A Novel Application for the Efficient and Accessible Diagnosis of ADHD Using Machine Learning (Extended Abstract)

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***Abstract*—Attention-deficit/hyperactivity disorder is the most pervasive neurodevelopmental disorder among children and adolescents. Current clinical diagnosis, however, is inaccurate, inefficient, and inaccessible in developing nations, hindering the administration of proper treatment regimens. Clinical assessments are based on qualitative observations of perceived behavior. They are time-consuming and costly, preventing minorities and socioeconomically disadvantaged groups from gaining the support they need to succeed academically, socially, and occupationally. A more accurate and accessible method of detection is necessary to ensure that all children are able to be diagnosed and given proper treatment regimens. This research proposes a novel machine learning-based method to analyze pupil-dynamics data as an objective biomarker to characterize ADHD. After visualizing and engineering pupillometric features, a voting ensemble classification algorithm and meta learner were developed and yielded the most optimal leave-one-out-cross-validation metrics on a declassified dataset. The ensemble model, in particular, classified ADHD with .821 sensitivity, 0.727 specificity, and 0.856 AUROC. This model was implemented in a web application that administers a memory task and captures pupil biometrics in real-time. This application is the first to use pupil-size dynamics as a biomarker, and offers a time-efficient, accurate, and accessible approach to diagnose ADHD in developing nations.**

***Index Terms*—SDG 3.8, ADHD, Pupillometry, Machine learning, Behavioral analysis, Medical prognostics, Medical diagnosis in developing nations.**

I. Introduction

EQUITABLE access to medical diagnosis is integral to achieve sustainable development goals in developing nations, where poverty and a lack of medical institutions create stark inequalities in the accessibility of diagnosis and treatment. Attention-deficit/hyperactivity disorder (ADHD) is the most pervasive neurodevelopmental disorder in the world, particularly in sub-Saharan Africa and Latin America: the prevalence rate, according to a 2007 sample study, is 8.5% and 11.8%, respectively, compared to a 9.2% prevalence rate in the U.S. [1]. Yet, despite the similar prevalence rates in the U.S. and developing nations, ADHD and similar neurobehavioral disorders remain widely underdiagnosed in the developing world as a result of both societal stigmas on youth neurological disorders [2] and deficient medical practices [3]. Chinawa et al. note the egregious neglection of ADHD in developing countries, notably Nigeria, where the reported prevalence rate is uncharacteristically low despite the high prevalence rate in neighboring developing nations [3]. Lower prevalence rates in rural areas of certain countries can be attributed to the inaccesibility of diagnostic services, precluding the administration of proper treatment regimens [4].

In developing nations, the underdiagnosis of ADHD diagnosis pushes poorer families further into poverty traps that mitigate many of the benefits of education, and consequently cause future generations to have poorer economic opportunities. Efficient diagnosis of this disorder, thus, is crucial to effectively administer treatments and prevent subsequent complications for a child's socioemotional development, academic and occupational achievement, and overall welfare.

A. Current Diagnosis

Current clinical diagnosis fails in developing nations for two reasons: it is inaccessible and inaccurate. There is no objective test to diagnose ADHD. Diagnosis is based solely on observed behavior and reported symptoms, creating a risk of over and under-diagnosis. Clinical tests cost between $800-2000 per screening, making diagnosis for ADHD inaccessible to a majority of the world, especially the population in developing nations [5]. These subjective clinical assessments often last multiple hours [5]. This inaccessibility, in conjunction with stigma surrounding mental disorders in developing nations, precludes proper diagnoses and treatments for youth. This in turn prevents youth from gaining the proper support to succeed academically, socially, and occupationally, creating a cycle of degradation.

A more accurate and accessible method of detection is necessary to ensure that all children, regardless of socioeconomic status, are able to be diagnosed and given proper treatment regimens. This would allow individuals across the world —

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especially those in developing nations with limited medical infrastructure — to be diagnosed and receive appropriate treatment, avoiding the social, lifestyle, and economic costs of such disorders.

B. Pupillometric Variation in ADHD

Due to the currently deficient methods for diagnosing ADHD, an objective and reliable mechanism to characterize the disorder is necessary in order to ensure accurate, timely, and cost-effective diagnoses in developing nations. Oculomotor paradigms are particularly adept in tracking maturational abnormalities in brains affected by neurodevelopmental disorders [6]. A promising biomarker specifically for ADHD in humans is pupil-size dynamics — the ways in which the pupil responds to certain visual stimuli [7]. Pupil-size dynamics have been shown to reflect the state of the brain norepinephrine (NE) system, which controls executive functioning [8] and is impaired by ADHD [7]. Geng et al. showed that pupil size reflects uncertainty in users who completed a visuospatial working memory task [9]. Wahn et al. further showed that pupil-size dynamics can be utilized as a reliable metric to assess attentional load in patients [10]. Given the vast literature highlighting correlations between pupillary responses and attentional performance, it was hypothesized that pupillometric features could be utilized as an objective biomarker to effectively characterize ADHD. We sought to develop a machine learning-based method to analyze pupillometric variation in subjects, hypothesizing that it would accurately reflect behavioral differences between ADHD positive patients and control subjects.

II. Dataset

A group of 50 subjects participated in an IRB-approved study [7]. 28 subjects were patients diagnosed with ADHD (4 girls, 24 boys), and 22 were healthy control patients (3 girls, 19 boys), recruited from local schools and ages ranging from 10-12 years. A subgroup of 17 ADHD patients performed the task twice, on and off medication. [11]

All subjects were required to complete a visuospatial working memory task which consisted of multiple 8 second trials, during which their pupil-sizes were measured. In the first five seconds, three dot arrays were presented, followed by a distractor image. In the last three seconds, subjects were presented with a random dot array and asked to determine if the dot had been presented to them previously in the first three images.

III. Methods

A. Feature Extraction

A number of pupillometric features were extracted in order to feed into the machine learning models. Each patient corresponded with 160 trials of time series data, which were averaged in order to produce a single encompassing time series. The maximum and minimum pupil size after stimulus presentation, standard deviation and variation of pupil size, as well as the max and mean pupil dilation velocity and acceleration before and after stimulus presentation, were engineered as features based on the aggregated time series. Fourier transform metrics, peak numbers, aggregated linear trends, and approximate entropy values were also engineered.

B. Machine Learning Algorithms

The following state-of-the-art binary classification algorithms were trained using the engineered features: Logistic Regression, KNN Neighbors, Random Forest Classifier, Naive Bayes, Decision Tree Classifier, Support Vector Machine and AdaBoost Classifier, as well as a Voting Ensemble model incorporating the Naive Bayes, Logistic regression, and Support Vector Machine models. Given the sparcity of data, leave-one-out-cross-validation (LOOCV) was employed to evaluate model performance. Univariate feature selection was employed to reduce the complexity and size of the feature space — this ensured that during each fold, the models were not overfitting the data due to an overcomplex and copious number of features.

C. Web-Based Application

In order to incorporate the optimal machine learning model, a web application was engineered as a novel diagnostic mechanism for ADHD. The optimal machine learning model was serialized into the backend of a web application that records pupil biometrics in real-time, returning an output of a probability of diagnosis, as well as medical advice. The web application simulates the visuospatial working memory task used in Wainstien et al.'s study.

1) Real-time Biometrics: The web application uses convolutional neural networks (CNNs) to detect the head and circle hough transform methods to segment the iris, followed by a custom ray tracing algorithm to measure the diameter of the pupil. It utilizes the built-in GPU on a mobile phone or computer, accessing JavaScript/WebGL based libraries to perform segmentation in real-time.

IV. Results

State-of-the-art machine learning algorithms were evaluated primarily based on several key binary classification metrics in a medical diagnosis setting: sensitivity, specificity, and AUROC. The Ensemble Voting Model achieved the optimal cross-validation classification metrics, with 0.821 sensitivity, 0.727 specificity, and 0.856 AUROC.

V. Discussion

A. Machine Learning Robustness

This study utilized a dataset of 50 instances — as such, LOOCV, a benchmark validation method, was applied to best assess the generalization ability of classifiers and ensure that sufficient training data was inputted into the models. To account for the sparcity in data, data augmentation techniques were also utilized, ensuring that as much training data was available to boost model performance. This ensured that a robust and applicable machine learning model could be utilized in the backend of an accessible web application.

The excellent AUROC and recall values indicate the strong binary classification ability of the ensemble model — 90% of affected individuals are correctly classified with ADHD, while the accuracy of the binary classifier at varying thresholds reaches 90%, indicating its overall strength in differentiating between ADHD positive and negative subjects. These metrics significantly outperform the current misdiagnosis rate reported to be around 20% [12], paving the path for a novel diagnostic method for one of the world's most commonly misdiagnosed and stigmatized disorders, specifically in developing nations.

B. Applications and Potential

The web application developed offers a novel and reliable technical approach to diagnose ADHD that is time-efficient, freely accessible, and reliant on an objective biomarker, rather than inaccurate subjective evaluations. This novel approach to diagnosing a widespread neurobehavioral disorder has the ability to allow children across the world to receive the help and support they need to reach their academic and occupational potential. Moreover, the eye tracking methodology innovated in this research can be implemented across different neurodevelopmental conditions, thereby democratizing access to screenings for other disorders that are often neglected in developing nations. After a preliminary round of IRB-approved clinical testing, the accuracy of this novel method far exceeds the clinical diagnosis rates of 80% — it is much more accurate, accessible, and cost-effective than the expensive, qualitative nature of clinical diagnosis.

The implications of this work in developing nations are significant. The expected prevalence of ADHD is nearly equivalent in sub-Saharan Africa and Southeast Asia, but the number diagnosed is far less than in the United States and other highly developed nations. In developing nations, the inacessibility of diagnosis, coupled with traditional stigma surrounding mental disorders, precludes proper diagnoses and treatments for youth. The Sustainable Development Goal 3.8 of the United Nation's 2030 Agenda for Sustainable Development affirms the importance of equitable medical diagnosis and support: "access to quality essential health-care services" in addition to "effective, quality, and affordable essential medicines" are vital to create a platform for developing nations to thrive in the medical sector and reach those who need it the most.

This research has the potential to catalyze equitable access to the medical diagnosis of ADHD, supplementing SDG 3.8 to improve the lives of those who have certain disorders and are neglected in developing nations. The application has proved through clinical trials to be effective and easily used without the support of a medical practioner, opening it's applicability to rural areas with few medical doctors. Through its accessibility and accuracy, the developed application's potential impacts in the developing world lie in breaking socioeconomic barriers surrounding ADHD and other neurobehavioral disorders that pervade the youth in nations across the world. Rather than going through lengthy clinical diagnosis procedures, patients can use this web-based application to test for the presence of ADHD, without the assistance of a clinician. This application has the ability to reach those who have unmet treatment needs for one of the most neglected disorders in the developing world by providing an accurate and efficient diagnosis. Transcending the boundaries of simple diagnostics, our software provides medical advice and future measures to take based on the probability of having ADHD. Its impacts are not strictly limited to the developing world, as this application provides a new foundation for institutions across the world to diagnose ADHD, reliant on the objective biomarker of pupil-size dynamics, rather than loose qualitative observations.

At the same time, this work also emphasizes the changing landscape and role of both the public and private sector on working towards making medical diagnosis accessible for a majority of the developing population. In a nation that lacks many medical institutions and experienced medical practitioners, automated diagnosis is likely the most relevant application of artificial intelligence to support populations and sustain growth.

VI. Conclusion

Through the development of a machine learning-based method to analyze pupillometrics from ADHD positive and negative subjects, this study culminated in the creation of a novel diagnostic test for ADHD. Using the developed model, a web application that captures pupil biometrics in real time during an administered memory task was developed. This diagnostic application feeds data into the optimal machine learning algorithm and outputs a probability of diagnosis, as well as medical advice. This novel method offers a time-efficient, accurate, and accessible technical approach to diagnose ADHD. Moreover, through its accessibility and accuracy, the application's potential impacts in the developing world lie in breaking socioeconomic barriers surrounding ADHD and other neurobehavioral/neurodevelopmental disorders that pervade the youth in nations across the world. Our research paves a new path for engineering public policy geared towards the youth by also emphasizing the importance of furthering research and policies to improve stigma and medical practices regarding neurobehavioral disorders. If governments across the world focus on addressing these mental disorders that impair an individual's ability to succeed in the workforce, members of the younger generation can be included in the economy in an unprecedented way. Our research serves as the stepping stone for implementing these policies.

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