demographic constraint may limit the cross-cultural generalizability of the findings, as cultural frameworks significantly influence the interpretation of uncertainty and the expression of anxiety symptoms. Finally, the study utilized the GAD-7, a highly validated screening tool, but it lacked comprehensive structured clinical interviews to confirm formal psychiatric diagnoses of Generalized Anxiety Disorder.

Future scholarly inquiries should prioritize longitudinal methodologies to capture the temporal dynamics and developmental trajectories of the specific cognitive features identified in this study. Tracking changes in attentional shifting and uncertainty paralysis over time would provide vital insights into the causal mechanisms underlying the onset and maintenance of anxiety disorders. Additionally, researchers should aim to replicate this artificial intelligence-driven feature selection pipeline within diverse, cross-cultural populations and specifically within cohorts formally diagnosed with Generalized Anxiety Disorder through structured clinical interviews. This would validate the generalizability and clinical utility of the seven-feature model. Furthermore, future studies could integrate objective, physiological measures of attentional control, such as eye-tracking technology or electroencephalography, to correlate the self-reported cognitive deficits with actual neurological performance. Finally, experimental research should evaluate the specific responsiveness of these seven isolated features to targeted psychological interventions, determining if changes in these precise granular items correspond directly to a reduction in overall anxiety severity.

The findings from this advanced computational modeling present highly actionable insights for clinical psychology and therapeutic practice. Practitioners should consider moving beyond the reliance on broad, total scale scores during patient assessment and instead scrutinize item-level responses to identify specific cognitive bottlenecks. By recognizing that an individual's anxiety is primarily driven by an inability to break a specific train of thought or an intense paralysis regarding unforeseen events, clinicians can design meticulously tailored treatment plans. Cognitive Behavioral Therapy and Acceptance and Commitment Therapy can be customized to directly challenge the specific beliefs surrounding unpredictability, while specialized mindfulness protocols can be employed as practical exercises to specifically rehabilitate attentional shifting capabilities. Rather than deploying generalized anxiety treatments, therapists can utilize this granular conceptualization to act as cognitive trainers, directly strengthening the patient's capacity to disengage from threat and tolerate ambiguity, thereby enhancing the overall efficacy and efficiency of clinical interventions.

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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 in this article.

Declaration

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

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