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Machine Learning Prediction of Attachment Type From Bio-Psychological Factors in Patients With Depression

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Objective Adult attachment style is linked to how an individual responds to threats or stress and is known to be related to the onset of psychiatric symptoms such as depression. However, as the current assessment of attachment type mainly relies on self-report questionnaires and can be prone to bias, there is a need to incorporate physiological factors along with psychological symptoms and history in this process. We aimed to predict the measurement of two important types of adult attachment with heart rate variability (HRV), early life stress experience, and subjective psychiatric symptoms.

Methods Five hundred eighty-two subjects with depressive disorder were recruited retrospectively from January 2015 to June 2021. The experience of early life stress and psychiatric symptoms were collected, and HRV measures were obtained as input for an ensembled Voting Regressor model of machine learning-based regression models, including linear regression, ElasticNet, Support Vector Machine (SVM), Random Forest, and Extreme Gradient Boosting (XGBoost).

Results Model performances evaluated with R-squared score averaged across 30 seeds were 0.377 and 0.188 for anxious- and avoidant-attachment, respectively. Mean absolute error averaged to 13.251 and 12.083, respectively. Shapley value importance analysis indicated that for both attachment types, the most important feature was the trait-anxiety, followed by emotional abuse, state-anxiety or self-reported depressive symptoms, and fear or helplessness felt in the moment of an early life stressor.

Conclusion Our results provide the evidence base that may be utilized in clinical settings to predict the degree of attachment type using bio-psychological factors.

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Keywords Object attachment; Machine learning; Depressive disorder; Early life stress; Autonomic nervous system.

INTRODUCTION

Attachment is one of the temperamentally internalized traits of an individual, meaning the ability to connect with others and develop supportive relationships as a coping resource.[1] It is postulated that adult attachment style is linked to psychological and biological systems that regulate how an individual responds to threat or stress.[2] Accordingly, past literature has shown evidence for associations between adult attachment style, stress, and health, with the formation of attachment playing a major role in the adaptation to stressful conditions or interpersonal relationships.[3]

Attachment type can be largely divided into secure and insecure attachment, with the insecure attachment being further divided into anxious, avoidant, and disorganized.[4,5] Secure attachment is defined as having confidence in the emotional availability and accessibility of figures perceived as a secure base for restoring emotional stability during stress.[4] It has been demonstrated that secure attachment has positive relationships with psychological adjustment of individuals, positive emotions, and a greater search for social support.[6,7] On the other hand, within the insecure attachment, anxious-attachment is characterized by a perceived inability to face challenging situations on one's own, increasing desire for interpersonal closeness and leading to intense feelings about

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the partner and fear of loss[2,8]; avoidant-attachment is characterized by difficulties in interpersonal relationship and worry of trusting people, resulting in emphasis on autonomy and independence in order to prevent negative emotions possibly evoked by rejection.[2,9] Individuals with high scores in both anxious and avoidant attachment scales are considered as having the disorganized attachment type.

An individual's type of attachment can be a valuable piece of information in planning their course of psychotherapy and predicting prognosis. Attachment styles provide cognitive schemas through which they perceive and relate to the world, including the clinician; thus, understanding an individual's attachment style can help identify targets for intervention[10] and plan the best course of treatment.[11] Researchers have attempted to explore the differential effect of attachment type on different gold standard treatments to guide precision medicine. For example, among clinically depressed patients, one randomized clinical trial (RCT) found greater treatment efficacy for supportive-expressive therapy compared to supportive therapy in patients with anxious attachment.[12] Another RCT found that depressed patients with higher attachment avoidance scores responded better to cognitive behavioral therapy compared to interpersonal psychotherapy.[13] Observational studies of depressed adult patients consistently found better treatment outcomes for patients with secure attachment.[14,15]

Assessment of attachment type

A widely recognized evaluation tool for adult attachment types is the Adult Attachment Interview (AAI),[16] a semi-structured interview with high interrater and test−retest reliability[17] as well as predictive[18] and discriminant validity.[19] Research shows that the AAI can help set the agenda for therapy, assess therapeutic relationships, understand defensive processes and transference-countertransference dynamics, or evaluate outcomes.[17,20,21] However, the AAI also has drawbacks that make it difficult to be used as a routine clinical assessment or in research settings with large samples. First, the AAI's coding system was developed for typical community samples of adults.[17] Clinical subjects have been found to show more insecure attachment representations than nonclinical subjects,[22] implying that the coding system may not be as valid in clinical populations. Later studies replicated such discrepancies between the two groups and suggested modifying the coding criteria of the AAI.[23-26] Certain characteristics of those with severe psychopathology, such as distorted thought processes, aggression, prior experience of therapy, or psychiatric medications, can interfere with the interview process as well.[17] Lastly, the AAI requires extensive additional resources, as it is recommended to be administered by a trained individual different from the main therapist, fully transcribed verbatim, and can take as long as four hours.

Altogether, clinicians would benefit from alternative ways to estimate attachment types that are not as time-consuming or vulnerable to complications by psychopathology. In this study, we have used a combination of shorter questionnaires along with biophysiological measurements to predict attachment types of depressed adults assessed by self-report, leveraging machine learning methods. It has been reported that self-report assessments of attachment may serve as a diathesis for poor interpersonal functioning and a marker of psychopathology, while the AAI may be a marker of interpersonal functioning and diathesis of psychopathology.[27] Therefore, in our sample where all participants have a common psychopathology, self-reported measures could be more valuable in evaluating the individual's vulnerability to poor prognosis.

Early life stress and psychiatric symptoms

A possible risk factor for the formation of insecure attachments is early life stress.[28] Early life stress is one of the important factors reported to be related to mental health including depression, referring to a diverse range of external experiences that are related to childhood maltreatment and/or stressful life events, such as abuse, neglect, domestic violence, and bullying during childhood or adolescence.[29,30] Research supports the model that such adverse childhood experiences may lead to insecure attachment style in adulthood.[31-33] These experiences have been reported to have a negative effect on the development of cognitive functions and emotional processing,[28,34] which may in turn, trigger the formation of insecure attachment and result in difficulties in emotional regulation and interpersonal relationships. Another indicator of insecure attachment can be the presence of psychiatric symptoms such as degrees of depression or anxiety. Broadly, disorders with mainly internalizing symptoms are associated with more anxious and disorganized attachments whereas disorders with mainly externalizing symptoms display more avoidant attachment as well as anxious attachments.[22] Depressive symptomatology in particular has been reported to be associated with the degree of insecure attachment.[22,35]

Physiological factors

One setback in research attempting to investigate associations between attachment type and psychological presentations, such as those presented in the previous subsection, is that assessments of psychopathologies are mainly based on self-report questionnaires.[5,36-39] Attachment types themselves may create biases in self-report, such as due to the propensity to express distress in anxious-attachment individuals and under-reporting of distress in avoidant-attachment individuals.[2]

Physiological tests may be useful both to see beyond such biases and to explore possible psychophysiological correlates of attachment style.[2,40] One physiological marker that has been shown to be associated with insecure attachment type is heart rate variability (HRV). The analysis of HRV is a useful tool for investigating physiological phenomena related to autonomic function, as it is regulated by the interaction between the sympathetic nervous system and the parasympathetic nervous system.[41] Higher HRV in those with secure attachment has been demonstrated in children and adolescents.[42,43] In one adult study, anxious-attachment was found to be correlated with self-reported stress and that avoidant-attachment was inversely correlated with a high frequency (HF) of HRV in healthy subjects under stressful situations.[2,44] Another study reported that activating attachment representations can enhance parasympathetic stress response in people with higher avoidant-attachment levels, and accordingly reduce HRV.[45]

Machine learning

Considering there are multiple psychological components to incorporate and the variety of measures that can be obtained from HRV,[46] a useful method to examine all of these variables is machine learning. With a large enough sample size, machine learning can be used to recognize complex patterns within data, and the flexibility of this learning method enables addressing a large multitude of possible influences and their complicated relationships.[47] In this study, we aim to utilize machine learning to predict the degree of anxious or avoidant attachment type with HRV measurements and self-reported questionnaires focused on early life stress and subjective psychiatric symptoms. We hope to identify factors that can be recognized in clinical settings to recognize attachment types better, and to aid clinicians in interpreting psychiatric presentations and predicting treatment outcomes.

METHODS

Data collection and ethical approval

Subjects were retrospectively recruited from inpatient or outpatient clinics at the Gangnam Severance Hospital, Department of Psychiatry from January 2015 to June 2021. Inclusion criteria were age 20 years or older, best-estimate clinician diagnosis of any depressive disorder by the Korean version of the Diagnostic and Statistical Manual of Mental Disorder, Fifth Edition,[48] and completion of all measures used for analysis. The exclusion criteria were patients with a history of significant medical, surgical, or neurological disorders. Per these criteria, data from 582 eligible subjects were compiled and analyzed. The authors assert that all procedures contributing to this work comply with the ethical standards of the relevant national and institutional committees on human experimentation and with the Helsinki Declaration of 1975, as revised in 2008. All procedures involving human subjects/patients were approved by the Institutional Review Board of Gangnam Severance Hospital, No. 3-2021-0440. Informed consent was waived by the approving ethics committee due to the retrospective nature of the study.

Assessment scales

To evaluate attachment types, Experience in Close Relationships-Revised (ECR-R) was used. ECR-R, which is the modified version of the ECR, is a selected set of questions to alleviate the problem of an excessive number of questions (323 items) in the previous version[49] (Korean version[50]). In detail, the ECR-R consists of 36 items related to the attitude towards close relationships, such as that with an intimate partner. Each item is rated on a 7-point Likert scale from "not at all" to "strongly agree." The resulting scores depicted the degree of anxious- or avoidant-attachment for each participant.

To identify early life stress, the Early Life Stress Questionnaire (ELSQ) produced and validated by the research team was used.[51] The questionnaire consisted of 10 items, each of which asked about "physical abuse," "emotional abuse," "sexual abuse," "familial violence," "neglect," "death of someone close," "separation from parents," "bullying," "natural disaster or accident," and "others." Possible answers were "never," "almost never," "sometimes," or "often." If any of the listed 10 experiences were answered to be positive, the subjects were additionally asked whether they had experienced fear or helplessness at the time and whether they had experienced derealization or depersonalization. In the previous study, the reliability analysis result (Cronbach α) of the ELSQ showed a reliability of 0.783.[51]

The following scales were used as measure of psychiatric symptoms: the Korean version of Inventory for Depressive Symptomatology (KIDS_SR, Cronbach $\alpha=0.96$[52]) and the Hamilton Rating Scale for Depression (HRSD, Korean version Cronbach $\alpha=0.76$[53]) was used to evaluate the severity of depressive symptoms; the State-Trait Anxiety Inventory (STAI) was used to evaluate general negative affect associated with anxiety or depression[54,55]; the Hamilton Anxiety Rating Scale (HAS) was used to evaluate level of anxiety[56]; the Perceived Stress Scale (PSS, Korean version Cronbach $\alpha=0.819$[57]) to evaluate recent stress levels.

Heart rate variability

For the HRV test, SA-6000 (Medicore Co., Ltd.) and QECG-3 (LAXTHA Inc.) were used. The participants sat down and rested for 5 minutes before the start of the test. Then, the elec-

trodes were attached to four limbs and 3 channels of electrocardiography timeseries signals were collected for 5 minutes. Processing of the raw electrocardiogram timeseries was performed with Python 3.8.5 using libraries "numpy," "biosppy," and "hrvanalysis" on a local Linux workstation. The "hrvanalysis" library enabled the calculation of HRV measures according to the guidelines of the Task Force of The European Society of Cardiology and The North American Society of Pacing and Electrophysiology.[58] The normal-to-normal interval (NNI) was obtained by applying a set of preprocessing steps to the raw timeseries, which included R-peak extraction, R-R interval calculation, ectopic beat removal, and R-peak interpolation.

Four domains of the HRV, including the time domain, frequency domain, non-linear domain, and geometrical domain were computed from the NNI information. A minimum number of features were selected from each domain to prevent overlap between information represented by each feature, which might potentially lead to overfitting. The time domain features, including mean of NNI (MeanNNI), standard deviation of NNI (SDNN), standard deviation of differences between adjacent NNI (SDSD), square root of the mean squared differences of successive NNI (RMSSD), median of NNI (MedianNNI), range of NNI (RangeNNI), coefficient of variation of successive differences (CVSD), coefficient of variation of NNI (CVNNI), mean heart rate (MeanHr), maximum heart rate (MaxHr), minimum heart rate (MinHr), and standard deviation of heart rate (StdHr), were all included for analysis as they are the most commonly used HRV measures.[46] One measure was included for each of the other three domains: low frequency and high frequency ratio (LF/HF) for the frequency domain, as it represents the ratio of sympathetic and parasympathetic activity; sample entropy (SampEn) for the non-linear domain, to measure the regularity and complexity of a time series; and triangular index (TriangularIndex) for the geometric domain.[41]

Attachment prediction models

Individual models

We compared the performance of various regression models in predicting the two attachment scores with the HRV parameters, early life stress, and subjective symptoms as input features. The full list of input features is provided in Table 1.

We split the dataset into training and test datasets by an 8:2 ratio, deriving 465 and 117 samples within each dataset, respectively. Each dataset was scaled using a standard scaler. Feature reduction was performed for the training and test dataset using principal component analysis (PCA). Specifically, after fitting the PCA model on the training dataset, the minimum number of components needed to achieve a cumulative explained variance ratio of 0.95 or higher was determined as the optimal number of components, and this number was used to fit and transform both training and test datasets.

For optimal performance, we used VotingRegressor to ensemble five widely accepted, robust, machine learning-based regression models including linear regression, ElasticNet, Support Vector Machine (SVM), Random Forest, and Extreme Gradient Boosting (XGBoost). Samples from the training dataset, which consist of pairs of input features and target score labels, were used to fit the model. A randomized hyperparameter search with 3-fold cross-validation was employed to identify the set of parameters producing the best average validation R^2 score across folds. The full hyperparameter search space is provided in Supplementary Material. The final performance of the ensembled model was evaluated with the test dataset in terms of the R^2 statistics. To minimize the possibility of model performance being affected by the stochasticity in training, we trained the models across 30 different seeds, and the average R^2 calculated across the seeds was used to evaluate the final performance of the models. Mean absolute error (MAE), root mean squared error (RMSE), and explained variance were calculated from the test set as well and averaged across seeds for each attachment type to further evaluate model performance.

We performed Shapely feature importance analyses[59,60] on the VotingRegressor model selected by the hyperparameter search for each seed. Because the training and test datasets were transformed with PCA, we took the following steps to determine feature importance: first, trained the SHAP explainer on the PCA transformed training set; then, fit the explainer on the PCA transformed test set; and lastly, averaged the absolute value for each feature. As values obtained from this process each represent the average contribution of each feature within the model, they were averaged across the 30 seeds to calculate estimates for respective feature importances, which we will refer to as "importance values." To compare the relative importance of early life stress, HRV features, and psychiatric symptoms, we calculated the mean importance values of features in each of the categories.

All analyses were performed using Python 3.12.2 with the "numpy," "pandas," "sklearn,"[61] "xgboost,"[62] and "shap"[59,60] packages.

RESULTS

Demographic characteristics

Five hundred eighty-two subjects were enrolled with a mean age of 44.7 years (SD 19.5 years, range 20–89 years), of which 414 (71.1%) were women. Demographics of enrolled subjects and their values of input features are summarized in

Table 1. Full list of input features for the regression models

Index	Feature	Abbreviation	Type
1	Physical abuse	ELS1	Early life stress (ELS)
2	Emotional abuse	ELS2	
3	Sexual abuse	ELS3	
4	Familial violence	ELS4	
5	Neglect	ELS5	
6	Death of someone close	ELS6	
7	Separation from parents	ELS7	
8	Bullying	ELS8	
9	Natural disaster or accident	ELS9	
10	Others	ELS10	
11	Fear or helplessness	ELS11	
12	Derealization or depersonalization	ELS12	
13	Hamilton Rating Scale for Depression	HRSD	Psychiatric symptoms (PsySx)
14	Korean version of Inventory for Depressive Symptomatology	KIDS_SR	
15	State-Trait Anxiety Inventory-State anxiety	STAI_S	
16	State-Trait Anxiety Inventory-Trait anxiety	STAI_T	
17	Perceived Stress Scale	PSS	
18	Hamilton Anxiety Rating Scale	HAS	
19	Mean of normal-to-normal intervals	MeanNNI	Physiologic features (HRV)
20	Standard deviation of the normal-to-normal interval	SDNN	
21	Standard deviation of differences between adjacent NN intervals	SDSD	
22	Square root of the mean squared differences of successive NNI	RMSSD	
23	Median of normal-to-normal intervals	MedianNNI	
24	Range of normal-to-normal intervals	RangeNNI	
25	Coefficient of variation of successive differences	CVSD	
26	Coefficient of variation of normal-to-normal interval	CVNNI	
27	Mean heart rate	MeanHr	
28	Max heart rate	MaxHr	
29	Min heart rate	MinHr	
30	Standard deviation of heart rate	StdHr	
31	Low frequency/high frequency ratio	LF/HF	
32	Triangular index	TriangularIndex	
33	Sample entropy	SampEn	

Table 2. The most common forms of early life stress were familial violence, reported in 429 participants (73.7%), followed by emotional abuse, reported in 424 participants (72.9%). For psychiatric symptoms, the HRSD, KIDS_SR, STAI-State anxiety (STAI_S), STAI-Trait anxiety (STAI_T), PSS, and HAS had a mean±SD of 18.3±7.1, 20.7±8.1, 58.9±12.1, 59.4±11.7, 22.4±6.7, and 20.0±10.3, respectively.

Model performance results

When the five individual models were ensembled using the predetermined list of 30 seeds, the average R^2 for the anxious- and avoidant-attachment scales were 0.377 and 0.188, respectively. Figure 1 shows the regression scatter plots of the VotingRegressor model at its seed of best performance for each scale. For other performance metrics, the mean explained variance for the anxious- and avoidant-attachment scales were 0.383 and 0.195, respectively. The model predicting the anxious-attachment scale had a mean MAE and mean RMSE of 13.251 and 16.122, respectively; for avoidant-attachment, the corresponding scores were 12.083 and 14.933. MAE and RMSE values were normalized into mean absolute percentage errors (MAPE) and coefficient of variation of RMSE (CV

Table 2. Demographics and input features

Variable	Value
Age (yr)	44.7±19.5
Sex, female	414 (71.1)
Marital status	
Unmarried	145 (24.9)
Married	387 (66.5)
Divorced or widowed	50 (8.6)
Education (yr)	12.22±3.71
Early life stress	
Physical abuse	354 (60.8)
Emotional abuse	424 (72.9)
Sexual abuse	154 (26.5)
Familial violence	429 (73.7)
Neglect	253 (43.5)
Death of someone close	252 (43.3)
Separation from parents	179 (30.8)
Bullying	299 (51.4)
Natural disaster or accident	118 (20.3)
Others	37 (6.4)
Psychological factors	
HRSD	18.3±7.06
KIDS_SR	20.7±8.08
STAI_S	58.9±12.10
STAI_T	59.4±11.70
PSS	22.4±6.72
HAS	20.0±10.30

Data are presented as mean±standard deviation or number (%). HRSD, Hamilton Rating Scale for Depression; KIDS_SR, Korean version of Inventory for Depressive Symptomatology; STAI_S, State-Trait Anxiety Inventory–State anxiety; STAI_T, State-Trait Anxiety Inventory–Trait anxiety; PSS, Perceived Stress Scale; HAS, Hamilton Anxiety Rating Scale

(RMSE)) for interpretability, yielding the following values: for anxious-attachment, MAPE 19.157%, CV(RMSE) 23.315%; for avoidant-attachment, MAPE 17.381%, CV(RMSE) 21.484%.

Feature importance analysis results

Results obtained from inverse-transformed SHAP values showed that, on average, STAI_T, ELS2 (emotional abuse), KIDS_SR, STAI_S, and ELS11 (fear or helplessness) had the highest importance values, in decreasing order (Figure 2). For the avoidant-attachment scale, the same five features were assigned the highest importance values but in a different order: from highest value, STAI_T, ELS2, STAI_S, KIDS_SR, and ELS11 (Figure 2). For both scales, five HRV features, including RMSSD, RangeNNI, SDSD, SDNN, and CVSD, had the lowest importance values.

Mean importance values of each feature category, psychiatric symptoms had the highest value for both attachment types, followed by early life stress and HRV physiological features (Figure 3). All three types of features had higher average importance values for anxious-attachment (early life stress, 2.059; psychiatric symptoms, 2.531; physiological features, 0.811) compared to avoidant-attachment (early life stress, 1.199; psychiatric symptoms, 1.471; physiological features, 0.439).

DISCUSSION

We attempted to predict the distribution of ECR-R scores in adults with depressive disorder using bio-psychological features reflective of psychopathologic symptoms by ensembling machine learning-based predictive models known to provide robust performance. Model performance, as evaluated based on how well the model explains the variability in

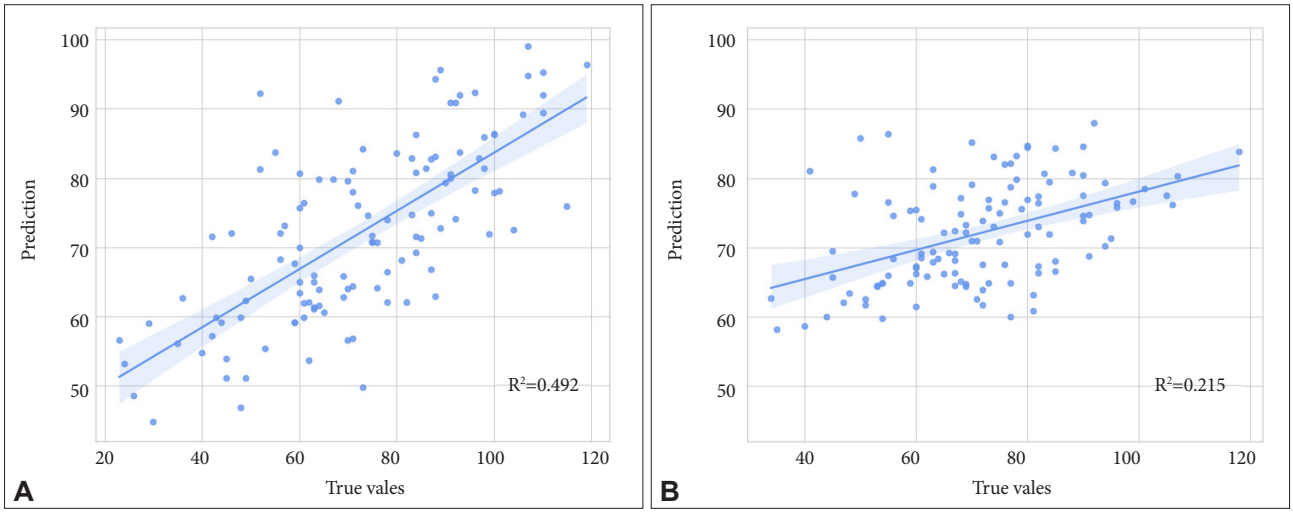


Figure 1. Regression plot of the ensembled model for each attachment type at seed of best performance. A: Anxious-attachment. B: Avoidant-attachment.

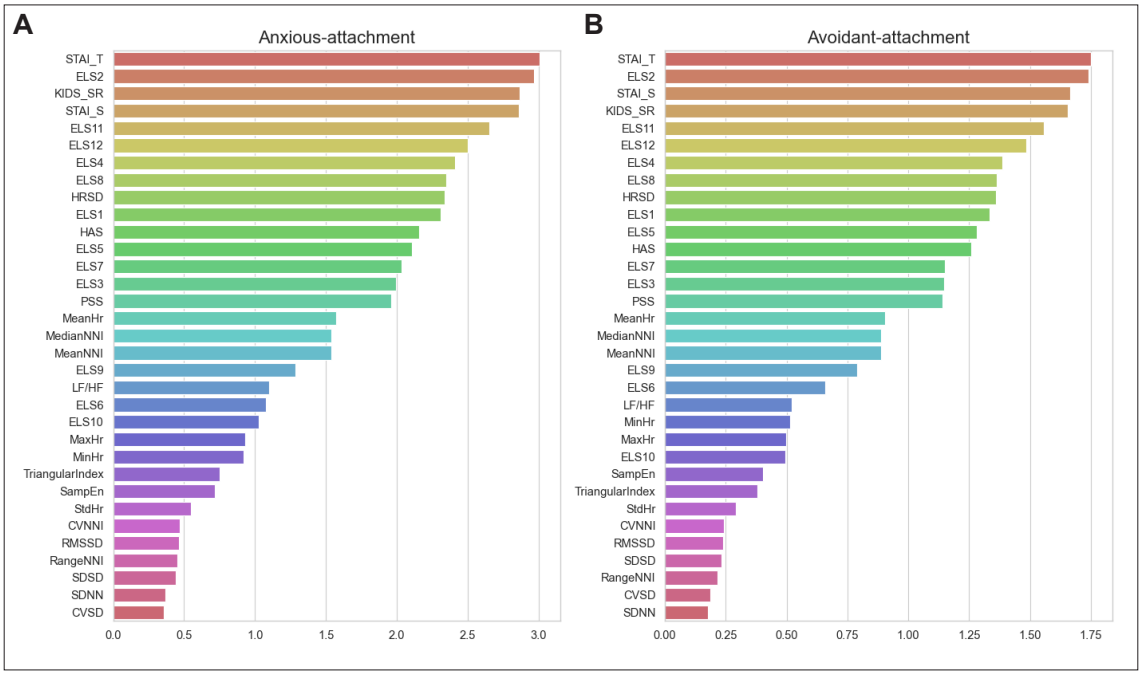


Figure 2. Feature importances of the VotingRegressor model for each attachment type, averaged over 30 seeds. A: Anxious-attachment. B: Avoidant-attachment. ELS, early life stress, with each item corresponding to features listed in Table 1. Psychiatric symptoms including: HRSD, Hamilton Rating Scale for Depression; KIDS_SR, Korean version of Inventory for Depressive Symptomatology; STAI_S, State-Trait Anxiety Inventory–State anxiety; STAI_T, State-Trait Anxiety Inventory–Trait anxiety; PSS, Perceived Stress Scale; HAS, Hamilton Anxiety Rating Scale. Physiologic features including: MeanNNI, mean of normal-to-normal intervals; SDNN, standard deviation of the normal-to-normal interval; SDSD, standard deviation of differences between adjacent normal-to-normal intervals; RMSSD, square root of the mean squared differences of successive NN intervals; MedianNNI, median of normal-to-normal intervals; RangeNNI, range of normal-to-normal intervals; CVSD, coefficient of variation of successive differences; CVNNI, coefficient of variation of normal-to-normal interval; MeanHr, mean heart rate; MaxHr, max heart rate; MinHr, min heart rate; StdHr, standard deviation of heart rate; LF/HF, low frequency/high frequency ratio; TriangularIndex, triangular index; SampEn, sample entropy.

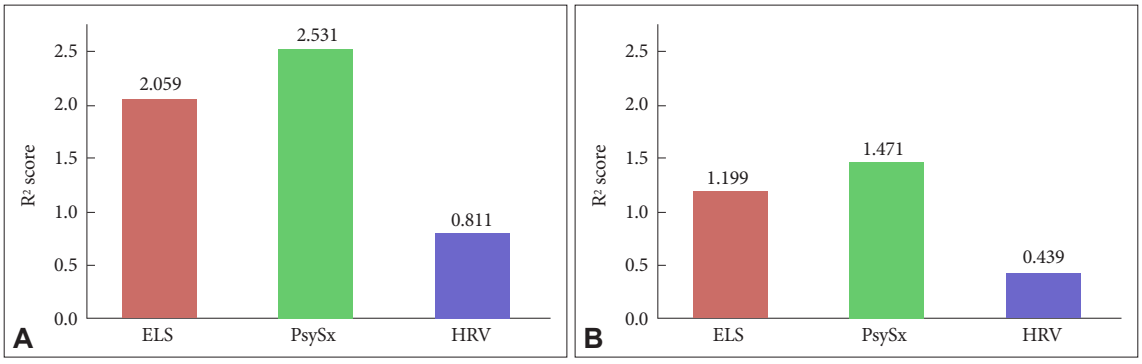


Figure 3. Average importance values of input features according to feature type. A: Anxious-attachment. B: Avoidant-attachment. ELS, early life stress; PsySx, psychiatric symptoms; HRV, heart rate variability (i.e., physiologic features).

outcome, was low to moderately low, while when evaluated based on accuracy of predictions made, the performance was moderately high. Trait anxiety, represented by STAI_T, was the most important factor in predicting ECR-R scores for both anxious- and avoidant-attachment scales. Other features identified to be of high importance were ELS2 and ELS11 from early life stress measures and state anxiety (STAI_S) and depressive symptomatology measured with the KIDS_SR from the psychiatric symptom features. While physiological features measured by HRV took part in prediction overall, judging by its mean importance value, its contribution was less than the other two categories.

Model performance

The explained portion of variability for each attachment scale as demonstrated by R^2 statistics and explained variance scores averaged at 0.377 and 0.383 for anxious-attachment and 0.188 and 0.195 for avoidant-attachment. This indicates

that the model for anxious-attachment, compared to the model for avoidant-attachment, likely captured a larger proportion of the relationships between our input features and attachment. Despite these low to moderately low scores, the models displayed reasonable accuracy in their predictions. MAE and RMSE values for both models (anxious-attachment, 13.251, 16.122; avoidant-attachment, 12.083, 14.933; respectively) were smaller the mean standard deviation averaged across seeds (anxious-attachment, 21.311; avoidant-attachment, 17.149). The values accounted for less than 20% of the mean range of the scales averaged across the test sets for the 30 seeds (range for anxious-attachment, 92.8; avoidant-attachment, 78.2). MAPE values of 19.2% for anxious-attachment and 17.4% for avoidant-attachment were both below 20%, translating to predictions being off by less than 20% of actual values. However, the gap between MAE and RMSE for both models suggest that the model may be sensitive to larger errors or outliers. Overall, although low R^2 values and sensitivity to outliers clearly require improvement, the model showed moderate performance with acceptable error levels that may be ground-setting for development of future models.

Psychiatric symptoms

The most important predictor for both the anxious- and avoidant-attachment scales was the STAI_T. STAI_T is a factor that determines individual differences in coping with external threats and shows a constant pattern throughout one's life.[55] The results of our study are consistent with previous studies that report the association between the STAI_T and anxious-/avoidant-attachment.[63-65] Anxiety experienced in early life that can affect attachment formation also affects trait anxiety, which involves presenting consistent patterns of anxiety-related feelings or thoughts or tendencies to engage in anxiety-related behaviors. This finding may also be interpreted as insecure attachment being a predictive factor of psychopathologic anxiety. Either way, this association found in our study suggests a need to be vigilant for anxiety symptoms in those with insecure attachment.

Among psychiatric symptoms other than STAI_T, the KIDS_SR and STAI_S scores were identified to be important, followed by HRSD (9th for both attachment types), HAS (11th for anxious-attachment, 12th for avoidant-attachment), and PSS (15th for both attachment types). Overall, this suggests that both depression and anxiety play a role in either the symptoms that arise from having insecure attachment or the development of insecure attachment itself, consistent with previous literature.[66] Stress appears to have contributed less to the model compared to anxiety and depression.

While KIDS_SR ranked higher than STAI_S for the anxious type, the order was reversed for the avoidant type, possibly implying that depressive symptomatology has a greater association with anxious-attachment than avoidant-attachment. This is in line with findings from previous literature that anxious-attachment can predict depressive symptoms.[67-69] It is possible that increased emotional awareness[70] in individuals with anxious-attachment led to increased endorsement of depressive symptomatology, reflected in the higher feature importance of the self-report questionnaire KIDS_SR compared to the clinician-administered HRSD. In contrast, individuals with avoidant-attachment tend to lack awareness of their emotional state and are less reactive to it,[70] as demonstrated in the relatively lower feature importance of the KIDS_SR despite the HRSD being equally important as for prediction of anxious-attachment.

Early life stress

One of the key findings in this study is the role of early life stress in predicting attachment type. For both attachment types, emotional abuse was identified as the second most important predictor among all factors, followed by fear or helplessness felt at the time of stressful event in 5th place. This was closely followed by derealization or depersonalization experienced at the moment, familial violence, and bullying. The relationship between early life stress and insecure attachment, or the lack thereof and secure attachment, has been reported in previous studies.[71,72] A review of existing literature suggests that early caregiving and early childhood adversities can impact the reactivity of the hypothalamic-pituitary-adrenocortical axis and the autonomic nervous system, which, in turn, have been found to be associated with insecure attachment.[73] Our results, along with these studies, suggest that investigating the presence of early-life psychosocial stressors can provide objective guidance for assessing attachment type.

It is also worth noting that, apart from emotional abuse, how the stressful event manifested in the individual, such as whether they felt fear, helplessness, derealization, or depersonalization, showed a stronger association with attachment scores than the presence of an early life stressor itself. This may be due to how the ELSQ is structured, as the last two items of the questionnaire likely assess how intense the stressors were, possibly reflecting the degree of disturbance in stress regulation functions of the individual. As such, individuals who answered "yes" to these two items may have been more severely impacted by their stressors. This implies that, regardless of the type, any early life stress, if stressful enough, can cause the development of insecure attachment. Similarly, it can be inferred that emotional abuse impairs the development of secure attachment, regardless of its severity. Therefore, our results suggest careful assessment of emotional abuse and how the individual experienced any early life stressor recognized.

Heart rate variability

Among HRV features, the four features with the highest importance were MeanHr, MedianNNI, MeanNNI, and LF/HF for both attachment types, with the 5th being MaxHr for anxious-attachment and MinHr for avoidant-attachment. Four of these five features were in the time domain, with all four being based on the mean or median value of heart rate rather than variability. In fact, measures for variability from the time domain, such as StdHr, SDSD, RMSSD, RangeNNI, SDNN, CVNNI, or CVSD, were found to be of the lowest importance among all features. There have been similar reports in the past, with one comprehensive meta-analysis demonstrating no or little relevance between time domain variability indices and psychopathology when HRV is measured for under 10 minutes.[74]

Considering the absence of standardized stress or attachment priming in our study design, there is a possibility that heart rate itself may be representative of the balance in the autonomic nervous system at an individual's resting state.[75] Our findings that the degree of anxious-attachment was more associated with MaxHr, while avoidant-attachment was more associated with MinHr, may suggest overactivation of the sympathetic nervous system in anxious-attachment and suppression of emotional response through activation of the parasympathetic nervous system in avoidant-attachment.

LF/HF was the only feature not within the time domain selected to be of relatively high importance. This is in concordance with previous literature that suggests that the LF/HF ratio represents sympathovagal balance in the autonomic system,[76] which is known to be dysregulated in those with insecure attachment. Specifically, HF, reflective of vagal tone,[77] has been found to differ depending on the degree of neuroticism of the subject,[52] and one study reported HF to be inversely associated with the degree of avoidant-attachment.[2]

Compared to early life stressors or psychiatric symptoms, HRV features were of lesser importance in the prediction of attachment type. The collective findings of past studies show heterogeneous findings regarding the association between HRV measures and attachment type,[77-79] with studies utilizing resting state HRV virtually nonexistent. Future studies with carefully designed experimental conditions, for example, directions to imagine an attachment figure or a standardized stress condition, are warranted to further explore the predictive value of HRV measures on attachment insecurity.

Limitations and future study directions

Some limitations should be noted in this study. First, the subject collection and evaluation were retrospectively done. This made it difficult to control for participant variables such as time of measurement in relation to the diagnosis of depressive disorder, psychiatric drug use, and life habits including prior alcohol use, smoking, caffeine, and amount of physical activity that can affect HRV measurements. It was also impossible to instruct participants to perform certain tasks or think of specific attachment figures that may trigger attachment-related stress, a commonly used method to evaluate differences in physiological response by attachment type.[53-55] A study with a more specific prospective design in the future would provide further validation of our results, such as longitudinal studies that assess early life stressors and psychopathology throughout childhood.

Second, we did not use the AAI, which is the most widely used method of assessing attachment styles. However, it is possible that the attachment style captured by the ECR-R is a more accurate representation of the adult's current functioning compared to the AAI that focuses on early childhood attachments with caregivers.[23] Further, the ECR-R addresses close relationships in general, rather than the select relationships addressed in the AAI. It has been suggested that this characteristic may potentially make the ECR a better tool than the AAI in detecting associations with the broad construct of personality.[23] Future research may benefit from incorporating both a self-report measure and the AAI to evaluate attachment types more accurately.

Third, model performance was not strikingly high, possibly implying that other variables should be additionally taken into consideration in the prediction of attachment scales. Despite the suboptimal performance, the model's acceptable predictive accuracy serves as a proof-of-concept that measurements collected from relatively routine instruments can be used to estimate attachment styles. Future studies incorporating other biomarkers and psychosocial factors affecting attachment may help evaluate attachment type in a more comprehensive and objective manner. Investigation of the mediating and/or moderating effects of various factors on the relationship between attachment type and treatment outcome could aid identification of potential additional predictors. Such research exploring the relationship among predictors, attachment type, and treatment outcome would provide deeper insight into the underlying mechanisms that impact individual trajectories of depression patients.

Lastly, as the entire study sample was diagnosed with depression, our results should be carefully interpreted as they may not be valid in individuals without depressive symptoms. However, the homogeneity of clinical psychopathology in this sample can be a strength when considering the clinical implications of our findings. There are a limited number of RCTs examining the differential response to various types of psychotherapy by attachment style among patients with de-

pression.[12,13] With improved predictive value, models like ours can be used to facilitate precision medicine research by decreasing the time and resources required to assess attachment. As such, constructing similar models for other psychiatric diagnoses, such as anxiety disorders or post-traumatic stress disorder, may be informative as well.

Conclusion

Despite limitations, this study is one of the first studies attempting to predict adults' attachment type through biological indicators and other factors such as early life stress, depression, and anxiety as well as the self-report questionnaires with a dataset including over 500 subjects. As attachment is an essential element to understand the psychodynamics of patients, and a predictive model of attachment type can potentially help to further justify clinical judgment in the future. We hope that our findings may contribute to providing deeper insight into the identification of causative and resulting features that factor in recognizing one's attachment type.

Supplementary Materials

The Supplement is available with this article at https://doi.org/10.30773/pi.2024.0392.

Availability of Data and Material

Data requests should be addressed to the corresponding author, B.-H.K., upon reasonable request.

Conflicts of Interest

The authors have no potential conflicts of interest to disclose.

Author Contributions

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