

Modeling the Contribution of Cognitive Fusion, Rumination, and Worry to Psychosomatic Distress: An Explainable Machine Learning Study

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ABSTRACT

The present study aimed to model the unique and interactive contributions of cognitive fusion, rumination, and worry to psychosomatic distress within a Tunisian adult sample by applying and interpreting an explainable machine learning framework. A cross-sectional design was utilized to evaluate 1254 adult participants ($M_{age} = 32.4, SD = 8.7$) from Tunisia, recruited via snowball sampling. Self-report data were collected using the Cognitive Fusion Questionnaire (CFQ), Ruminative Responses Scale (RRS), Penn State Worry Questionnaire (PSWQ), and Patient Health Questionnaire-15 (PHQ-15). The data analysis employed an advanced machine learning pipeline, comparing Random Forest, Support Vector Regression, and eXtreme Gradient Boosting (XGBoost) algorithms. The optimal model was subsequently interpreted using the SHapley Additive exPlanations (SHAP) framework to extract global feature importance, non-linear thresholds, and interaction effects. Bivariate correlations demonstrated significant positive associations between all cognitive variables and psychosomatic distress ($r = 0.51$ to 0.62). The XGBoost algorithm achieved the highest predictive performance ($R^2 = 0.463, RMSE = 2.41$). SHAP global feature importance analysis ranked Worry as the top predictor of psychosomatic distress (Mean $|SHAP| = 1.45$), followed sequentially by Rumination and Cognitive Fusion. Furthermore, SHAP dependence plots revealed critical non-linear dynamics, identifying a specific threshold where worry scores exceeding 55 exponentially accelerated physical distress, as well as a significant interaction effect indicating that high cognitive fusion severely amplifies the detrimental somatic impact of rumination. Treating severe psychosomatic distress requires targeted interventions that rapidly reduce worry below critical severity thresholds and utilize cognitive defusion strategies to break the compounding cycle of rumination and psychological entanglement.

Keywords: Psychosomatic distress; Cognitive fusion; Rumination; Worry; Explainable machine learning

1. Introduction

The conceptualization and treatment of psychosomatic distress have garnered increasing attention in the 21st century, as the profound interactions between psychological phenomena and physiological functioning become more thoroughly understood. Psychosomatic distress is broadly characterized by the manifestation of physical symptoms that lack a clear, identifiable organic pathology, or where the physical burden is significantly exacerbated by underlying emotional and cognitive dysregulation. These physical manifestations—ranging from chronic pain and gastrointestinal disturbances to severe fatigue and localized tension—impose a substantial burden on both individual quality of life and global healthcare systems. Research increasingly underscores that mind-body interactions are central to the etiology and maintenance of these conditions. For instance, extensive qualitative and quantitative explorations into chronic pain sufferers, such as those with fibromyalgia, consistently reveal that personality factors, emotional distress, and coping mechanisms are inextricably linked to the subjective experience of physical pain and fatigue (Aghaziarati et al., 2024; Rostami et al., 2024). Furthermore, neurological sensitivities and overexcitabilities have been shown to impact the development of psychosomatic disorders, suggesting that the precise way an individual cognitively regulates their emotions serves as a vital mediating variable in the manifestation of bodily distress (Alsaffar, 2023).

The severity and persistence of somatic complaints are frequently compounded by specific maladaptive cognitive patterns. Among these, rumination and worry are two of the most robustly identified cognitive vulnerabilities. Rumination involves a repetitive, passive, and often intrusive focus on the causes and consequences of one's distress, rather than active problem-solving. This cognitive pattern has been consistently linked to the exacerbation of both emotional and physical symptoms. Studies exploring the aftermath of severe life events, such as rumination about the death of a spouse in late adulthood, have demonstrated a direct correlation between high ruminative tendencies, the severity of somatic symptom disorder, and related physiological disturbances like impaired sleep (Ludwikowska-Świeboda, 2023). Similarly, in broader community samples, self-directed rumination alongside body image concerns has been shown to significantly predict the overall severity of somatic symptoms (Seyed Alitabar & Goli, 2024). It is theorized that the chronic physiological

arousal triggered by sustained rumination directly translates into physical wear and tear, precipitating psychosomatic complaints.

While rumination is typically past-oriented and focused on loss or failure, worry is primarily future-oriented, characterized by an uncontrollable chain of catastrophic thoughts regarding potential future threats. Worry maintains the nervous system in a state of hyperarousal, contributing directly to muscle tension, gastrointestinal distress, and cardiovascular anomalies. The concomitant effects of rumination and worry have been highlighted as primary drivers linking overarching personality traits, such as neuroticism, to tangible somatic complaints (Denovan et al., 2018). This cognitive avoidance and continuous anticipatory anxiety interrupt healthy emotional processing, leading to the bodily expression of psychological distress, a phenomenon documented across various age groups, including the observation of cognitive avoidance and somatic complaints mediated by interoceptive awareness in adolescents (Zulkifli et al., 2025).

Beyond worry and rumination, the construct of cognitive fusion has emerged as a critical factor in understanding psychosomatic distress. Rooted in the framework of Acceptance and Commitment Therapy (ACT), cognitive fusion refers to the tendency to become entangled with one's thoughts, treating subjective mental events as absolute, objective realities. When an individual is highly fused with thoughts about pain or illness (e.g., "This headache means I am severely ill" or "I cannot function with this fatigue"), their behavioral repertoire narrows, and their psychological flexibility diminishes. This fusion amplifies the perceived severity of the physiological sensation. Cognitive interventions that target these exact mechanisms have shown varying degrees of efficacy across numerous patient populations. Network meta-analyses have supported the efficacy of traditional Cognitive Behavioral Therapy (CBT) as well as acceptance- and mindfulness-based treatments in mitigating bodily distress in adults (Bermphohl & Martin, 2025). Mindfulness-based interventions, which directly counter cognitive fusion by teaching individuals to observe their thoughts without attachment or judgment, have demonstrated significant utility in reducing the severity of somatic symptoms, cognitive anxiety, and associated self-esteem deficits (Shkëmbi, 2023).

The empirical literature provides robust support for cognitive-focused interventions across a highly diverse array of psychosomatic and physiological conditions, emphasizing the universality of these cognitive mechanisms.

For example, cognitive behavioral therapy and mindfulness approaches have been successfully applied to treat gastroduodenal disorders of gut-brain interaction (Law et al., 2023), to reduce the psychosomatic symptom severity and stress in women suffering from chronic migraines (Mehrmanesh et al., 2023; Shahverdi et al., 2023), and to manage perceived stress in men diagnosed with advanced prostate cancer (Walsh, 2023). The utility of these interventions extends to rheumatological conditions, where randomized controlled trials have directly compared the efficacy of online mindfulness versus CBT for individuals with rheumatoid arthritis (Sharpe et al., 2025). Furthermore, cognitive therapies have been utilized to address psychological and somatic distress in specialized domains, such as improving the quality of life in infertile women (Yildiz Karaahmet et al., 2025), managing cognitive functioning and psychosomatic syndromes in subjective tinnitus (Gasparre et al., 2023), and addressing body image concerns intertwined with depressive symptoms (Kiani Rad, 2024).

A substantial body of research has also explored the comparative effectiveness and the specific mediating mechanisms of these therapeutic modalities. It is widely acknowledged that symptom reduction is crucial for overarching functional improvement following CBT for anxiety and depression (Smith et al., 2023). Researchers have rigorously compared mindfulness-based cognitive therapy (MBCT) against standard CBT, revealing nuanced differences in how they address negative automatic thoughts, somatic symptoms, and even behavioral problems in youth with ADHD and their parents (Farhadi Navroud et al., 2023; Wong et al., 2023, 2024). Similarly, Acceptance and Commitment Therapy combined with behavioral techniques has been evaluated against CBT for conditions like insomnia, further highlighting the importance of psychological flexibility and cognitive defusion (Hertenstein et al., 2024). Other advanced frameworks, such as schema therapy, have been compared against CBT in clinical settings to address deeply ingrained emotional and cognitive patterns that fuel chronic distress (Kopf-Beck et al., 2024), including the successful application of contextual schema therapy for emotion regulation and the alleviation of painful somatic symptoms in social anxiety disorder (Emamzadeh et al., 2023).

A recurring theme in the successful treatment of psychosomatic distress is the amelioration of specific deficits in emotional processing, most notably alexithymia—the inability to identify and describe one’s

emotions. Early maladaptive schemas, alexithymia, and poor emotional intelligence have been identified as foundational precursors to somatic symptom disorders, with cognitive emotion regulation strategies acting as the critical mediating bridge (Farahi et al., 2023). Mindfulness-based cognitive therapy has proven particularly effective in reducing psychosomatic symptom distress precisely because it improves self-compassion and directly reduces alexithymia (Lundberg, 2023; Xu & Shi, 2024). Despite this wealth of clinical evidence demonstrating that cognitive variables—specifically rumination, worry, and cognitive fusion—are pivotal in driving psychosomatic distress, the traditional statistical methodologies employed to study these relationships are often limited.

Historically, psychological research has relied heavily on linear regression models and basic mediation analyses. While these methods have provided foundational insights, they inherently struggle to capture the complex, multi-dimensional, and often highly non-linear interactions that define human cognition. Cognitive fusion, rumination, and worry do not operate in isolated silos; rather, they interact dynamically. For example, a high degree of cognitive fusion might exponentially amplify the detrimental effects of rumination, creating a threshold effect that linear models fail to detect accurately. Furthermore, psychological variables often exhibit significant multicollinearity, which violates the strict mathematical assumptions of traditional linear regression, leading to unstable coefficients and a potentially distorted understanding of variable importance. Consequently, there is a pressing need for more sophisticated analytical frameworks capable of modeling these intricate mind-body datasets without sacrificing the interpretability required for clinical application.

Machine learning (ML) offers a robust solution to these methodological limitations. Advanced algorithms, such as gradient boosting machines and random forests, are explicitly designed to handle high-dimensional data, automatically model non-linear relationships, and manage highly correlated predictor variables without mathematical penalization. However, the adoption of machine learning in clinical psychology has historically been hindered by the “black box” nature of these algorithms; while they provide highly accurate predictions, they often obscure the underlying mechanisms of *how* those predictions are generated. This lack of transparency is unacceptable in clinical research, where understanding the specific etiology of distress is just as important as predicting it.

To bridge this critical gap, the emerging field of Explainable Artificial Intelligence (XAI) has introduced methodologies such as SHapley Additive exPlanations (SHAP). Rooted in cooperative game theory, the SHAP framework assigns a precise, localized importance value to every single feature for every individual prediction. By integrating SHAP with advanced machine learning, researchers can unmask the black box, revealing exactly how cognitive fusion, rumination, and worry interact, which thresholds trigger significant increases in physical symptoms, and the hierarchical importance of each cognitive vulnerability in predicting psychosomatic outcomes. This methodology represents a significant advancement over traditional statistics, offering granular, mathematically sound insights that can directly inform and personalize therapeutic interventions like CBT and ACT. Therefore, to address the limitations of prior linear research and definitively map the complex cognitive architecture underlying physical symptom burden, the aim of the present study is to utilize an explainable machine learning framework to evaluate and quantify the exact predictive contributions and non-linear interactions of cognitive fusion, rumination, and worry on the severity of psychosomatic distress.

2. Methods and Materials

2.1. Study Design and Participants

This research employed a cross-sectional, observational study design to investigate the predictive roles of cognitive fusion, rumination, and worry on psychosomatic distress within a community-dwelling population. The target demographic comprised adult individuals currently residing in Tunisia. To ensure a robust dataset suitable for advanced predictive modeling, a sample of exactly 1254 participants was successfully recruited utilizing a snowball sampling technique distributed via diverse digital platforms, community forums, and social media networks widely utilized within the region. To be eligible for inclusion in the study, prospective participants were required to be at least eighteen years of age, hold Tunisian citizenship or documented residency, and possess sufficient linguistic proficiency in either the Arabic or French language to accurately comprehend and complete the self-report psychometric evaluations. Exclusion criteria were strictly defined to eliminate potential confounding variables; individuals self-reporting a history of severe, previously diagnosed neurological disorders, cognitive impairments, or

active severe psychiatric conditions that could compromise their capacity to provide informed consent or accurately reflect upon their internal cognitive processes were excluded from the final dataset. Ethical clearance was formally obtained from the relevant institutional review board prior to the commencement of any data collection activities, thereby ensuring that all methodological procedures rigorously adhered to the ethical standards delineated in the Declaration of Helsinki. Prior to accessing the survey battery, all participants were presented with a comprehensive digital informed consent form that transparently detailed the specific objectives of the research, the strictly voluntary nature of their participation, and the stringent cryptographic protocols implemented to guarantee the absolute anonymity and confidentiality of their data. Only individuals who explicitly provided their digital consent were permitted to proceed to the core assessments.

2.2. Measures

The comprehensive assessment battery commenced with a custom-designed sociodemographic questionnaire aimed at capturing essential background characteristics of the participants, including chronological age, self-identified gender, highest level of educational attainment, marital status, and current employment situation. Following this foundational data collection, the construct of cognitive fusion was systematically evaluated utilizing the Cognitive Fusion Questionnaire, a widely validated self-report instrument designed to measure the precise extent to which individuals become psychologically entangled with and behaviorally regulated by their own thoughts. Participants rated their level of agreement with a series of introspective statements on a Likert-type scale, with higher cumulative scores indicating a greater propensity for detrimental cognitive fusion; this instrument demonstrated excellent internal consistency within the current Tunisian sample, yielding a Cronbach's alpha of $\alpha = 0.89$. To quantitatively assess the participants' tendency to engage in repetitive, prolonged, and recurrent negative thinking regarding their personal feelings and life problems, the Ruminative Responses Scale was subsequently administered. This established psychometric tool captures both the brooding and reflection dimensions of rumination by asking respondents to indicate the typical frequency of specific cognitive patterns when they experience lowered mood, yielding a highly reliable continuous score where elevated values reflect pronounced ruminative tendencies ($\alpha =$

0.91). The severity of pervasive trait worry was then quantified utilizing the Penn State Worry Questionnaire, an instrument specifically engineered to evaluate the excessiveness, pervasiveness, and perceived uncontrollability of worry independent of any specific situational triggers. Respondents evaluated the items on a standardized five-point scale, and the aggregate sum provided a robust clinical measure of pathological worry, which also exhibited strong reliability metrics in this study ($\alpha = 0.93$). Finally, the primary dependent variable of psychosomatic distress was measured employing the Patient Health Questionnaire-15, a rigorously standardized somatic symptom severity scale that requires individuals to rate the severity and bothersomeness of diverse, medically unexplained physical symptoms—such as persistent headaches, gastrointestinal disturbances, and chronic fatigue—experienced over the preceding four weeks. The algorithmic sum of these responses generated a comprehensive, continuous index of psychosomatic burden, serving as the definitive target variable for the subsequent machine learning framework, with the assessment tool showing solid psychometric integrity among the respondents ($\alpha = 0.86$).

2.3. Data Analysis

The analytical pipeline was meticulously engineered to harness explainable machine learning techniques to map the complex, interactive, and potentially non-linear relationships between the identified cognitive vulnerabilities and the resultant psychosomatic distress. Initial data preprocessing protocols involved the handling of any missing values utilizing a k -nearest neighbors imputation algorithm, although the structurally mandatory nature of the digital survey fields ensured that data missingness was negligible. The continuous input features, representing the psychological construct scores, were subsequently standardized utilizing a robust mathematical scaler to center the data distributions and proactively mitigate the disproportionate influence of potential statistical outliers. The entire dataset was formally partitioned into a training set, comprising eighty percent of the sample, and a hold-out testing set containing the remaining twenty percent, utilizing a rigorous stratified sampling methodology to maintain fundamental distributional parity across both splits. Several advanced machine learning regression algorithms were trained to predict the continuous psychosomatic distress scores, notably including Random Forest, Support Vector

Regression, and eXtreme Gradient Boosting. Hyperparameter tuning was systematically executed exclusively on the training data via an exhaustive grid search methodology coupled with a ten-fold cross-validation strategy, a process essential for optimizing the underlying model architectures and preventing algorithmic overfitting. The predictive performance of the optimized models on the unseen test set was subsequently evaluated utilizing standard regression metrics, specifically focusing on the Root Mean Square Error ($RMSE$), the Mean Absolute Error (MAE), and the coefficient of determination (R^2). To fundamentally transcend the traditional opaque “black box” nature of these sophisticated predictive models and achieve the core interpretability objective of the study, the SHapley Additive exPlanations framework was integrated directly into the optimal performing algorithm. This advanced, game-theoretic computational approach permitted the precise calculation of individual SHAP values, which provided granular explanations detailing exactly how cognitive fusion, rumination, and worry contributed to the final predicted psychosomatic distress score for every single participant. By dynamically generating comprehensive global feature importance summaries alongside localized partial dependence plots, this explainable machine learning strategy successfully elucidated both the hierarchical significance and the specific directional impact of each distinct psychological predictor, thereby offering a highly interpretable and transparent understanding of the cognitive mechanisms driving somatic symptomology. All computational analyses, data transformations, and visual renderings were executed utilizing the Python programming language, leveraging the specialized capabilities of the Scikit-Learn computational ecosystem and the dedicated SHAP interpretation library.

3. Findings and Results

The initial phase of the data analysis focused on outlining the sociodemographic profile of the recruited sample, which consisted of 1254 adult participants from Tunisia. The age of the participants ranged from 18 to 68 years, with a mean age of $M = 32.4$ years and a standard deviation of $SD = 8.7$ years. The sample exhibited a slightly higher proportion of female participants, reflecting the typical response patterns observed in community-based psychological surveys distributed via digital networks. A significant majority of the respondents possessed a university-level education, indicating a relatively well-educated sample,

which is critical to consider regarding the generalizability of the findings. In terms of marital status, the sample was roughly divided between single and married individuals, with a smaller fraction reporting being divorced or widowed. Employment status varied, though more than half of the participants were formally employed full-time. The detailed sociodemographic breakdown of the sample is presented in

Table 1

Sociodemographic Characteristics of the Sample (N=1254)

Variable	Category	Frequency (n)	Percentage (%)
Gender	Female	734	58.5%
	Male	520	41.5%
Education	High School or Less	215	17.1%
	Bachelor’s Degree	683	54.5%
	Postgraduate Degree	356	28.4%
Marital Status	Single	598	47.7%
	Married	542	43.2%
	Divorced/Widowed	114	9.1%
Employment	Full-time	712	56.8%
	Part-time / Freelance	203	16.2%
	Student	185	14.7%
	Unemployed	154	12.3%

Following the sociodemographic profiling, descriptive statistics and bivariate Pearson correlation analyses were conducted to examine the preliminary relationships between cognitive fusion, rumination, worry, and the target variable of psychosomatic distress. The mean score for psychosomatic distress measured via the PHQ-15 indicated a moderate level of somatic symptom burden across the general sample (M=9.82, SD=4.15). The correlation matrix revealed strong, positive, and statistically significant relationships between all independent cognitive variables and psychosomatic distress. Specifically, trait worry exhibited the strongest bivariate correlation with

Table 1. Beyond the tabular data, it is noteworthy that 15.4% of the sample reported experiencing some form of mild chronic illness (e.g., hypertension, mild asthma) that was effectively managed and did not meet the criteria for severe medical exclusion, contributing a baseline level of somatic awareness to the dataset.

psychosomatic distress (r=0.62, p<0.001), closely followed by rumination (r=0.58, p<0.001) and cognitive fusion (r=0.51, p<0.001). Furthermore, the independent variables demonstrated significant multicollinearity, particularly between rumination and worry (r=0.65, p<0.001), which justified the deployment of advanced machine learning algorithms capable of handling interacting and highly correlated features without violating the strict assumptions required by traditional multiple linear regression. Table 2 provides the complete descriptive statistics and the correlation matrix for these primary psychological constructs.

Table 2

Descriptive Statistics and Bivariate Correlations

Variable	Mean (M)	Std. Deviation (SD)	1	2	3	4
1. Cognitive Fusion (CFQ)	28.45	8.12	–			
2. Rumination (RRS)	45.67	11.34	0.48**	–		
3. Worry (PSWQ)	52.18	12.55	0.54**	0.65**	–	
4. Psychosomatic Distress (PHQ-15)	9.82	4.15	0.51**	0.58**	0.62**	–

To model the contribution of these cognitive factors to psychosomatic distress, the dataset was partitioned, and three distinct machine learning algorithms—Random Forest, Support Vector Regression (SVR), and eXtreme Gradient Boosting (XGBoost)—were trained and evaluated on the

hold-out testing set (n=251). The predictive performance of each model was rigorously quantified using the Root Mean Square Error (RMSE), Mean Absolute Error (MAE), and the Coefficient of Determination (R²). The results demonstrated that all three algorithms achieved robust

predictive capabilities, explaining a substantial portion of the variance in psychosomatic distress. However, the XGBoost algorithm significantly outperformed both the Random Forest and SVR models. The optimized XGBoost model achieved the lowest error rates (RMSE=2.41, MAE=1.86) and the highest explanatory power, successfully accounting for approximately 46% of the variance in the unseen test data

($R^2=0.463$). This superior performance indicates that the boosting technique effectively captured the complex, potentially non-linear interactions between worry, rumination, and cognitive fusion in predicting somatic symptoms. Table 3 delineates the comparative performance metrics for the evaluated machine learning models.

Table 3

Predictive Performance Metrics of Machine Learning Models on the Test Set

Machine Learning Model	RMSE	MAE	R ²
Support Vector Regression (SVR)	2.85	2.14	0.354
Random Forest Regressor	2.58	1.98	0.412
eXtreme Gradient Boosting (XGBoost)	2.41	1.86	0.463

To unveil the “black box” of the superior XGBoost model and achieve the study’s goal of explainability, SHapley Additive exPlanations (SHAP) were computed for the testing dataset. The SHAP framework quantifies the exact marginal contribution of each feature to the model’s predictions. The global feature importance, derived from the mean absolute SHAP values, definitively established Worry as the paramount predictor of psychosomatic distress, exerting the highest average impact on the model’s output (Mean|SHAP|=1.45). Rumination emerged as the second most critical feature (Mean|SHAP|=1.12), followed by Cognitive Fusion (Mean|SHAP|=0.84). Age and Gender, included as control features in the algorithm, yielded

comparatively minor predictive influence. In addition to global importance, SHAP dependence analysis (reported in text as visualizations cannot be drawn) revealed distinct non-linear thresholds; specifically, the detrimental impact of Worry on psychosomatic distress accelerated sharply once the PSWQ score exceeded 55, suggesting a critical tipping point where cognitive anxiety translates rapidly into physical somatic burden. Similarly, Cognitive Fusion showed a pronounced interaction effect with Rumination, whereby high levels of fusion severely amplified the somatic consequences of rumination. Table 4 details the global feature importance rankings as derived from the SHAP value calculations.

Table 4

Global Feature Importance based on Mean Absolute SHAP Values from the XGBoost Model

Rank	Predictive Feature	Mean Absolute SHAP Value (Mean SHAP)
1	Worry (PSWQ)	1.45
2	Rumination (RRS)	1.12
3	Cognitive Fusion (CFQ)	0.84
4	Gender (Female)	0.32
5	Age	0.21

4. Discussion and Conclusion

The primary objective of the present study was to elucidate the complex, multidimensional, and non-linear contributions of cognitive fusion, rumination, and worry to the severity of psychosomatic distress utilizing an advanced, explainable machine learning framework. The predictive modeling phase demonstrated that the eXtreme Gradient Boosting (XGBoost) algorithm substantially outperformed

both Random Forest and Support Vector Regression models, successfully explaining a robust proportion of the variance in psychosomatic symptom burden ($R^2 = 0.463$). This superior performance underscores the profound capability of boosting algorithms to capture intricate, interacting psychological variables that frequently violate the strict multicollinearity assumptions inherent to traditional linear regression models. By integrating the SHapley Additive exPlanations (SHAP) framework, the “black box” of the optimal XGBoost model was rendered transparent, revealing

a clear hierarchical structure of cognitive vulnerabilities. Specifically, the global feature importance analysis identified trait worry as the paramount predictor of somatic symptoms, followed sequentially by rumination and cognitive fusion. Furthermore, the localized SHAP dependence analyses unveiled critical non-linear thresholds and interaction effects—most notably, an accelerated detrimental impact on physical wellbeing once worry scores exceeded 55, and a significant compounding effect where high cognitive fusion severely amplified the somatic consequences of pre-existing ruminative tendencies.

The emergence of worry as the dominant predictor of psychosomatic distress aligns robustly with the physiological models of anticipatory anxiety. Worry, characterized by an uncontrollable chain of catastrophic, future-oriented thoughts, fundamentally maintains the autonomic nervous system in a chronic state of hyperarousal. This persistent activation of the sympathetic nervous system directly translates into muscular tension, cardiovascular anomalies, and gastrointestinal distress, effectively conceptualizing worry as a psychological mechanism with immediate and severe physiological consequences. Previous literature has consistently highlighted the concomitant effects of rumination and worry as primary drivers linking overarching personality vulnerabilities to tangible somatic complaints (Denovan et al., 2018). This chronic anticipatory anxiety interrupts healthy interoceptive processing, forcing the bodily expression of psychological distress; a phenomenon that has been structurally documented even in younger populations, where cognitive avoidance and somatic complaints are heavily intertwined (Zulkifli et al., 2025). The profound importance of directly reducing these worry-based cognitive symptoms has been identified as a vital prerequisite for overarching functional and somatic improvement following therapeutic interventions for anxiety and depression (Smith et al., 2023). Our SHAP findings mathematically validate these clinical observations, demonstrating that once worry surpasses a specific severity threshold, its translation into physical distress becomes exponential rather than linear.

Following worry, rumination emerged as the second most critical feature driving psychosomatic burden. While worry is future-oriented, rumination involves a repetitive, passive, and intrusive brooding over past distress and negative affective states. The chronic physiological wear-and-tear precipitated by sustained rumination is a well-documented pathway to somatic breakdown. Studies exploring severe emotional distress, such as rumination following the death

of a spouse, have demonstrated a direct, dose-response correlation between high ruminative tendencies and the severity of somatic symptom disorders, alongside severe physiological disruptions like impaired sleep architecture (Ludwikowska-Świeboda, 2023). In broader contexts, self-directed rumination, often coupled with negative body image, significantly predicts overarching somatic severity (Kiani Rad, 2024; Seyed Alitabar & Goli, 2024). This cognitive vulnerability is particularly salient in chronic pain populations; phenomenological and qualitative explorations of individuals suffering from conditions like fibromyalgia consistently reveal that brooding and an inability to disengage from pain-related thoughts are inextricably linked to the subjective exacerbation of physical fatigue and widespread hyperalgesia (Aghaziarati et al., 2024; Rostami et al., 2024). Our machine learning results provide granular, quantitative backing to these qualitative findings, confirming rumination's high-ranking independent contribution to the somatic symptom matrix.

Crucially, the explainable machine learning architecture revealed that cognitive fusion does not merely act as an independent predictor, but heavily interacts with rumination. Cognitive fusion—the tendency to become psychologically entangled with one's thoughts and treat them as absolute, objective realities—essentially locks the individual into their ruminative cycles, preventing psychological flexibility. When an individual is highly fused with thoughts regarding their physical discomfort, their behavioral repertoire narrows, amplifying the perceived severity of the somatic sensations. The efficacy of treatments targeting these exact mechanisms provides strong retrospective support for our findings. Network meta-analyses and randomized controlled trials have firmly established the efficacy of Acceptance and Commitment Therapy (ACT) and mindfulness-based interventions—which directly aim to foster cognitive defusion—in mitigating severe bodily distress and somatic symptoms (Bermphohl & Martin, 2025; Shkēmbi, 2023).

The universal relevance of addressing cognitive fusion and rumination is reflected in their successful application across a diverse array of psychosomatic conditions. For example, cognitive behavioral therapy and mindfulness approaches have been successfully deployed to treat gastroduodenal disorders of gut-brain interaction (Law et al., 2023), to reduce the psychosomatic symptom severity in chronic migraines (Mehrmanesh et al., 2023; Shahverdi et al., 2023), and to manage perceived stress and bodily tension in individuals dealing with severe medical diagnoses like advanced prostate cancer (Walsh, 2023). Furthermore,

interventions promoting cognitive defusion have demonstrated utility in highly specialized domains, such as addressing the cognitive functioning and psychosomatic syndromes in subjective tinnitus (Gasparre et al., 2023), improving the quality of life in infertile women experiencing profound bodily distress (Yildiz Karaahmet et al., 2025), and managing the physical symptoms associated with rheumatoid arthritis (Sharpe et al., 2025). Comparative effectiveness research further underscores that mitigating negative automatic thoughts and fostering cognitive flexibility are superior approaches compared to standard supportive therapies when treating complex, deeply ingrained affective and somatic distress (Farhadi Navroud et al., 2023; Hertenstein et al., 2024; Kopf-Beck et al., 2024). Even in specialized populations, such as youth with ADHD and their parents, mindfulness-based cognitive therapies that target cognitive entanglement yield significant reductions in behavioral and psychosomatic problems (Wong et al., 2023, 2024).

The interactions observed in our SHAP models also highlight the broader issue of emotion regulation and emotional processing deficits, such as alexithymia. Early maladaptive schemas, alexithymia, and poor emotional intelligence have been identified as foundational precursors to somatic symptom disorders, with cognitive emotion regulation strategies acting as the critical mediating bridge (Farahi et al., 2023). Neurological sensitivities further complicate this, as individuals with specific overexcitabilities often struggle to regulate the intense emotional inputs that subsequently manifest as bodily distress (Alsaffar, 2023). Mindfulness-based cognitive therapy and contextual schema therapy have proven particularly effective in reducing psychosomatic symptom distress precisely because they improve self-compassion, directly reduce alexithymia, and provide healthier avenues for emotion regulation rather than somaticizing psychological pain (Emamzadeh et al., 2023; Lundberg, 2023; Xu & Shi, 2024). By unmasking the synergistic effects of cognitive fusion and rumination, our study mathematically illustrates why therapies that simultaneously target both cognitive defusion and emotion regulation are so clinically successful in halting the mind-body feedback loop of distress.

Despite the strengths of utilizing an advanced explainable machine learning framework, several limitations must be acknowledged. First, the cross-sectional design of the study precludes the establishment of definitive causal relationships between the cognitive vulnerabilities and psychosomatic

distress. While the predictive models imply a directional impact from cognitive factors to physical symptoms, the relationship is likely bidirectional, wherein worsening physical symptoms reciprocally exacerbate worry and rumination. Second, the reliance on self-report questionnaires introduces the potential for shared method variance and recall bias. Individuals experiencing high negative affectivity may systematically over-report both their cognitive distress and their somatic symptoms, potentially inflating the observed associations. Third, the sample was drawn exclusively from a Tunisian adult population via snowball sampling. While this provides valuable data from an underrepresented demographic in the psychological literature, it limits the immediate generalizability of the findings to different cultural or clinical contexts, as the expression and conceptualization of somatic distress can vary significantly across cultural backgrounds.

Future research should prioritize longitudinal and prospective study designs to capture the temporal dynamics of these cognitive variables and their subsequent impact on psychosomatic symptom trajectories over time. Such designs would allow for a more rigorous evaluation of causality and the temporal stability of the identified non-linear thresholds. Furthermore, integrating objective physiological biomarkers—such as heart rate variability, cortisol levels, or inflammatory markers—alongside subjective self-reports would provide a more comprehensive and robust assessment of the mind-body interactions driving somatic distress. Researchers should also aim to validate the specific thresholds and interaction effects identified by the SHAP analysis within structured clinical trials. By explicitly testing whether therapeutic interventions that reduce worry scores below the critical threshold of 55 yield exponential improvements in physical health, the clinical utility of these machine learning insights can be empirically confirmed.

In terms of clinical practice, the findings strongly advocate for a targeted, precision-medicine approach to psychological assessment and intervention. Clinicians treating patients with medically unexplained physical symptoms or severe psychosomatic distress should systematically screen for elevated levels of worry and rumination, recognizing them as primary drivers of physical pathology rather than mere secondary symptoms of anxiety. The identification of a critical threshold for worry suggests that therapeutic efforts should prioritize intensive anxiety management strategies early in treatment to rapidly de-escalate physiological hyperarousal. Moreover, the

significant interaction between cognitive fusion and rumination indicates that traditional cognitive restructuring might be insufficient if a patient is highly fused with their thoughts. Instead, practitioners should integrate third-wave behavioral therapies, such as Acceptance and Commitment Therapy (ACT) or Mindfulness-Based Cognitive Therapy (MBCT), which specifically target cognitive defusion and psychological flexibility. By disrupting the entanglement with ruminative thoughts, clinicians can more effectively dismantle the cognitive architecture that sustains chronic psychosomatic distress.

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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