




A LightGBM Analysis of Emotional Well-Being in Children with Autism Spectrum Disorder: Predictive Contributions of Sensory Sensitivity, Parent–Child Attachment, and Social Competence

Elīna. Ozoliņa¹, Nomvula. Dlamini^{2*}, Mercy. Atieno³

¹ Department of Clinical Psychology, University of Latvia, Riga, Latvia

² Department of Psychology, University of Cape Town, Cape Town, South Africa

³ Department of Community Psychology, Maseno University, Maseno, Kenya

* Corresponding author email address: nomvula.dlamini@uct.ac.za

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ABSTRACT

The present study aimed to investigate the predictive contributions of sensory sensitivity, parent–child attachment, and social competence to emotional well-being among children with Autism Spectrum Disorder (ASD) using a Light Gradient Boosting Machine (LightGBM) model and explainable artificial intelligence techniques. This cross-sectional predictive study was conducted among 428 children diagnosed with Autism Spectrum Disorder in South Africa. Emotional well-being served as the target variable, while sensory sensitivity, parent–child attachment, and social competence were entered as predictor variables. Data were collected using standardized caregiver-report instruments with established psychometric properties. After preliminary data screening and preprocessing, the dataset was randomly divided into training and testing subsets using an 80:20 ratio. A LightGBM algorithm was implemented to develop the predictive model, and hyperparameter optimization was performed through five-fold cross-validation. Model performance was evaluated using the coefficient of determination (R^2), root mean square error (RMSE), mean absolute error (MAE), and mean squared error (MSE). Feature importance analysis and Shapley Additive Explanations (SHAP) were employed to determine the relative contribution and direction of influence of each predictor variable. The LightGBM model demonstrated strong predictive performance, explaining 82.1% of the variance in emotional well-being within the testing dataset ($R^2 = 0.821$). Correlation analyses revealed significant positive associations between emotional well-being and both parent–child attachment ($r = 0.68, p < .01$) and social competence ($r = 0.74, p < .01$), whereas sensory sensitivity was significantly negatively associated with emotional well-being ($r = -0.61, p < .01$). Feature importance analysis indicated that social competence was the most influential predictor (39.8%), followed by parent–child attachment (33.3%) and sensory sensitivity (26.9%). SHAP analyses confirmed these findings, demonstrating that higher levels of social competence and stronger parent–child

attachment increased predicted emotional well-being, whereas elevated sensory sensitivity reduced emotional well-being predictions. The findings indicate that emotional well-being among children with ASD is strongly shaped by social, relational, and sensory factors. Social competence emerged as the most influential predictor, highlighting the importance of adaptive social functioning for positive emotional outcomes. Secure parent–child attachment also contributed substantially to emotional well-being, while sensory sensitivity functioned as a significant risk factor. The high predictive accuracy of the LightGBM model demonstrates the value of machine learning approaches for identifying key determinants of emotional well-being and supports the development of targeted interventions focusing on social skills enhancement, family relationships, and sensory regulation to improve psychological outcomes among children with ASD.

Keywords: *Autism Spectrum Disorder; Emotional Well-Being; LightGBM; Machine Learning; Sensory Sensitivity; Parent–Child Attachment; Social Competence*

1. Introduction

Autism Spectrum Disorder (ASD) is a complex neurodevelopmental condition characterized by persistent differences in social communication and interaction, accompanied by restricted, repetitive patterns of behavior, interests, and sensory experiences. Recent conceptualizations emphasize that autism should not be viewed solely through a deficit-oriented lens but rather as a multidimensional developmental condition involving unique cognitive, emotional, sensory, and interpersonal profiles that shape children's adaptation and quality of life across contexts (Chen, 2023; Greaves-Lord et al., 2022; Hirota & King, 2023). The prevalence of ASD has increased substantially during recent decades, resulting in greater attention to the factors that contribute to psychological adjustment, emotional functioning, and long-term well-being among affected children. Contemporary clinical and developmental frameworks increasingly recognize emotional well-being as a critical outcome because it reflects children's ability to experience positive emotions, regulate distress, establish meaningful relationships, and maintain adaptive functioning despite developmental challenges (Abualait et al., 2024; Marukyan, 2023; Zotti et al., 2025). Although significant advances have been made in understanding the diagnostic and behavioral characteristics of ASD, researchers continue to emphasize the need for a deeper understanding of the psychosocial and sensory mechanisms that influence emotional well-being and resilience throughout childhood (Bach & Vestergaard, 2023; Cheney et al., 2023; Neu & Bradford, 2025).

Emotional well-being in children with ASD is increasingly recognized as a multidimensional construct encompassing positive affect, emotional regulation, psychological security, life satisfaction, adaptive coping, and social connectedness. Many children with ASD

experience elevated levels of emotional difficulties, including anxiety, emotional dysregulation, frustration, loneliness, and reduced subjective well-being relative to their neurotypical peers. These challenges often emerge from the interaction between neurodevelopmental differences and environmental demands rather than from autism itself (Labarca et al., 2025; Lei et al., 2024; Zotti et al., 2025). Research has demonstrated that emotional outcomes among autistic children vary considerably, suggesting that specific protective and risk factors influence individual trajectories of adjustment. Consequently, identifying the determinants of emotional well-being has become a major priority within autism research because positive emotional functioning is associated with improved social participation, academic adaptation, family relationships, and long-term quality of life (Alhammashi et al., 2024; Costa-Cordella et al., 2023; Romeo, 2025).

Among the factors that have attracted substantial attention, sensory sensitivity has emerged as one of the most distinctive and clinically relevant characteristics of ASD. Sensory processing differences involve atypical responses to environmental stimuli, including hypersensitivity or hyposensitivity to auditory, visual, tactile, olfactory, vestibular, and proprioceptive inputs. Current diagnostic frameworks recognize sensory processing abnormalities as a core feature of autism, reflecting their pervasive influence on daily functioning and psychological adjustment (Greaves-Lord et al., 2022; Hirota & King, 2023). Studies have consistently shown that children with ASD frequently experience sensory overload, discomfort, and difficulty integrating sensory information, which may contribute to heightened stress, emotional distress, behavioral dysregulation, and reduced participation in social environments (Filipova et al., 2023; Ghosh et al., 2022; Trudel et al., 2022). Sensory challenges can affect virtually

every aspect of a child's life, including school participation, communication, sleep quality, emotional regulation, and interpersonal interactions (Johnson et al., 2023; Lawson et al., 2022; Savarese et al., 2025).

Emerging evidence suggests that sensory processing characteristics may serve as powerful predictors of emotional functioning. Children who experience heightened sensory sensitivity often encounter chronic environmental stressors that increase vulnerability to anxiety, frustration, avoidance behaviors, and diminished psychological well-being. Conversely, effective management of sensory experiences has been associated with improved adaptation and emotional outcomes (Nimbley et al., 2022; Pride et al., 2023; Suprunowicz et al., 2025). Research has further demonstrated significant associations between sensory processing patterns and social functioning, indicating that sensory difficulties may indirectly affect emotional well-being through their impact on social engagement and relationship formation (Fotoglou et al., 2023; Zhai et al., 2023). Neuroplasticity-oriented approaches have additionally highlighted the possibility that interventions targeting sensory processing may improve broader developmental outcomes, including emotional adjustment and quality of life (Savarese et al., 2025; Suprunowicz et al., 2025). Despite these advances, the relative contribution of sensory sensitivity to emotional well-being remains insufficiently understood, particularly when examined alongside relational and social variables within integrated predictive models.

Another factor that may play a fundamental role in emotional well-being among children with ASD is parent-child attachment. Attachment theory proposes that secure relationships with caregivers provide children with a foundation for emotional regulation, psychological security, social exploration, and resilience in the face of stress. Although attachment processes were initially developed within the context of typically developing populations, increasing evidence suggests that attachment relationships remain critically important for autistic children (Costa-Cordella et al., 2023; Romeo, 2025). Secure attachment relationships can facilitate emotional understanding, enhance self-regulation capacities, and promote adaptive coping with environmental challenges. In contrast, disruptions in attachment security may increase vulnerability to emotional difficulties, social withdrawal, and psychological distress (Alhammashi et al., 2024; Sideraki & Drigas, 2022).

Recent investigations have emphasized the importance of family dynamics and caregiver responsiveness in shaping emotional and social adaptation among children with ASD. Parents often serve as primary sources of emotional support and environmental regulation, particularly when children experience difficulties navigating social or sensory demands. Studies examining mindful parenting, family relationships, and reflective functioning have shown significant associations between positive parent-child interactions and emotional-social adaptation in autistic children (Alhammashi et al., 2024). Furthermore, mentalization-based and attachment-informed interventions have demonstrated promising outcomes in enhancing emotional understanding, interpersonal functioning, and psychological adjustment among children with ASD (Costa-Cordella et al., 2023). Theoretical perspectives increasingly suggest that attachment security may function as a protective mechanism that buffers the emotional consequences of sensory stressors and social challenges, thereby contributing directly and indirectly to emotional well-being (Romeo, 2025; Sideraki & Drigas, 2022).

Social competence represents a third factor that may substantially influence emotional well-being among autistic children. Social competence refers to the capacity to engage effectively in social interactions, understand social cues, establish relationships, communicate appropriately, and adapt behavior to varying interpersonal contexts. Difficulties in social communication and interaction are central characteristics of ASD, often contributing to social isolation, peer rejection, loneliness, and reduced opportunities for positive social experiences (Chen, 2023; Lei et al., 2024). However, considerable heterogeneity exists within autistic populations, and many children develop meaningful social skills and relationships that support psychological adjustment and emotional health. Consequently, social competence has emerged as an important indicator of adaptive functioning and quality of life in ASD (Fotoglou et al., 2023; Zhai et al., 2023).

A growing body of literature indicates that social competence is closely associated with emotional well-being. Children who possess stronger social skills are more likely to experience social inclusion, friendship quality, self-confidence, and emotional support from peers and caregivers. These experiences contribute to positive emotional states and may reduce the likelihood of anxiety, depression, and social withdrawal (Alhammashi et al., 2024; Lei et al., 2024). Furthermore, social competence appears to interact with sensory and attachment-related processes.

Sensory processing differences may affect children's ability to participate comfortably in social environments, while secure attachment relationships can facilitate the development of social understanding and interpersonal confidence (Costa-Cordella et al., 2023; Zhai et al., 2023). Such findings suggest that emotional well-being may be best understood through a multidimensional framework that simultaneously considers sensory, relational, and social influences.

Additional evidence supporting the importance of emotional well-being in ASD can be observed across diverse domains of functioning. Research examining feeding behaviors, food selectivity, and eating-related challenges has demonstrated that sensory and emotional factors significantly influence daily adaptation among autistic children (Ferrara et al., 2025; Kozak et al., 2023; Nibley et al., 2022). Studies investigating pain communication, trauma assessment, self-harming behaviors, and functional somatic symptoms similarly reveal the intricate relationships among sensory experiences, emotional regulation, and psychological well-being (Johnson et al., 2023; Labarca et al., 2025; Michna et al., 2022; Zotti et al., 2025). Furthermore, emerging intervention research involving music therapy, dance-based programs, sensory-motor training, and neuroplasticity-focused approaches highlights the potential for targeted interventions to improve emotional and developmental outcomes by addressing underlying sensory and social processes (Li et al., 2023; Makhetai, 2024; Savarese et al., 2025; Suprunowicz et al., 2025). These findings collectively support the notion that emotional well-being is shaped by interconnected developmental systems rather than isolated psychological characteristics.

Although previous studies have identified meaningful associations among sensory processing, attachment relationships, social competence, and emotional adjustment, several limitations remain within the existing literature. Most investigations have relied on traditional statistical approaches that assume linear relationships and may not adequately capture the complex interactions among developmental variables. Emotional well-being in ASD is likely influenced by nonlinear pathways involving multiple interacting predictors, making conventional analytic methods potentially insufficient for uncovering nuanced predictive patterns (Lei et al., 2024; Zhai et al., 2023). Recent developments in artificial intelligence and machine learning offer new opportunities to address these limitations. Machine learning algorithms can process high-dimensional data, detect nonlinear relationships, identify complex

interactions, and generate highly accurate predictive models. Such approaches have become increasingly valuable in psychological and developmental research because they provide both predictive precision and practical insights for intervention planning.

Among machine learning techniques, Light Gradient Boosting Machine (LightGBM) has emerged as a particularly powerful algorithm due to its efficiency, scalability, and ability to handle complex nonlinear relationships. LightGBM can identify the relative importance of predictors while maintaining strong predictive performance, making it well suited for investigating emotional well-being among children with ASD. By integrating sensory sensitivity, parent-child attachment, and social competence within a single predictive framework, it becomes possible to determine not only whether these variables are associated with emotional well-being but also which factors contribute most strongly to individual differences in psychological adjustment. Such knowledge may inform assessment practices, intervention design, and family-centered support programs aimed at promoting positive developmental outcomes among autistic children (Ferrara et al., 2023; Ferrera-Fernández et al., 2025; Neu & Bradford, 2025).

Therefore, the aim of the present study was to examine the predictive contributions of sensory sensitivity, parent-child attachment, and social competence to emotional well-being in children with Autism Spectrum Disorder using a LightGBM machine learning model.

2. Methods and Materials

2.1. Study Design and Participants

This study employed a cross-sectional predictive modeling design to investigate the extent to which sensory sensitivity, parent-child attachment, and social competence contribute to the prediction of emotional well-being among children diagnosed with Autism Spectrum Disorder (ASD). The research was conducted in South Africa between January and September 2025 and was grounded in a machine learning framework utilizing the Light Gradient Boosting Machine (LightGBM) algorithm. This design was selected because of its capacity to identify complex nonlinear relationships and interaction effects among psychological and developmental variables that may not be adequately captured through conventional statistical techniques.

The study population consisted of children with a confirmed diagnosis of Autism Spectrum Disorder who were

enrolled in specialized educational centers, autism intervention clinics, and developmental support programs across the provinces of Gauteng, Western Cape, and KwaZulu-Natal. Participants were recruited through collaboration with educational psychologists, pediatric developmental specialists, and autism support organizations. Eligibility criteria included a formal ASD diagnosis based on the criteria of the Diagnostic and Statistical Manual of Mental Disorders, Fifth Edition (DSM-5), an age range between 7 and 12 years, and the ability of parents or primary caregivers to provide informed consent and complete study questionnaires. Children with severe intellectual disability that prevented meaningful participation in routine educational and social activities or those with significant neurological disorders unrelated to ASD were excluded from the study. A total of 428 children met the inclusion criteria and participated in the research. The sample included both boys and girls representing diverse socioeconomic and cultural backgrounds.

2.2. Measures

Emotional well-being was assessed using the Emotional Well-Being Scale for Children developed by Stirling (2015). This instrument was designed to evaluate positive emotional functioning, psychological adjustment, life satisfaction, emotional resilience, and overall subjective well-being in children and adolescents. The scale consists of 20 items rated on a five-point Likert continuum ranging from strongly disagree to strongly agree. Higher scores indicate greater levels of emotional well-being. Previous psychometric evaluations have demonstrated satisfactory internal consistency, construct validity, and convergent validity across diverse child populations. The instrument has been widely used in developmental and educational research, and its reliability has consistently exceeded the recommended threshold of .80 in previous studies.

Sensory sensitivity was measured using the Short Sensory Profile Second Edition (SSP-2) developed by Dunn (2014). The SSP-2 is a standardized caregiver-report instrument designed to assess patterns of sensory processing in children. The measure contains 34 items organized into domains reflecting auditory, visual, tactile, movement, and multisensory processing characteristics. Respondents rate the frequency of sensory-related behaviors on a five-point scale ranging from almost never to almost always. Higher scores reflect greater sensory sensitivity and atypical sensory processing experiences. The SSP-2 has demonstrated strong

psychometric properties, including excellent internal consistency coefficients, test-retest reliability, and construct validity across clinical and developmental populations, particularly among children with Autism Spectrum Disorder.

Parent-child attachment was assessed using the Parent Attachment Scale derived from the Inventory of Parent and Peer Attachment developed by Armsden and Greenberg (1987). This instrument evaluates the quality of emotional bonds between children and their parents through dimensions such as trust, communication, emotional closeness, and feelings of security. The scale consists of 25 items rated on a five-point Likert format ranging from almost never true to almost always true. Higher scores indicate stronger and more secure attachment relationships. Extensive research has supported the scale's factorial validity, internal consistency, and predictive validity across diverse cultural settings. Previous studies have also demonstrated its suitability for children with developmental differences and special educational needs.

Social competence was measured using the Social Skills Improvement System Rating Scales (SSIS-RS) developed by Gresham and Elliott (2008). This widely used assessment tool evaluates social functioning across several domains, including communication, cooperation, empathy, engagement, responsibility, and self-control. The parent-report version employed in the present study contains 46 items scored on a four-point Likert scale ranging from never to almost always. Higher scores indicate stronger social competence and adaptive social functioning. The SSIS-RS has demonstrated excellent psychometric characteristics, including high internal consistency coefficients, robust construct validity, and strong predictive utility in educational and clinical settings. Previous investigations involving children with Autism Spectrum Disorder have confirmed its effectiveness in measuring social strengths and difficulties.

All questionnaires were completed by parents or primary caregivers who had regular daily contact with the child. Data collection was conducted through both paper-and-pencil and secure electronic survey formats. Prior to analysis, the collected data were screened for missing values, response inconsistencies, and outliers. Cases with excessive missing data were excluded, while limited missing values were addressed using appropriate imputation procedures to preserve statistical integrity.

2.3. Data Analysis

Data analysis was performed using Python programming language and specialized machine learning libraries, including LightGBM, Scikit-learn, NumPy, and Pandas. Initially, descriptive statistics were calculated to summarize participant characteristics and study variables. Means, standard deviations, skewness, and kurtosis values were examined to evaluate data distribution and quality. Correlation analyses were also conducted to provide preliminary insights into relationships among emotional well-being, sensory sensitivity, parent–child attachment, and social competence.

The primary analytical approach involved the implementation of the Light Gradient Boosting Machine (LightGBM), an advanced ensemble machine learning algorithm based on gradient boosting decision trees. LightGBM was selected because of its computational efficiency, ability to handle high-dimensional data, robustness against multicollinearity, and capacity to model complex nonlinear associations among predictors. Emotional well-being served as the target variable, while sensory sensitivity, parent–child attachment, and social competence were entered as predictor variables.

Prior to model development, the dataset was randomly divided into training and testing subsets using an 80:20 ratio. Hyperparameter optimization was performed through grid search procedures combined with five-fold cross-validation to identify the optimal model configuration. Model performance was evaluated using multiple indices, including the coefficient of determination (R^2), root mean square error (RMSE), mean absolute error (MAE), and mean squared error (MSE). To enhance interpretability, feature importance

analysis was conducted using gain-based importance metrics generated by the LightGBM algorithm. In addition, Shapley Additive Explanations (SHAP) values were calculated to provide a detailed understanding of the relative contribution and direction of influence of each predictor variable on emotional well-being outcomes.

The significance and predictive utility of the final model were determined by comparing observed and predicted emotional well-being scores within the testing dataset. The combination of machine learning prediction accuracy and explainable artificial intelligence techniques enabled a comprehensive examination of the factors contributing to emotional well-being among children with Autism Spectrum Disorder and provided a robust framework for identifying the most influential psychosocial and sensory determinants.

3. Findings and Results

The final sample consisted of 428 children diagnosed with Autism Spectrum Disorder (ASD). Among the participants, 297 children (69.4%) were male and 131 (30.6%) were female. The mean age of the participants was 9.41 years ($SD = 1.72$), with ages ranging from 7 to 12 years. Most participants were enrolled in specialized educational programs (58.2%), while the remainder attended inclusive educational settings with specialized support services (41.8%). Regarding ASD severity levels, 38.8% were classified as Level 1, 44.6% as Level 2, and 16.6% as Level 3 according to DSM-5 diagnostic criteria. No significant differences were observed between demographic subgroups regarding data completeness or participation rates, indicating adequate representativeness of the sample.

Table 1

Descriptive Statistics and Correlations Among Study Variables

Variable	Mean	SD	1	2	3	4
1. Emotional Well-Being	67.84	12.91	—			
2. Sensory Sensitivity	89.17	15.42	-0.61**	—		
3. Parent–Child Attachment	84.36	13.25	0.68**	-0.39**	—	
4. Social Competence	73.48	14.67	0.74**	-0.47**	0.58**	—

Table 1 presents the descriptive statistics and Pearson correlation coefficients among the study variables. Emotional well-being demonstrated a moderate to high average score ($M = 67.84$, $SD = 12.91$). Sensory sensitivity showed a substantial negative association with emotional well-being ($r = -0.61$, $p < .01$), indicating that children who

experienced greater sensory processing difficulties tended to report lower levels of emotional well-being. Parent–child attachment exhibited a strong positive correlation with emotional well-being ($r = 0.68$, $p < .01$), suggesting that secure and supportive parent–child relationships are associated with more favorable emotional outcomes. Social

competence demonstrated the strongest bivariate relationship with emotional well-being ($r = 0.74, p < .01$), highlighting the importance of adaptive social functioning in promoting psychological adjustment among children with

ASD. Significant intercorrelations were also observed among the predictor variables, although none exceeded levels typically associated with problematic multicollinearity.

Table 2

Performance Metrics of the LightGBM Prediction Model

Performance Metric	Training Set	Testing Set
R ²	0.893	0.821
RMSE	4.27	5.91
MAE	3.12	4.43
MSE	18.23	34.93
Explained Variance	0.896	0.824

The predictive performance of the LightGBM model is presented in Table 2. The model demonstrated excellent predictive accuracy across both training and testing datasets. On the testing dataset, the model accounted for 82.1% of the variance in emotional well-being scores ($R^2 = 0.821$), indicating substantial explanatory power. The RMSE value of 5.91 and MAE value of 4.43 suggest relatively low prediction error and strong generalization performance.

Comparison of training and testing metrics revealed only a modest reduction in predictive accuracy, indicating minimal overfitting and supporting the robustness of the final model. These findings demonstrate that the selected psychosocial and sensory predictors collectively provide a highly accurate prediction of emotional well-being among children with ASD.

Table 3

LightGBM Feature Importance Rankings

Predictor Variable	Gain Importance	Relative Importance (%)
Social Competence	842.16	39.8
Parent–Child Attachment	704.81	33.3
Sensory Sensitivity	568.37	26.9
Total	2115.34	100.0

Table 3 presents the feature importance results generated by the LightGBM algorithm. Social competence emerged as the most influential predictor, accounting for 39.8% of the total model importance. This finding indicates that children's ability to engage effectively in social interactions, demonstrate communication skills, and maintain adaptive peer relationships played the greatest role in predicting emotional well-being outcomes. Parent–child attachment ranked as the second most important predictor, contributing 33.3% of total predictive power. This result highlights the

significance of secure emotional bonds and supportive family relationships in fostering positive emotional adjustment among children with ASD. Sensory sensitivity accounted for 26.9% of model importance and remained a substantial predictor despite contributing less variance than the social and relational factors. Collectively, these findings suggest that although sensory processing challenges are important determinants of emotional functioning, social competence and attachment-related processes may exert even stronger influences on emotional well-being.

Table 4

SHAP Summary Statistics for Predictor Contributions

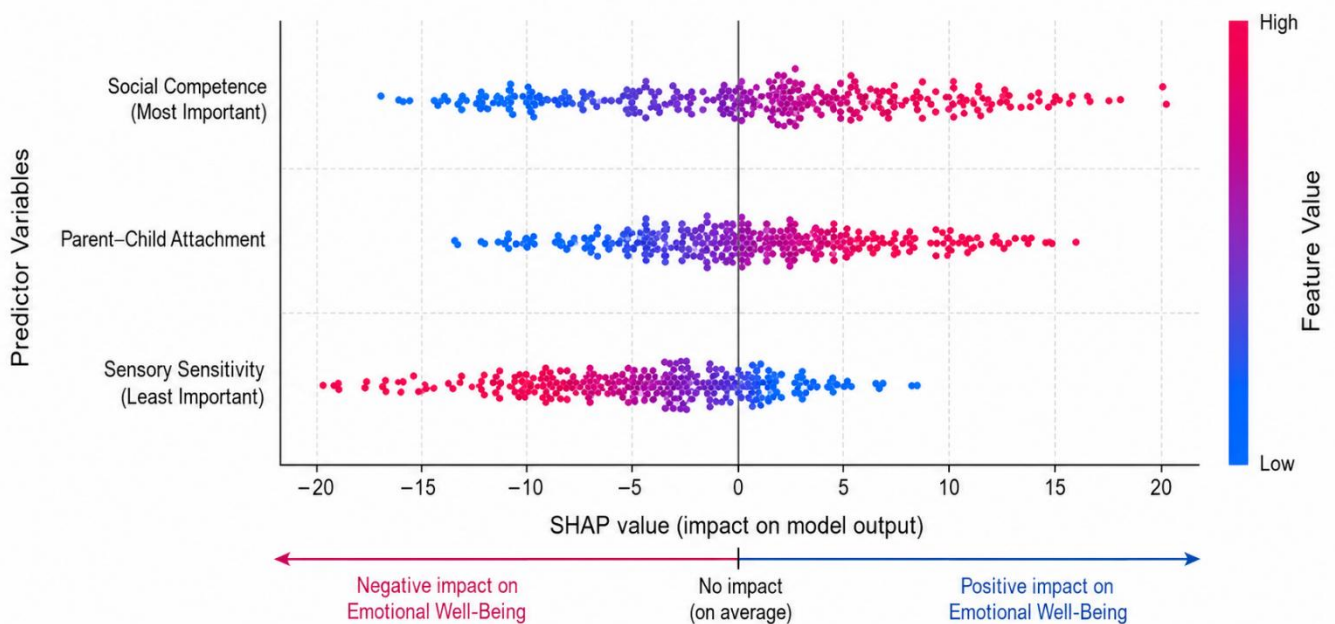
Predictor Variable	Mean Absolute SHAP Value	Rank
Social Competence	7.24	1
Parent–Child Attachment	6.18	2
Sensory Sensitivity	5.37	3

The SHAP analysis results reported in Table 4 further clarified the contribution of each predictor to individual predictions generated by the LightGBM model. Consistent with the feature importance findings, social competence displayed the highest mean absolute SHAP value (7.24), indicating the greatest average influence on predicted emotional well-being scores. Parent-child attachment followed with a mean SHAP value of 6.18, while sensory sensitivity demonstrated a mean SHAP value of 5.37.

Examination of individual SHAP distributions revealed that higher levels of social competence and stronger parent-child attachment consistently increased predicted emotional well-being, whereas elevated sensory sensitivity generally reduced predicted emotional well-being. The consistency between SHAP results and gain-based feature importance analyses provides strong evidence for the stability and interpretability of the predictive model.

Figure 1

SHAP Summary Plot Illustrating the Direction and Magnitude of Predictor Effects on Emotional Well-Being



The SHAP summary plot provided a detailed visualization of the influence of predictor variables across all observations. The figure demonstrated that higher social competence scores were consistently associated with positive SHAP values and increased emotional well-being predictions. Similarly, stronger parent-child attachment scores shifted predictions toward higher levels of emotional well-being, reflecting the protective role of secure relational bonds. In contrast, elevated sensory sensitivity scores generated predominantly negative SHAP values, indicating a substantial adverse effect on emotional well-being. The dispersion of SHAP values further revealed that social competence exhibited the widest range of influence across participants, suggesting considerable variability in its impact among children with ASD. Parent-child attachment showed a similarly robust but slightly less variable pattern, whereas sensory sensitivity demonstrated a more consistent negative influence. Overall, the SHAP visualization confirmed that

social competence represented the most powerful positive predictor, followed by parent-child attachment, while sensory sensitivity functioned as the primary risk factor associated with poorer emotional well-being outcomes. The convergence of findings across correlation analyses, model performance indices, feature importance rankings, and SHAP interpretability procedures provides strong support for the reliability and validity of the LightGBM model in predicting emotional well-being among children with Autism Spectrum Disorder.

4. Discussion

The present study examined the predictive contributions of sensory sensitivity, parent-child attachment, and social competence to emotional well-being among children with Autism Spectrum Disorder (ASD) using a Light Gradient Boosting Machine (LightGBM) model. The findings

demonstrated that the machine learning model achieved a high level of predictive accuracy, explaining more than 82% of the variance in emotional well-being. Furthermore, social competence emerged as the strongest predictor of emotional well-being, followed by parent–child attachment and sensory sensitivity. Correlational analyses revealed that social competence and parent–child attachment were positively associated with emotional well-being, whereas sensory sensitivity demonstrated a substantial negative relationship with emotional well-being. The SHAP analyses further confirmed the relative importance of these variables and illustrated the direction of their effects on emotional outcomes. Collectively, these findings suggest that emotional well-being in children with ASD is influenced by an interconnected network of social, relational, and sensory factors and that machine learning approaches can effectively model these complex relationships.

One of the most important findings of the present study was the strong predictive role of social competence. Social competence emerged as the most influential variable within the LightGBM model and demonstrated the strongest positive association with emotional well-being. This finding suggests that children with ASD who possess stronger communication abilities, greater interpersonal effectiveness, enhanced cooperation, and more adaptive social engagement are more likely to experience positive emotional functioning. These results are consistent with previous studies indicating that social functioning is closely connected to psychological adjustment and quality of life among autistic individuals. Difficulties in social communication often contribute to loneliness, peer rejection, reduced social participation, and emotional distress, whereas successful social interactions may foster self-confidence, belongingness, and emotional security (Chen, 2023; Lei et al., 2024). The present findings are particularly consistent with evidence showing that social interaction abilities can predict broader developmental outcomes among children with ASD and that stronger social functioning is associated with improved emotional adaptation (Fotoglou et al., 2023; Zhai et al., 2023).

The prominence of social competence within the predictive model may be understood from developmental and ecological perspectives. Social interactions provide opportunities for emotional expression, emotional regulation, and reciprocal support. Children who successfully navigate social situations receive more positive feedback from peers, teachers, and family members, which can reinforce positive self-perceptions and emotional resilience. Conversely, deficits in social competence may

increase vulnerability to social exclusion, misunderstanding, and chronic stress. Research investigating social anxiety and emotional functioning among autistic individuals has demonstrated that social difficulties frequently contribute to emotional distress and reduced well-being (Lei et al., 2024). Therefore, the strong contribution of social competence observed in the present study is theoretically and empirically consistent with contemporary developmental models emphasizing the central role of interpersonal functioning in emotional health.

The findings also revealed that parent–child attachment was a powerful positive predictor of emotional well-being. Children who experienced stronger attachment relationships with their parents exhibited significantly higher levels of emotional well-being. This finding aligns closely with attachment theory, which posits that secure attachment relationships provide children with emotional security, confidence, and effective strategies for coping with stress. Within the context of ASD, parents often serve as primary regulators of environmental demands, emotional experiences, and social learning opportunities. Consequently, secure parent–child relationships may be especially important for promoting positive emotional outcomes among autistic children (Costa-Cordella et al., 2023; Romeo, 2025).

The present findings support previous research demonstrating significant associations between family functioning, caregiver responsiveness, and emotional-social adaptation in children with ASD. Alhammashi and colleagues reported that mindful parenting, positive family relationships, and parental reflective functioning contribute substantially to children's social and emotional adaptation (Alhammashi et al., 2024). Similarly, mentalization-based and attachment-oriented approaches have emphasized the importance of secure emotional bonds in promoting self-regulation, emotional understanding, and interpersonal functioning among autistic children (Costa-Cordella et al., 2023). The results of the current study extend this literature by demonstrating that attachment remains highly influential even when considered simultaneously with sensory sensitivity and social competence within a sophisticated machine learning framework. The SHAP analysis further suggested that increases in attachment security consistently enhanced predicted emotional well-being, highlighting its protective role across the sample.

Another significant finding was the negative predictive effect of sensory sensitivity on emotional well-being. Children exhibiting greater sensory sensitivity tended to

report lower levels of emotional well-being, and sensory sensitivity accounted for a substantial proportion of the model's predictive power. This finding is consistent with a growing body of literature indicating that atypical sensory processing represents one of the most pervasive challenges experienced by autistic individuals. Sensory hypersensitivity can expose children to chronic environmental stress, discomfort, sensory overload, and difficulties participating in everyday activities, all of which may negatively affect emotional functioning (Filipova et al., 2023; Ghosh et al., 2022; Trudel et al., 2022).

The negative association observed in the present study is supported by research demonstrating that sensory processing difficulties influence emotional regulation, behavioral adaptation, sleep quality, and social participation. Lawson and colleagues found that sensory-related interventions targeting sleep problems could improve daily functioning among autistic children, suggesting that sensory experiences are closely linked to emotional outcomes (Lawson et al., 2022). Similarly, studies examining eating behaviors and food selectivity have shown that sensory sensitivities can create persistent challenges that contribute to stress and reduced quality of life (Ferrara et al., 2025; Kozak et al., 2023; Nibley et al., 2022). The present findings further support evidence indicating that sensory characteristics are associated with social interaction abilities and may influence emotional well-being both directly and indirectly through their impact on social functioning (Zhai et al., 2023).

The current results may also be interpreted within emerging neuroplasticity and sensory integration frameworks. Contemporary theories propose that atypical sensory processing affects how autistic children perceive, interpret, and respond to environmental stimuli. Persistent sensory overload may lead to heightened physiological arousal, increased anxiety, emotional exhaustion, and avoidance behaviors. Over time, these experiences can undermine emotional well-being and adaptive functioning. Recent work emphasizing neuroplasticity-based approaches suggests that interventions targeting sensory processing may produce broader improvements in emotional and developmental outcomes (Suprunowicz et al., 2025). Similarly, sensorimotor interventions have demonstrated promising effects on sensory and behavioral functioning among children with ASD (Savarese et al., 2025). The present findings reinforce the importance of considering sensory experiences as a central component of emotional well-being rather than merely a secondary characteristic of autism.

An additional contribution of this study lies in the successful application of LightGBM for predicting emotional well-being. Traditional statistical methods often focus on linear associations and may not adequately capture complex interactions among developmental variables. In contrast, the machine learning model achieved excellent predictive performance and identified meaningful hierarchical relationships among predictors. The relatively high explanatory power of the model suggests that emotional well-being in ASD is strongly influenced by the combined effects of social competence, attachment security, and sensory processing characteristics. The consistency observed across correlation analyses, feature importance metrics, and SHAP explanations further supports the robustness and interpretability of the model.

The findings also contribute to a broader understanding of emotional well-being within ASD by integrating perspectives from developmental psychology, attachment theory, sensory integration research, and social adaptation frameworks. Previous studies have highlighted the importance of addressing emotional difficulties in autistic populations because emotional distress can increase vulnerability to anxiety disorders, self-harming behaviors, trauma-related difficulties, and broader psychosocial challenges (Labarca et al., 2025; Michna et al., 2022). Research examining pain communication, functional somatic symptoms, and complex psychosocial presentations similarly emphasizes the importance of considering emotional functioning as a central outcome in autism-related care (Johnson et al., 2023; Zotti et al., 2025). The present study demonstrates that emotional well-being is not determined by a single factor but rather emerges from interactions among sensory experiences, family relationships, and social competencies.

Furthermore, these findings align with intervention studies suggesting that developmental outcomes can be enhanced through programs targeting social participation, sensory functioning, and emotional support. Music-based interventions have demonstrated benefits for perceptual and adaptive abilities among autistic children (Li et al., 2023). Dance-based therapeutic approaches have shown promise for improving psychosocial functioning and emotional expression (Makheti, 2024). Family-centered interventions and attachment-oriented programs have similarly been associated with improved emotional and social outcomes (Alhammashi et al., 2024; Costa-Cordella et al., 2023). The strong predictive contributions identified in the present study suggest that interventions addressing these domains

simultaneously may be particularly effective in promoting emotional well-being.

5. Conclusion

Overall, the findings indicate that emotional well-being among children with ASD is strongly associated with their capacity to engage successfully in social relationships, maintain secure attachment bonds with caregivers, and manage sensory experiences effectively. While sensory sensitivity represents an important risk factor, social competence and parent–child attachment appear to function as particularly powerful protective factors. The results underscore the value of multidimensional conceptualizations of emotional well-being and highlight the potential of machine learning methodologies for advancing understanding of developmental processes in autism.

Several limitations should be considered when interpreting the findings of this study. First, the cross-sectional design precludes conclusions regarding causality among the study variables. Although the machine learning model identified strong predictive relationships, it cannot determine the temporal direction of effects. Second, the study relied primarily on parent-reported measures, which may introduce reporting bias and shared method variance. Third, the sample was recruited from specific regions of South Africa, which may limit the generalizability of the findings to other cultural or geographical contexts. Fourth, emotional well-being is a complex construct that may be influenced by additional factors not included in the present model, such as cognitive functioning, educational experiences, socioeconomic status, peer relationships, and co-occurring mental health conditions. Finally, although the LightGBM model demonstrated strong predictive accuracy, machine learning results remain dependent on the characteristics of the available dataset and should be validated using independent samples.

Future studies should employ longitudinal designs to examine developmental pathways linking sensory sensitivity, attachment, social competence, and emotional well-being over time. Researchers may also investigate additional predictors, including executive functioning, emotional regulation, school climate, peer acceptance, family stress, and adaptive behavior. Comparative studies involving different age groups and cultural contexts would provide greater insight into the universality and variability of these relationships. Future investigations could further explore interactions among predictors and examine potential

mediating and moderating mechanisms. The use of multimodal assessment approaches incorporating behavioral observations, physiological indicators, and clinician ratings may also strengthen future research. Additionally, comparing different machine learning algorithms and explainable artificial intelligence techniques may improve understanding of predictive processes and contribute to more personalized intervention planning.

The findings suggest that practitioners should prioritize interventions that strengthen social competence, enhance parent–child relationships, and address sensory processing challenges simultaneously. Educational and clinical programs should include structured opportunities for social skills development, peer interaction, and communication training. Family-centered approaches that promote parental responsiveness, emotional support, and positive attachment relationships may contribute substantially to children's emotional well-being. Schools and service providers should also implement sensory-friendly environments and individualized sensory supports to reduce stress and improve daily functioning. Multidisciplinary collaboration among psychologists, occupational therapists, educators, speech-language therapists, and families may be particularly beneficial in addressing the interconnected factors influencing emotional well-being. Finally, the integration of predictive analytics and data-informed decision-making into clinical practice may help professionals identify children at greater risk for emotional difficulties and tailor interventions to individual needs.

Authors' Contributions

Authors equally contributed 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

The authors report no conflict 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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