Research Square

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Validation of the Adult Developmental Coordination Disorder Questionnaire (ADC) and Machine Learning–Based Prediction of Emotional Distress: the Moderating Role of Self-Esteem

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Abstract

Background

Adult developmental coordination difficulties are associated with increased psychological vulnerability, however, culturally validated screening tools and evidence for psychological risk stratification remain limited in Chinese adults. This study validated the revised Chinese version of the Adult Developmental Coordination Disorder/Dyspraxia Checklist (ADC) and examined whether self-esteem moderated the association between coordination difficulties and emotional distress, as well as whether machine-learning models could improve psychological risk identification.

Methods

This cross-sectional study comprised translation, cognitive interviewing, and psychometric evaluation. A total of 2,332 adults completed the Chinese ADC. The sample was randomly split, with one half used for item analysis and exploratory factor analysis and the other used for additional validity analyses. Additionally, 1,258 participants completed the DASS-21. Test–retest reliability was evaluated in 50 participants over a two-week interval. Machine-learning analyses (n = 1,258) were conducted to predict emotional distress using five regression models with cross-validation and SHAP-based interpretation. Moderation analyses further examined the buffering role of self-esteem across ADC dimensions.

Results

The 37-item ADC formed a stable three-factor structure (motor coordination, executive function, social avoidance) with high reliability, accounting for 45.68% of cumulative variance. Ensemble models (random forest and gradient boosting) outperformed linear models in predicting psychological distress (maximum $R^2 = 0.510$), whereas prediction of self-esteem was comparatively modest across models ($R^2 = 0.199–0.216$). Participants in the probable DCD group, particularly those with prominent motor coordination difficulties, showed significantly higher DASS-21 scores ($p < 0.001$). Two latent subgroups were visualized using t-SNE following K-means clustering, and self-esteem moderated the association between motor coordination difficulties and psychological distress. High-risk classification demonstrated superior discriminative capability of the ensemble model (Random Forest AUC = 0.813), further supporting the value of ADC dimensions in identifying adults with elevated emotional-distress risk.

Conclusion

The Chinese ADC demonstrates strong psychometric quality. Ensemble-based models predicted psychological distress (max $R^2 = 0.510$) more accurately than linear models. Motor coordination deficits

defined a high-risk subgroup characterized by elevated DASS-21 scores ($p < 0.001$). t-SNE analyses identified two mental health subpopulations, and self-esteem moderated ADC–distress associations. SHAP analyses identified motor coordination as the primary predictor, supporting ensemble-based risk stratification. Individuals with marked motor coordination and executive difficulties alongside low self-esteem may represent a particularly vulnerable subgroup for emotional distress.

Introduction

The Developmental Coordination Disorder (DCD), also known as dyspraxia, is a specific neurodevelopmental disorder that originates in childhood but is increasingly recognized as a lifelong challenge extending into adulthood[1–3]. Characterised by impaired motor coordination, clumsiness, and difficulties in acquiring new motor skills[4], DCD affects approximately 7–20% of the population worldwide[5–7]. While the majority of research on DCD has focused on children, growing evidence indicates that adults with DCD continue to experience pervasive difficulties that extend beyond motor impairments, including challenges in academic achievement, occupational performance, mental health, and social participation[5, 8–12]. These impairments are not only detrimental to individual quality of life but also undermine long-term psychosocial adjustment, occupational functioning, and social participation across adulthood.

Adults with DCD face substantial impact across both physical and psychological domains. Their quality of life and life satisfaction have been consistently reported to be lower than those of the general population[8]. Core symptoms often involve deficits in both fine and gross motor skills, which severely limit individuals' functional performance in daily activities such as learning, work, and daily living tasks (e.g., cooking, driving, writing, etc.) [5]. Due to insufficient participation in physical activities, adults with DCD may be more likely to adopt a more sedentary lifestyle, increasing the risk of obesity and potentially negatively impacting cardiovascular health, cardiopulmonary function, and overall physical fitness[13]. These physical health risks further compound the burden of DCD across the lifespan. Moreover, such physical limitations often interact with psychological vulnerability.

Emotional and psychological challenges represent a particularly significant aspect of adult DCD. Multiple studies have shown that adults with DCD experience higher levels of depression, anxiety, and stress compared to the general population [14–17, 9]. These difficulties are compounded by impairments in executive function—such as planning, organizational ability, and sustained attention—which further exacerbate vulnerability to emotional distress[5, 2, 9]. Over time, the accumulation of motor and psychological challenges has been linked to lower educational attainment, reduced employment opportunities, and greater social withdrawal [10–12].

From a psychological perspective, these findings suggest that DCD is not only a disorder of motor coordination but also a condition associated with elevated emotional distress and reduced life satisfaction. According to the Environmental Stress Hypothesis (ESH), developmental coordination

disorder (DCD) as a primary stressor may increase an individual's risk of developing internalising psychological problems. This model builds upon Pearlin's stress process framework (Pearlin, 1989; Pearlin, Menaghan, Lieberman, & Mullan, 1981), explicitly delineates stressors including life events, chronic stress, and trauma (Turner, Wheaton, & Lloyd, 1995). It elucidates how these stressors exert direct and indirect effects on psychological distress through the mediating and moderating roles of perceived social support and psychosocial resources such as self-esteem and sense of control. Among these, self-esteem, as a core component of self-concept, serves as a key buffering variable in the stress–psychological distress relationship (Pearlin et al., 1981; Turner et al., 1995; Shang, Feng, Yan, & Sun, 2025).[18]. For adults with Developmental Coordination Disorder (DCD), persistent functional deficits and social failures may erode overall self-worth. Conversely, higher self-esteem may buffer the association between motor impairment and emotional distress [19]. Positive self-esteem has been hypothesized to moderate the effect of DCD symptoms on psychological distress.

Despite mounting evidence for both motor and psychological difficulties in adults with DCD, the disorder remains under-recognized, in part due to the lack of efficient, culturally validated screening instruments. The Adult Developmental Coordination Disorder/Dyspraxia Checklist (ADC) is a widely used self-report assessment tool for screening adults with DCD and motor disorders [11]. It has been translated into several languages, including Uzbek, German, and Italian, and has demonstrated cost-effectiveness and reliability across settings[12, 20, 21]. Importantly, the ADC not only captures functional and motor difficulties but also provides insights into psychosocial consequences, making it a valuable resource for psychological and functional heterogeneity in adult DCD[21, 4, 22]. However, to date, no validated Chinese version of the ADC is available, which substantially limits research and screening for adult DCD in Chinese populations.

While culturally validated screening instruments such as the ADC are essential for identifying motor coordination difficulties, measurement alone may be insufficient to capture the heterogeneity of psychological risk among adults with DCD. Motor coordination difficulties often co-occur with psychosocial stressors, giving rise to complex and potentially non-linear relationships with mental health outcomes. Traditional statistical approaches may be limited in their ability to model such multidimensional interactions or to distinguish high-risk subgroups within heterogeneous populations. This study integrates machine learning with SHAP feature attribution to establish a data-driven framework that consolidates ADC dimensions with psychological risk, thereby extending the utility of ADC scores from psychometric assessment to interpretable psychological risk stratification. This approach not only complements the psychometric validation of the ADC but also strengthens its utility in identifying individual psychological vulnerability.

Against this background, the present study has three primary objectives: (1) to translate, culturally adapt, and psychometrically evaluate the Chinese ADC; (2) to examine whether self-esteem moderates the association between motor coordination difficulties and psychological distress; and (3) to develop machine-learning models with SHAP-based interpretation to predict emotional-distress risk and identify

individuals at elevated risk of internalizing problems. A culturally validated screening instrument combined with interpretable risk stratification may facilitate the identification of psychologically vulnerable adults with DCD-related functional difficulties.

Methods

Design

This study utilized a cross-sectional design consisting of two principal phases: (1) translation, cognitive interviews, and psychometric validation of the Chinese version of the Adult Developmental Coordination Disorder /Dyspraxia Checklist (ADC); (2) machine-learning–based prediction of emotional distress using psychometric variables. The study workflow is illustrated in Fig. 1.

Phase I: translation and cultural adaptation

Translation and back-translation

With the consent and authorization of the original scale designers, Professor Amanda Kirby and Professor Sara Rosenblum, and given that the original questionnaire was in English, this study conducted a systematic translation process prior to testing, following the standard procedure of "translation—comprehensive review—back-translation—pre-test" (1) The original ADC was independently translated into Chinese by bilingual psychologists to produce a preliminary version; (2) A panel of 10 experts specializing in cognitive development and motor coordination reviewed and revised the draft, incorporating adjustments to align with Chinese language conventions and behavioral characteristics; (3) The revised Chinese version was back-translated into English and submitted to the original authors for review, with further revisions made based on feedback; (4) Multiple rounds of back-translation and revision were conducted to ensure semantic equivalence and cultural adaptability; (5) The final version of the localized ADC questionnaire was then established.

Pilot Test

To ensure the applicability of the Chinese version of the ADC among the target population and to assess the clarity and comprehensibility of the translated questionnaire items, a pre-test was conducted on 100 college students prior to the formal survey. The purpose of the pretest was to evaluate the feasibility of the questionnaire in actual administration, identify and correct potential semantic ambiguities or comprehension barriers, and thereby enhance the reliability and accuracy of data from the large-scale survey.

The results showed that 92% of participants found the questionnaire content clear and easy to answer. For individual items that raised questions, the research team supplemented necessary explanatory notes based on feedback. For example, in the original questionnaire's Section A, the question regarding

"instrument playing" was adjusted to "handicrafts" (such as origami, paper cutting, etc.) based on cultural adaptation. However, during the pretest, a small number of students remained uncertain about the scope of "handicrafts", so examples were added in parentheses in the questionnaire. 88% of participants completed the questionnaire within 10 minutes. The results indicate that the Chinese version of the ADC has good acceptability and feasibility among the target population.

Data collection procedure

Data were collected uniformly by the researchers. The researchers used standardized instructions to explain the purpose and process of the study, ensuring that participants fully understood the study content before signing the informed consent form and completing the questionnaire. Adult participants were recruited in Shanghai, China, through both on-site recruitment and web-based questionnaire platforms, thereby ensuring high accessibility and anonymity. Participants received appropriate financial compensation. A total of 2,500 questionnaires were distributed in this study, with a response rate of 93.28%.

Phase II: Machine Learning Modeling and Prediction of Emotional Distress

To further examine the predictive validity of ADC traits in emotional distress and assess the incremental contribution of self-esteem, machine learning analyses were conducted across the subsample (N = 1258; 1,139 in the typical developmental group and 119 in the pDCD group), including participants who completed both the DASS-21 and RSES measures to ensure a representative distribution across the DCD risk continuum. Prior to modeling, all variables underwent missing value handling, outlier checks, and Z-score standardization to ensure estimation stability.

In accordance with the research objectives, separate regression models (for predicting continuous emotional distress indicators) and classification models (for identifying individuals at high risk of emotional distress) were constructed. For continuous outcomes, five regression models were used: linear regression, ridge regression, LASSO regression, random forest, and gradient boosting. For high-risk classification, five classification models were used: logistic LASSO, logistic ridge, decision tree, random forest, and gradient boosting. Model performance was optimised through five-fold cross-validation.

Model performance was comprehensively evaluated using multiple metrics: regression models were assessed by R^2, MSE, and MAE; classification models were evaluated by AUC, accuracy, precision, recall, and F1 score. Furthermore, SHAP (SHapley Additive exPlanations) was employed to interpret feature contributions, revealing the relative importance of ADC subscale scores and self-esteem in predicting emotional distress, thereby enhancing the model's theoretical interpretability.

Sample

Eligibility criteria required basic reading and writing ability and willingness to participate in the study. All participants provided informed consent prior to enrollment. No additional exclusion criteria were applied. A total of 2,332 participants were included in this study. For the machine learning component, a subsample of 1,258 participants with complete ADC and DASS-21 was used for machine learning analyses, comprising 1,139 typically developing individuals and 119 participants with probable DCD. This subsample was used exclusively for regression and classification modeling, ensuring that machine learning analyses were conducted independently of psychometric validation to minimize analytical bias. All participants signed informed consent forms, and this study was approved by the Ethics Committee of Shanghai University of Sport, with ethics approval number 102772023RT147.

Instruments

DASS-21

The instrument was developed to assess emotional distress across three domains, namely depression, anxiety, and stress, as conceptualized by Lovibond and Lovibond[23]. Depression was operationalized as diminished self-esteem and motivation alongside dysphoric mood; anxiety was reflected in anticipatory fear and heightened sensitivity to potential threats; and stress was characterized by chronic hyperarousal and low frustration tolerance. The measure consisted of a 21-item self-report questionnaire, with seven items per domain, each rated on a four-point Likert scale. Higher scores indicated greater severity of emotional distress. All DASS-21 subscale and total scores were multiplied by two to ensure comparability with the full DASS, after which established clinical cut-off criteria (depression ≥ 10; anxiety ≥ 8; stress ≥ 15) were applied[24]. These thresholds were used for risk-screening purposes rather than clinical diagnosis.

Rosenberg Self-Esteem Scale, RSES

The Rosenberg Self-Esteem Scale (RSES) is a widely used self-report measure of global self-esteem. It comprises 10 items rated on a four-point Likert scale, with total scores ranging from 10 to 40; higher scores indicate greater self-esteem[25]. Consistent with prior research, scores below 15 are regarded as indicative of low self-esteem[26].

ADC

The original ADC consists of 40 items covering situations that may be encountered in learning, work, and daily life, reflecting the functional performance of adults in areas related to developmental coordination disorder. Completing the questionnaire takes approximately 15–20 minutes. The questionnaire includes three subscales: A, B, and C. Subscale A (10 items) requires respondents to recall experiences from their childhood; subscale B (10 items) requires respondents to answer based on their daily life performance as adults; Subscale C (20 items) primarily assesses others' perceptions of the participant's current performance. The original English version of the questionnaire was developed by Professors Amanda

Kirby and Sara Rosenblum[11]. The present study did not develop a new questionnaire; rather, it used an authorized Chinese version of the published ADC with permission from the original authors.

Statistical analysis

Phase I: Psychometric Revision and Validation

Descriptive statistics were computed to summarise participant demographics, with categorical variables presented as frequencies and percentages and continuous variables as means ± SD. Item discrimination was assessed using independent samples t-tests between high- and low-scoring groups and item-total correlations. Construct validity was evaluated through exploratory factor analysis (EFA) using principal axis factoring with oblique rotation. Factor retention followed predefined criteria, including adequate factor loadings, minimum items per factor, resolution of cross-loadings based on semantic and theoretical consistency, and clear interpretability. Discriminant validity was examined using the heterotrait-monotrait Ratio (HTMT). Internal consistency was evaluated using Cronbach's α; test–retest reliability was estimated with Spearman's rank correlation coefficients.

Phase II: Machine Learning Modeling and Prediction of Emotional Distress

A systematic machine learning workflow was employed to predict emotional distress based on ADC traits, with the aim of extending ADC utility from psychometric assessment to interpretable psychological risk identification. Machine learning regression models, including random forest, gradient boosting, LASSO, ridge, and linear regression, were applied to predict continuous DASS-21 scores. All variables were standardised prior to analysis, and model performance was optimised using five-fold cross-validation to reduce the risk of overfitting. Regression model performance was evaluated using R^2, mean squared error (MSE), and mean absolute error (MAE).

To further explore psychological heterogeneity within the sample, K-means clustering was applied to identify latent patterns of emotional-distress risk. In addition, self-esteem was included as an exploratory variable in subsequent analyses to examine its potential contribution to emotional distress and to enhance the interpretability of model outputs. SHAP (SHapley Additive exPlanations) was employed to quantify feature contributions within the machine learning models.

Finally, classification models, including random forest, gradient boosting, decision tree, and logistic regression with LASSO or ridge regularisation, were constructed to identify individuals at high risk of emotional distress. Classification performance was evaluated using the area under the receiver operating characteristic curve (AUC), accuracy, precision, recall, and F1 score.

Results

Sociodemographic data

This study included 2,332 valid participants, comprising 947 males (40.6%) and 1,385 females (59.4%), aged 18 to 59 years (M = 28.57, SD = 11.60). The overall valid response rate was 93.28%.

Item analysis

Item discrimination was examined using independent-samples t-tests comparing the top 27% (high-score group) and bottom 27% (low-score group) of total ADC scores. All retained items demonstrated significant discrimination between groups (all $p < 0.001$). Item–total correlation coefficients ranged from 0.35 to 0.72, indicating acceptable item homogeneity.

Construct validity

The original ADC comprises three subscales: Subscale A, which assesses childhood motor difficulties to distinguish them from adulthood-onset decline, and Subscales B and C, which evaluate perceived current performance difficulties. An EFA was conducted on 1166 valid responses. The data showed excellent suitability for factor analysis (KMO = 0.960; $\chi^2 = 22{,}943.672$, $p < 0.001$). Principal axis factoring with oblique rotation was performed, with the number of factors fixed at three in accordance with the theoretical structure of the original scale. Item retention was based on the following criteria: factor loadings ≥ 0.40, at least three items per factor, resolution of cross-loadings according to semantic and theoretical consistency, and clear interpretability of the extracted factors. Accordingly, item C16 was removed because of substantial cross-loading on Factors 2 and 3. The retained 37 items showed factor loadings ranging from 0.43 to 0.76. Based on the content of the items, the three factors were named "motor coordination," "executive function," and "social avoidance." The three factors together explained 45.68% of the total variance. Detailed factor loadings are presented in Table 1.

Table 1
Factor Loadings of Individual Items in the Chinese Version of the ADC

Factor 1: Motor Coordination		**Factor 2: Executive Function**		**Factor 3: Social Avoidance**	
item	Loading	item	Loading	item	Loading
A1	0.76	C21	0.47	C26	0.55
A2	0.62	C22	0.61	C27	0.67
A3	0.67	C23	0.51	C28	0.68
A4	0.54	C24	0.58	C29	0.69
A5	0.63	C25	0.45		
A6	0.69	C30	0.43		
A7	0.73	C31	0.46		
A8	0.65	C32	0.55		
A9	0.64	C33	0.53		
A10	0.72	C34	0.55		
B11	0.72	C35	0.45		
B12	0.76	C37	0.61		
B13	0.66	C38	0.61		
B14	0.58				
B15	0.74				
B16	0.75				
B17	0.62				
B18	0.64				
B19	0.49				
B20	0.66				
Note: ADC: the Adult Developmental Coordination Disorder Questionnaire					

Discriminant Validity

Discriminant validity was evaluated using the Heterotrait–Monotrait Ratio (HTMT). All HTMT values were below the recommended threshold of 0.85, ranging from 0.387 to 0.613, supporting adequate discriminant validity among the three factors (Table 2).

Table 2
Discriminant Validity Test of the Chinese Version of the ADC Using HTMT (n = 1166)

Factor	Motor Coordination	Executive Function	Social Avoidance
Motor Coordination			
Executive Function	0.613		
Social Avoidance	0.387	0.577	

Reliability

Internal consistency reliability was satisfactory in the full sample (N = 2332), with Cronbach's α coefficients ranging from 0.73 to 0.94 across subscales. Test–retest reliability was assessed in a subsample of 50 participants over a two-week interval, yielding Spearman correlation coefficients ranging from 0.65 to 0.88, indicating acceptable temporal stability.

Correlation matrix of study variables

Pearson correlation analyses were conducted to examine associations among ADC dimensions, DASS-21 scores, and self-esteem. Motor coordination difficulties, executive function difficulties, and social avoidance were positively correlated with depression, anxiety, and stress scores. Self-esteem was negatively correlated with all DASS-21 dimensions. Correlation coefficients are reported in Fig. 2. Preliminary screening further indicated a high prevalence of emotional distress in the sample (54.7% at high risk), with anxiety being the most prominent (50.9%). This provides sufficient variance for subsequent modeling analyses to explore the unique association between ADC-related functional difficulties and psychological risk.

Regression Model Performance Heatmap

Regression Model Performance Heatmap.

Across target variables, model rankings were consistent, though explanatory power varied (see Fig. 3). Random forest achieved the highest prediction for DASS-21 total score ($R^2 = 0.510$), followed by gradient boosting ($R^2 = 0.505$), whereas linear regression, ridge regression, and LASSO regressions showed similar performance ($R^2 = 0.466–0.468$). Subscale predictions for depression and anxiety were comparable ($R^2 \approx 0.48–0.51$), stress was lower ($R^2 = 0.405–0.442$), and self-esteem (RSES) was poorly predicted across all models ($R^2 = 0.199–0.216$). Linear-based models demonstrated highly consistent results, indicating comparable generalization under current data conditions.

Distributional Differences in DASS-21 Scores Across Risk Groups

Based on research developing the ADC scale, this study employed the mean plus 1.5 standard deviations as the threshold for identifying probable developmental coordination disorder (DCD) risk[11]. Individuals

with an ADC total score > 90.4 points were classified into the pDCD group (n = 119, 9.5%), while the remaining were assigned to the typical development (TD) group (n = 1139, 90.5%). Based on this grouping, box plot results revealed that the pDCD group exhibited a significantly higher median DASS-21 total score than the TD group, accompanied by a greater interquartile range and a higher proportion of outliers (see Fig. 4). This indicates a higher overall level of psychological distress and greater individual variability within this group. In contrast, the TD group exhibited a relatively concentrated score distribution and lower overall levels. Differences between the two groups reached statistical significance, providing robust distributional evidence for subsequent risk subgroup identification and predictive model analysis.

t-SNE Visualization of K-means Clustering

This study employed t-SNE to present a two-dimensional visualisation of the K-means clustering results (see Fig. 5). The dimensionality reduction outcome reveals the spatial distribution characteristics of two latent mental health subpopulations within the embedded space. Cluster 0 (pink) exhibits relatively high spatial heterogeneity, whereas Cluster 1 (brown) demonstrates strong intragroup compactness. This visualisation facilitates an intuitive understanding of the relative distribution patterns across multidimensional mental health indicators for different subpopulations, providing a structural reference for subsequent subpopulation feature comparisons and risk stratification.

SHAP Analysis of Feature Importance in Predicting DASS-21 Scores

Figure 6 presents the SHAP analysis of feature importance in predicting DASS-21 scores. Points represent individual feature contributions, colored by feature value. Motor coordination and executive function are primary predictors, with motor coordination exerting the strongest influence; social avoidance shows minimal impact. This attribution indicates that the model's high discriminative power fundamentally relies on the core symptoms of ADC, further confirming that deficits in physical coordination and executive control are the primary functional drivers of psychological vulnerability.

Correlations Between ADC and Psychological Distress (DASS-21) and the Role of RSES

In this study, we examined the moderating role of self-esteem (RSES) in the relationship between the dimensions of the Developmental Coordination Disorder (DCD) assessment tool (ADC) and scores on the Depression, Anxiety and Stress Scale (DASS-21). Figure 7 illustrates the regression trends for centered scores across the three ADC dimensions—motor coordination, executive function, and social avoidance—at low (-1SD), average, and high (+ 1SD) RSES levels. Results indicate that within the dimensions of motor coordination and executive function, high levels of self-esteem significantly mitigated the adverse impact of functional impairment on psychological well-being. This manifested as a markedly flattened trajectory of psychological distress alongside increasing impairment severity, confirming self-esteem's protective buffering effect. In contrast, social avoidance showed a crossover

interaction pattern. Higher self-esteem was associated with lower distress at low levels of social avoidance, but this protective association weakened and eventually reversed as social avoidance increased.

Classification Performance for High-Risk Emotional Distress

Categorical analysis was based on a subsample (N = 1,258) with complete ADC and DASS-21 data, comprising individuals exhibiting varying degrees of DCD-related behavioral characteristics. The behavioral dimensions assessed by ADC (motor coordination, executive function, and social avoidance) served as predictor variables for modeling emotional high-risk states (DASS-21 ≥ 21). Analysis employed Logistic LASSO, logistic ridge, decision trees, random forests, and gradient boosting models. ROC curves illustrated trade-offs between sensitivity and specificity, with AUC evaluating model discrimination (see Fig. 8). Results indicated that Random Forest (AUC = 0.813) and Gradient Boosting (AUC = 0.814) performed best, followed by Logistic Ridge and LASSO (AUC = 0.797), while the Decision Tree model showed relatively lower performance (AUC = 0.772). The dashed line represents the random classification baseline. The findings indicate that DCD-related behavioral characteristics possess strong predictive efficacy in identifying individuals at high risk for emotional disorders, supporting a dimensional association between motor coordination and executive function deficits and psychological vulnerability.

Confusion Matrix and Model Robustness

The confusion matrix was employed to evaluate the robustness of five classification models in high-risk classification tasks, encompassing Logistic LASSO, Logistic Ridge, decision trees, random forests, and gradient boosting models. Each matrix presented true positives (TP), false positives (FP), true negatives (TN), and false negatives (FN), providing a basis for comparing model sensitivity and specificity (see Fig. 9). Results indicated that the ensemble models demonstrated the strongest and largely comparable performance in identifying high-risk individuals. Random Forest yielded 127 true positives (TP) and 52 false positives (FP), reflecting favorable discriminative accuracy and relatively low misclassification rates. In contrast, the Decision Tree model exhibited a relatively higher number of 54 false negatives (FN) and a lower number of correctly identified high-risk cases (106 TP), suggesting a potential tendency toward overclassification when distinguishing between high- and low-risk individuals. These findings provide empirical support for selecting classification models for high-risk psychological distress.

Discussion

This study validated the Chinese version of the ADC and explored the mechanisms linking motor coordination to emotional distress through a multi-method approach. In a large community sample, the 37-item ADC demonstrated a robust three-factor structure—motor coordination, executive function, and social avoidance—with excellent psychometric properties. Beyond traditional validation, this study integrated machine learning (Random Forest and SHAP analysis) and moderation modeling to identify

the "motor–emotion" pathway. Our findings reveal that motor coordination deficits and executive difficulties are the primary drivers of psychological vulnerability, while self-esteem acts as a critical buffer that mitigates the impact of functional impairments on emotional distress. These results support the Environmental Stress Hypothesis in a Chinese context, highlighting the importance of addressing both functional difficulties and psychosocial resilience in adults with DCD-related characteristics.

Factor analysis revealed that the Chinese version shares a similar structure with the German version[20], emphasizing symptoms domains rather than temporal dimensions as in the English and Italian version[11]. This shift from temporal dimensions to components related to symptoms, specifically motor coordination and executive function, suggests that in adults, the characteristics of the impairment itself, rather than the developmental period in which it emerges, are more psychometrically salient for identifying DCD risk. Notably, the emergence of 'social avoidance' as a distinct third factor represents a significant cultural adaptation within the Chinese context. While the German version focuses on a fine/gross motor split[20], our findings highlight the psychosocial ramifications of motor difficulties. The identification of 'social avoidance' as a distinct factor underscores the psychosocial consequences of motor difficulties and may reflect the salience of interpersonal functioning in collectivist cultural contexts [27, 16, 28, 29]. Its emergence highlights the cultural salience of interpersonal functioning and extends the structural conceptualization of adult DCD.

Importantly, ADC scores correlated strongly with negative emotional indicators, reinforcing the psychological significance of screening adults at risk of DCD-related functional difficulties. While previous studies have linked motor coordination to anxiety and depression [30–31, 9], our study advances this understanding by employing SHAP analyses. This machine learning approach revealed that motor coordination and executive dysfunction contributed most strongly to model predictions of emotional distress, with motor coordination emerging as the most influential feature. These findings align with evidence that poorer motor coordination is associated with greater internalizing symptoms and everyday EF impairments [27]. These findings are consistent with the Environmental Stress Hypothesis[18], which conceptualizes motor deficits as chronic stressors that may gradually erode psychosocial resources and increase vulnerability to internalizing symptoms. At the population level, DCD has been associated with lower quality of life (QOL) [32], emotional–cognitive burdens appear to be linked to motor severity and diminished self-efficacy[33]. Moreover, the increasing co-occurrence of DCD and overweight/obesity across development highlights the importance of considering both physical and psychological well-being when evaluating long-term adjustment in DCD[34], highlights the importance of integrated physical- and mental-health approaches within public-health services.

The present findings provide critical empirical support for the Environmental Stress Hypothesis (ESH) by demonstrating the moderating role of self-esteem in the association between motor coordination difficulties and psychological distress[18, 35]. Within the theoretical framework, motor coordination deficits are conceptualized as a primary stressor, and the progression from functional impairment to internalizing problems is substantially shaped by individual psychosocial resources. This interpretation

aligns with recent structural modeling evidence showing that self-esteem mediates the impact of DCD on participation outcomes in adults, highlighting its central role within the DCD-related psychosocial pathway[36].

Although focused on participation rather than emotional distress, that study converges with the present findings in identifying self-esteem as a pivotal mechanism linking motor impairment to broader maladaptive outcomes. The moderation analyses in this study (Fig. 7) clearly demonstrate the core function of self-esteem as a stress buffer: among individuals with higher self-esteem, the predictive effects of motor coordination and executive function deficits on anxiety and depression were significantly attenuated, whereas among those with lower self-esteem, these associations were markedly amplified, exhibiting a nonlinear escalation of risk. The psychologically vulnerable subgroup identified through machine learning models—characterized by the co-occurrence of severe functional impairment and low self-esteem—further confirms that although motor dysfunction serves as the initial trigger of psychological stress, low self-esteem may mark a particularly high-risk context in which emotional distress becomes more pronounced. This finding underscores the protective value of self-esteem in interrupting the motor–emotion cascade and suggests that clinical interventions should extend beyond functional compensation at the physical level to prioritize the enhancement of self-esteem as a core strategy for strengthening resilience and alleviating the psychological burden associated with DCD. Moreover, recent longitudinal research with adolescents has reinforced the importance of self-esteem in this context, demonstrating a significant positive association between higher self-esteem and better mental well-being among individuals with DCD, and highlighting that self-esteem, alongside social communication skills, may be a key target for interventions aimed at improving mental health outcomes[10]. Nevertheless, the social avoidance dimension reveals that self-esteem's buffering effect is contextually constrained. In situations of extreme social avoidance or self-threat, the buffering effect of self-esteem may diminish or even reverse. Individuals with high self-esteem may experience heightened psychological distress, potentially due to an amplified gap between the ideal self and actual functioning. This shift transforms self-esteem from a psychological resource into a source of identity threat[37, 38]. These findings indicate that self-esteem plays a crucial role in interventions, and should be prioritised for enhancement alongside functional rehabilitation to alleviate the psychological burden associated with DCD.

The study's strengths lie in its large sample size, comprehensive measurement indicators, and triangulation through modern machine learning methods. Limitations include potential recall and social desirability biases from self-report scales, and the cross-sectional design's constraints on causal inference. Future research should focus on examining measurement equivalence across different subgroups, establishing clinical cut-off points and sensitivity for the Chinese adult population, and incorporating objective physical activity assessment alongside clinical diagnosis for calibration.

Conclusion

This study validated the stable three-factor structure of the Chinese version of the ADC, demonstrating satisfactory internal consistency and temporal stability. Moderate to strong associations between ADC scores and depression, anxiety, and stress supported its convergent validity. Beyond bivariate associations, machine-learning analyses suggested that motor coordination and executive function difficulties were the most informative features for identifying elevated emotional distress, while low self-esteem marked a particularly vulnerable subgroup. These findings support the potential utility of the Chinese ADC for psychological screening and interpretable risk stratification in adults with DCD-related functional difficulties and underscore the psychological significance of adult DCD. Future research should examine measurement invariance across subgroups and further validate the ADC against clinical interviews and objective motor assessments.

Declarations

Ethics approval and consent to participate

This study was approved by the Ethics Committee of Shanghai University of Sport, China (Approval No. 102772023RT147). All procedures involving human participants were conducted in accordance with the Declaration of Helsinki and its later amendments or comparable ethical standards. All participants were informed that their participation was voluntary and that they could withdraw from the survey at any time before submitting their responses. Informed consent was obtained from all individual participants included in the study.

Consent for publication

Not applicable, as no individual identifiable information is included in this manuscript.

Competing interests

The authors declare no competing interests.

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Author Contribution

D.W. conceived the study, conducted the investigation, collected and analysed the data, performed the statistical analyses, prepared the figures and tables, and drafted the manuscript. B.Z. supervised the study, contributed to the study design, interpretation of the findings, and critical revision of the manuscript for important intellectual content. L.J. provided guidance on the machine-learning analyses

and contributed to manuscript revision. A.K. granted permission for use of the scale and contributed to manuscript revision. All authors reviewed and approved the final manuscript.

Data Availability

The datasets generated and/or analysed during the current study are not publicly available due to privacy and ethical considerations, but are available from the corresponding author on reasonable request.

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Figures

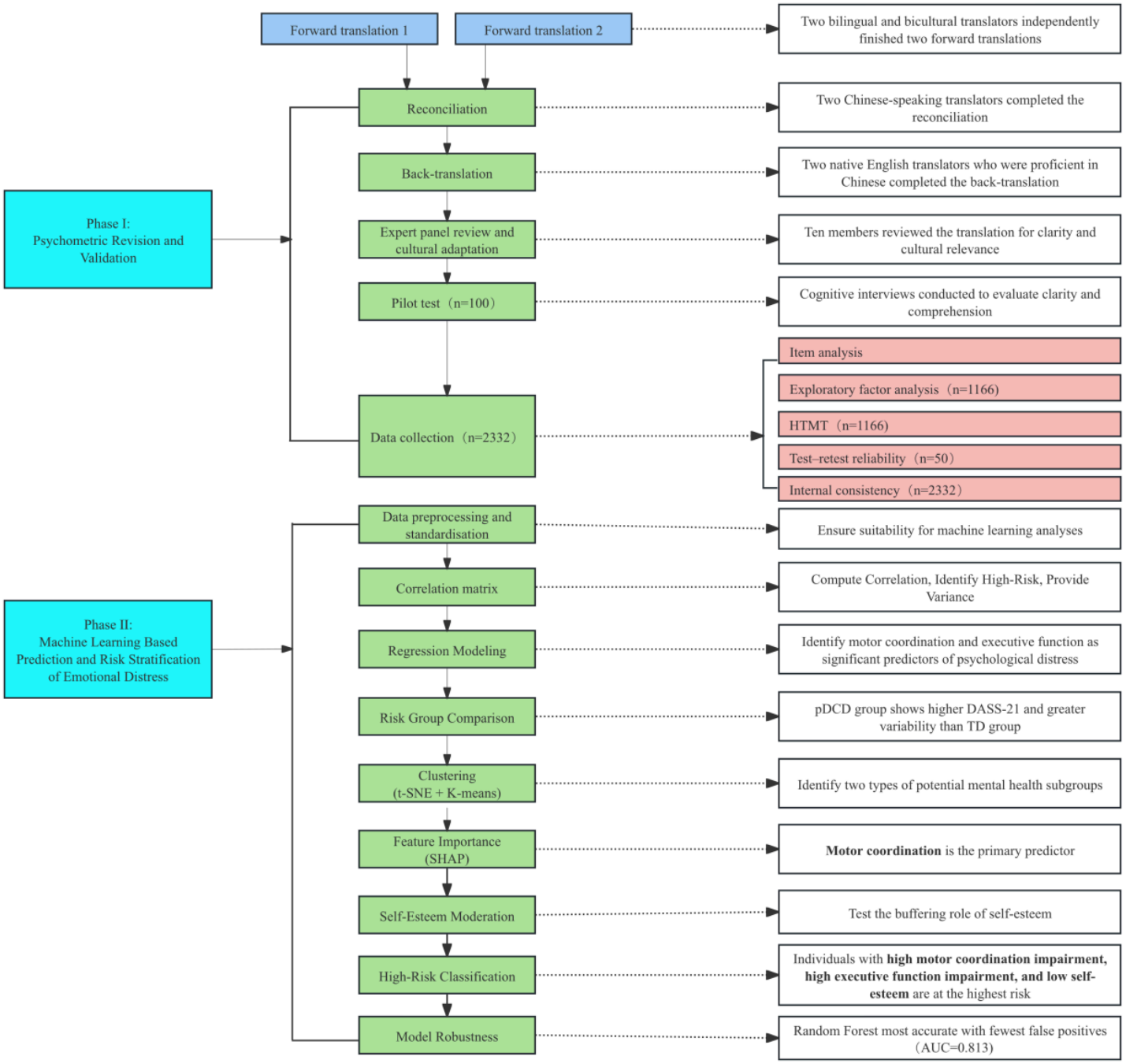


Figure 1

Flow of the multiple standardized phases of the study

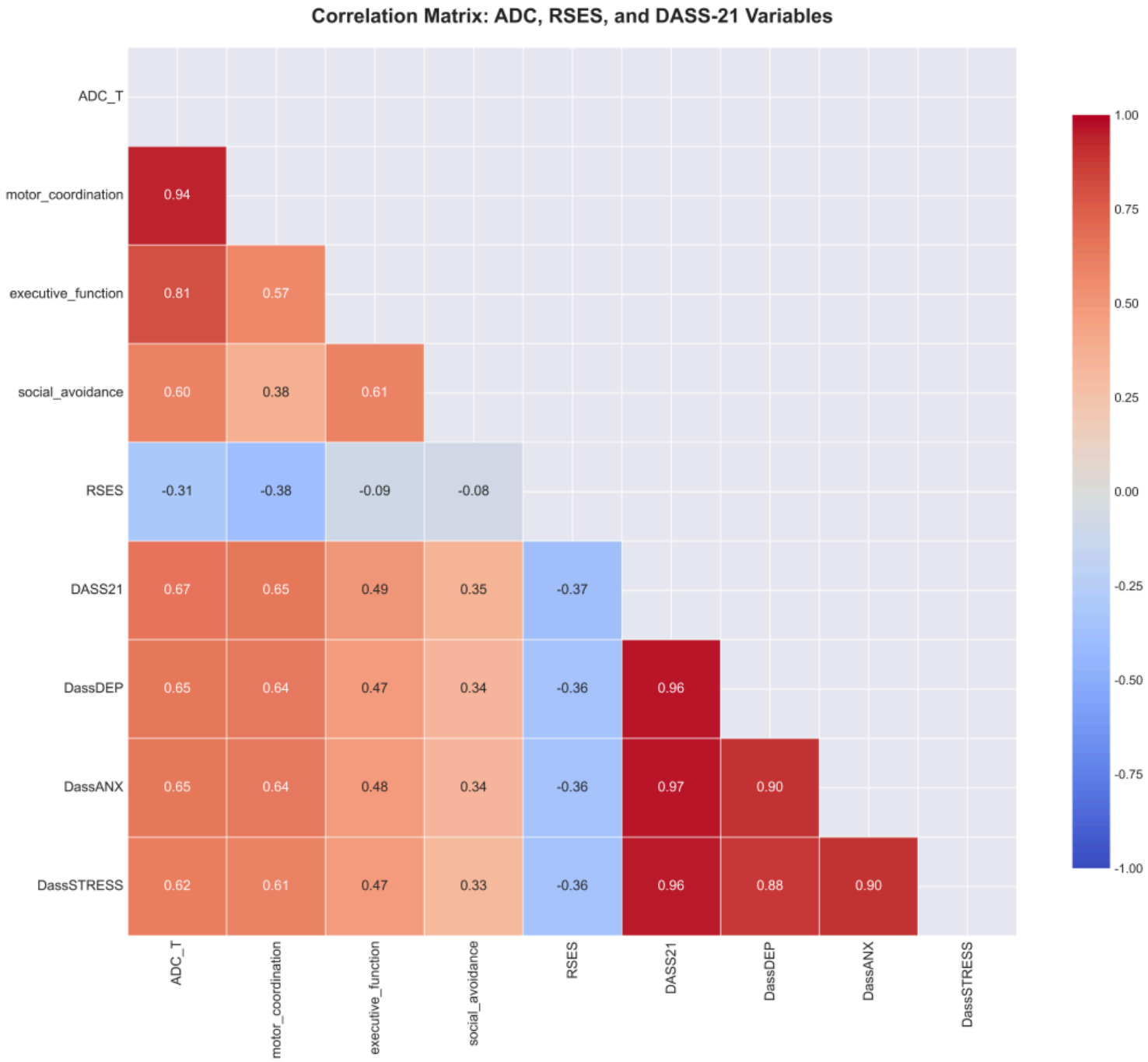


Figure 2

Correlation heatmap of ADC, RSES, and DASS-21 variables.

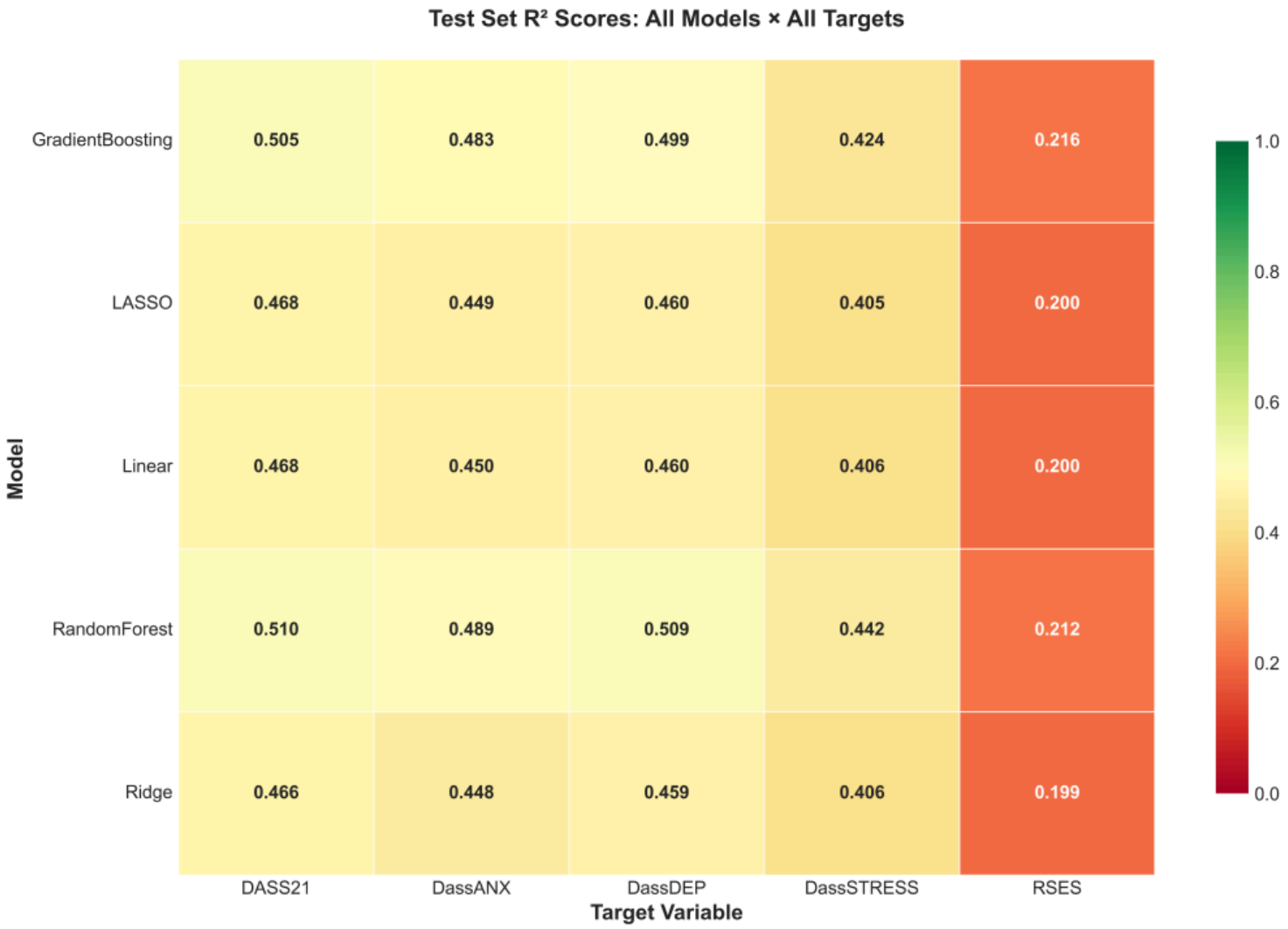


Figure 3

Heatmap of regression model performance. Test-set (R^2) values for five machine learning algorithms are depicted, ranging from lower (red) to higher (green) scores.

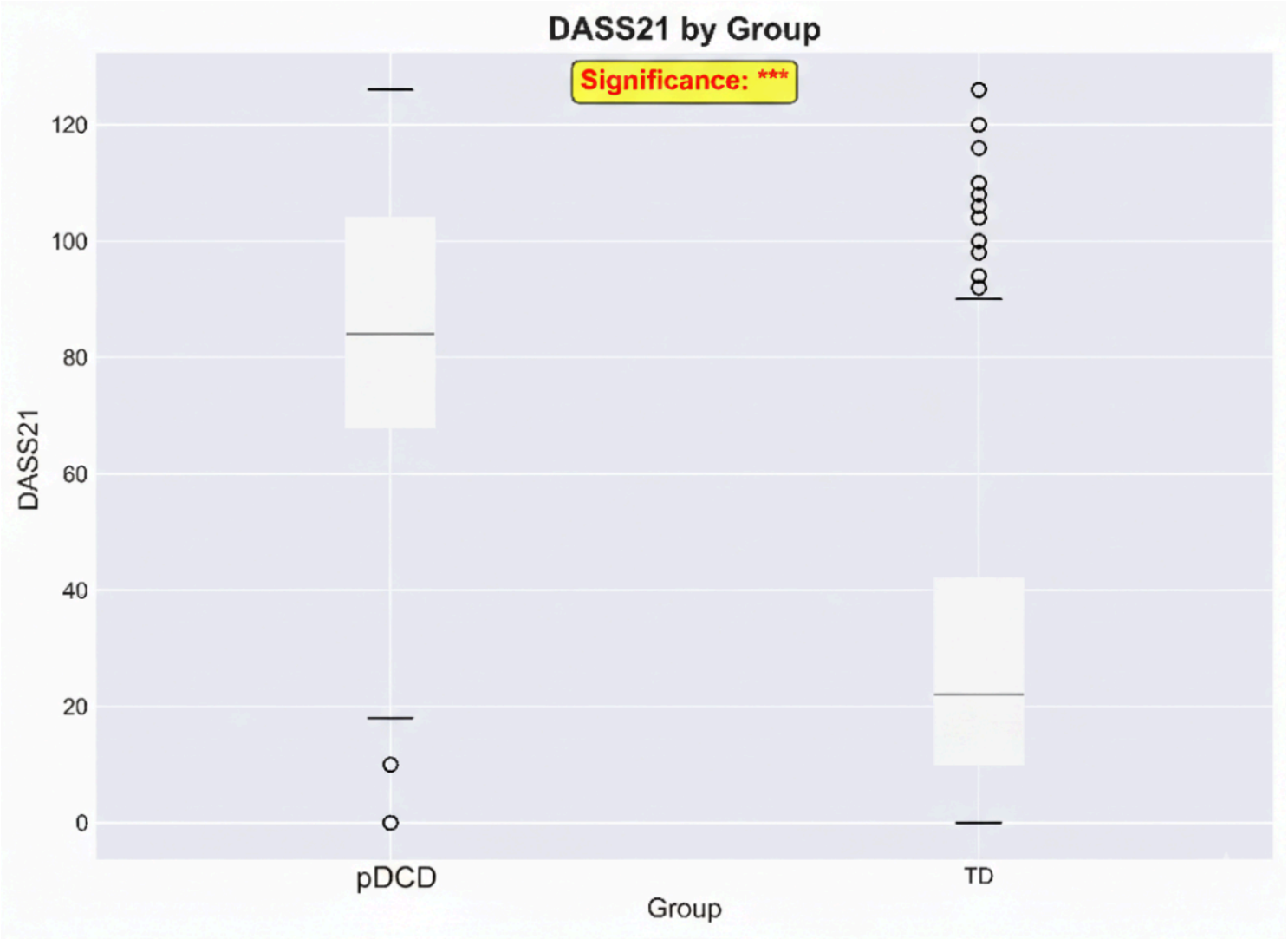


Figure 4

Boxplot of psychological distress across risk groups. The box plot illustrates the score distribution between the probable DCD (pDCD) group and the typical development (TD) group, with asterisks denoting the level of statistical significance between groups.

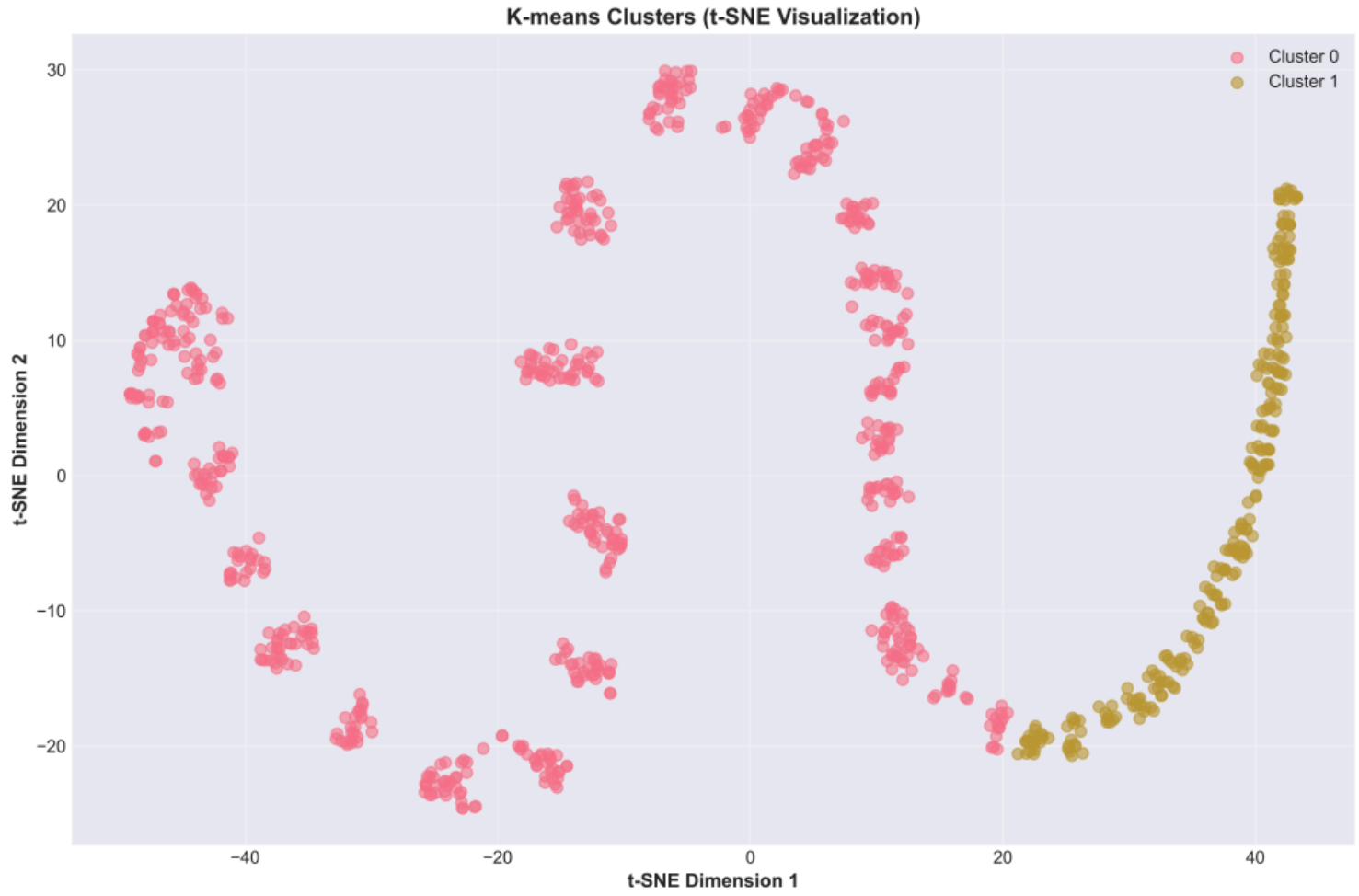


Figure 5

K-means clustering t-SNE visualization. Points represent individuals, with colors distinguishing different clusters, showing the distribution of subgroups in the two-dimensional t-SNE space.

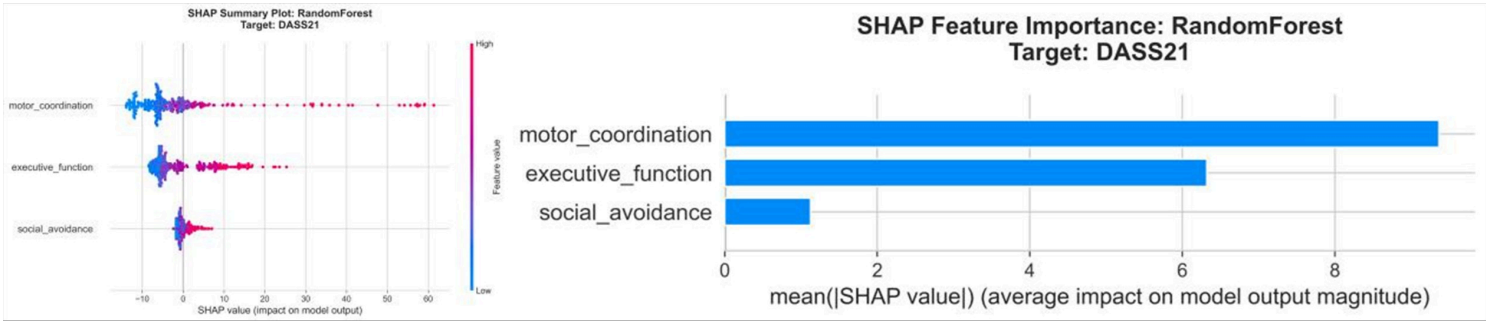


Figure 6

SHAP Interpretation Model. (a) Feature contributions: high (red) = high risk, low (blue) = low risk. (b) Predictor ranking from Random Forest.

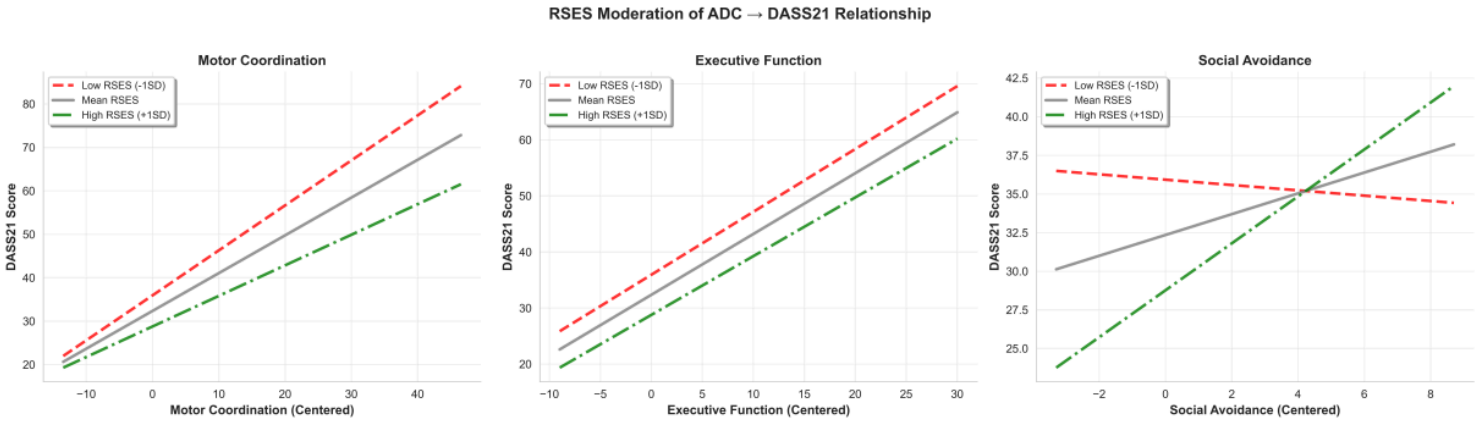


Figure 7

RSES Moderation of the ADC–DASS-21 Association. Slopes for the associations between ADC dimensions and psychological distress (DASS-21) vary across RSES levels (−1SD, mean, +1SD), confirming a significant moderating effect of RSES.

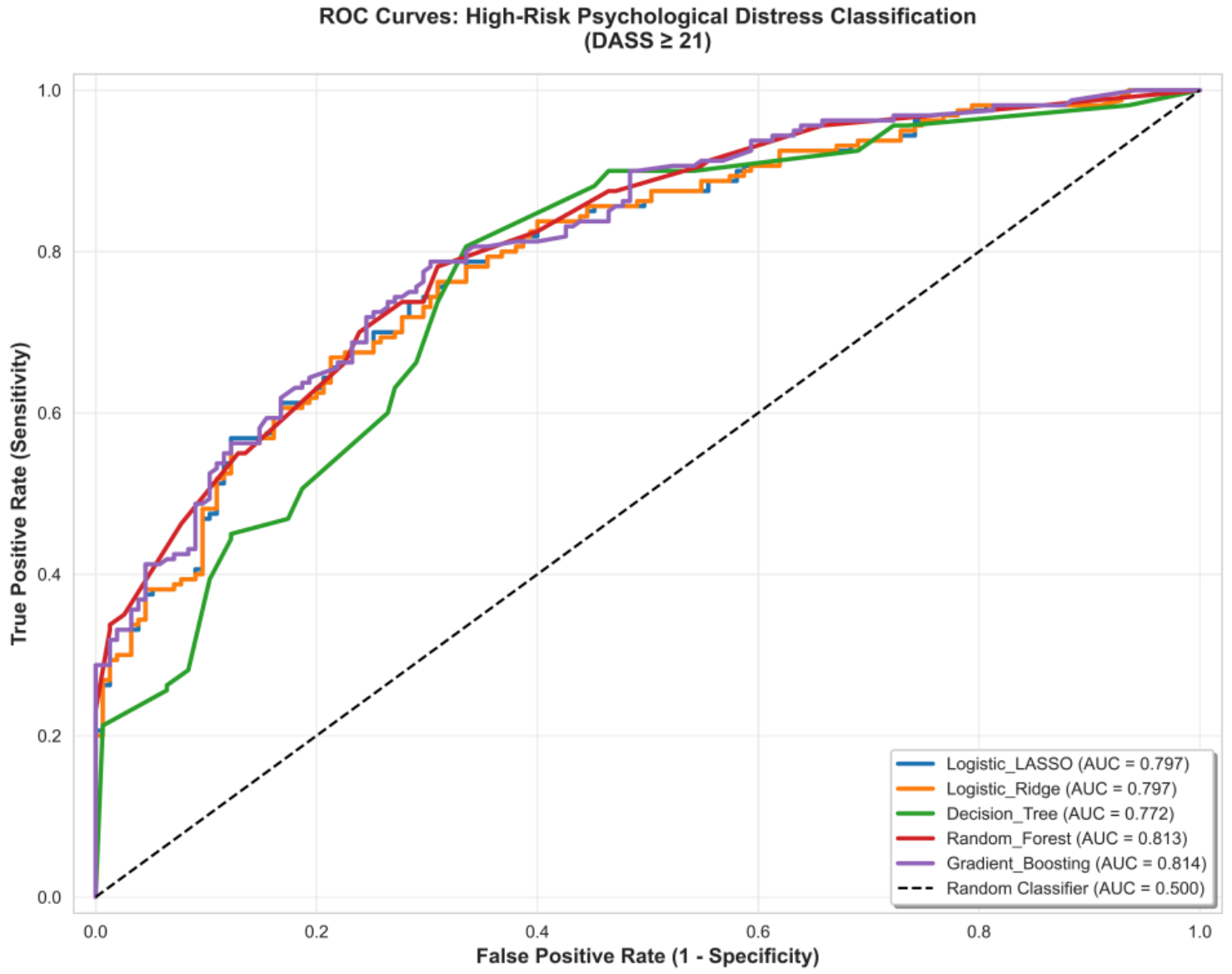


Figure 8

Comparison of ROC Curves for Classification Models. Performance comparison of five models for identifying high-risk psychological distress (DASS-21 ≥ 21) based on the entire subsample.

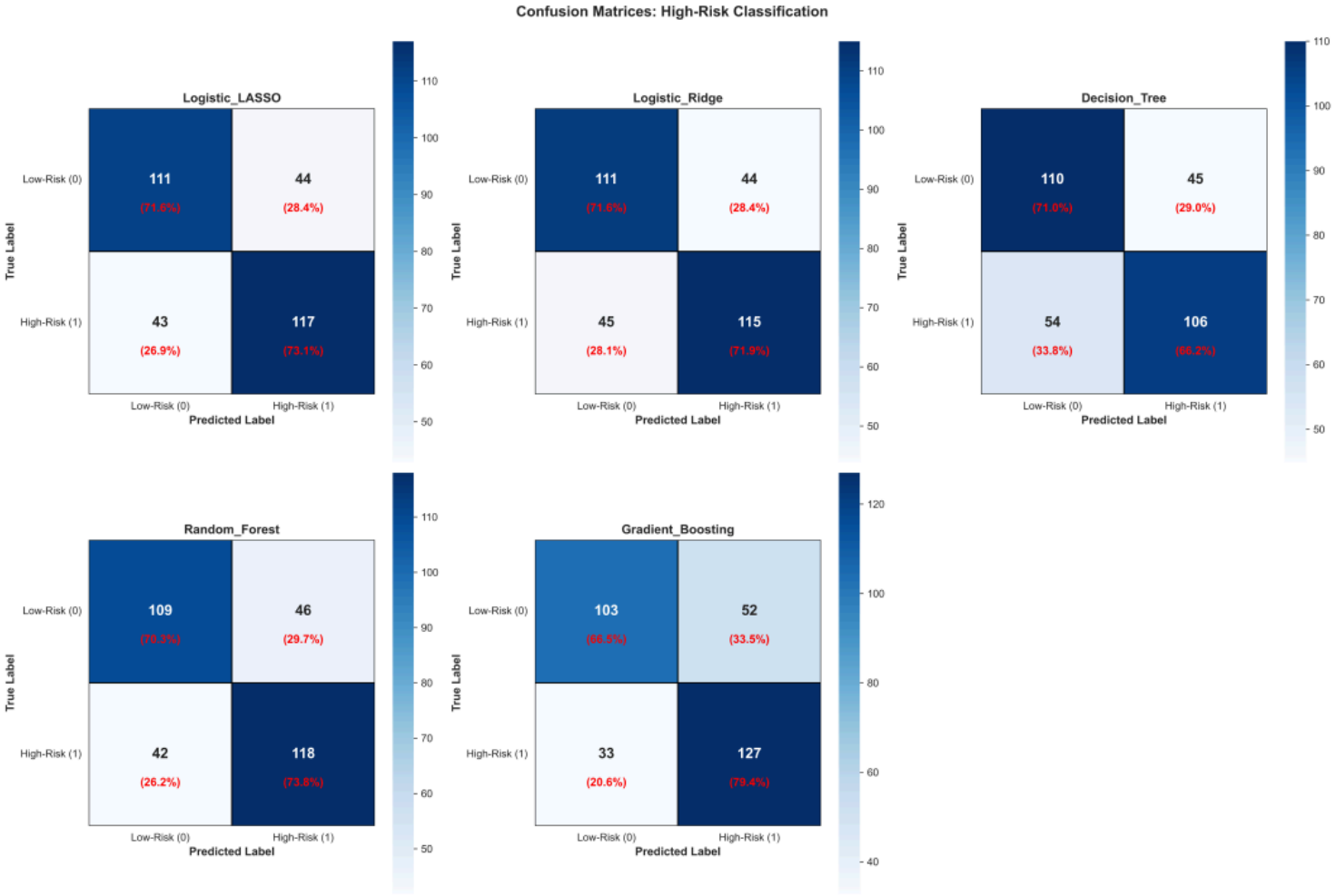


Figure 9

Confusion Matrices for High-Risk Classification. True/false positives and negatives across five classifiers, contrasting model-specific sensitivity and specificity.