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A Machine Learning Approach for Scalable Early-Age Dyslexia Detection Correlating Phonological Speech Analysis and Eyeball Tracking

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Abstract – Dyslexia concerns a persistent and unexpected difficulty in developing age and experience appropriate word reading skills, which encompasses proficiency in accuracy and efficiency. It is termed a reading disability that at an early age is extremely hard to trace because the degree and type of dyslexia are unique to an individual, their genetics and environmental factors. While there is yet no full understanding of the cause of dyslexia, or agreement on its precise definition, it is certain that many individuals suffer persistent problems in learning to read for no apparent reason. Since this could drastically affect literacy skills and academic engagement, there is a need to address the quantifiable screening process for dyslexia as early, effectively, and objectively as possible.

Our solution attempts to screen dyslexia problems for children at every age. This mechanism correlates an eyeball tracking and speech-recognition technology, written in python with Matplotlib as the main plotting library. The solution utilised is a scalable measure of dyslexia at every age. While the user is asked to read a passage on the screen, the camera traces the pupil's positions with respect to eye momentum and direction, recording the independent variables- fixations and saccades. By analyzing the distribution pattern of existing datasets, the model makes a prediction. The user is then asked to read aloud a series of 25 words, while the algorithm processes the speech and identifies any discernible differences in speech-features (associated with dyslexia). The independent variables (input parameters) are reaction time, backtracking, unexpected pronunciation and reading time. The final algorithm prediction provides results on the predicted level of dyslexia.

This novel solution aims to give estimative predictions by combining eyeball tracking (reading) and speech recognition (phonology) so that the early detection of dyslexia leads to early intervention.

Keywords – dyslexia analysis, eyeball tracking, fixations, saccades, phonological testing.

1. INTRODUCTION

Dyslexia concerns a persistent and unexpected difficulty in developing age and experience appropriate word reading skills, which encompasses proficiency in accuracy and efficiency.[1] It is the most studied and the most known learning disorder in the world, yet is still one of the hardest to diagnose and resolve. According to Geurrero et al,, it can have different clinical manifestations in different phases of life and can influence different dominions of life. In 2019, 131 million students enrolled in government schools, joining the estimated 747 million children of primary-school age worldwide (United Nations Department of Economic and Social Affairs, 2019[2]), where they embarked on their journey of learning to read and write, skills that will carry them through high school and beyond. For up to 20% of these children across different languages and countries, however, this journey carries with it a risk of school failure due to an inability to learn to read as expected. A report released by the Indian government in 2015 estimated that at least 35 million Indian children are dyslexic with millions more suspected to be undiagnosed. Intervention research indicates that targeted, evidence-based programs in kindergarten and first grade can substantially improve reading outcomes for children who require intensive intervention in order to become successful readers. However, pre- and beginning readers are not routinely screened for risk in part due to the formidable logistical and financial challenges of providing millions of children with a full clinical assessment of the language and cognitive skills that are precursors to reading. There exists a need to objectively identify the disability of dyslexia, especially in young children, given that early intervention goes a long way in paving high self-confidence for children while yielding a high literacy-rate for the country.

Underlying skill reading is a multifaceted network of competencies for both understanding language meaning and recognizing printed words. General language competencies include knowledge of word meaning, facts and concepts as well as mastery of grammar and the structure of language at the sentence, text and discourse levels. In accordance with the ideology of the Guerrero et al paper, we will be considering individuals typically displaying a broad spectrum of ability in both reading and its precursor skills as lower end of the spectrum termed in clinical literature, “specific learning disability in reading” or “developmental dyslexia”.

This broad-spectrum inclusion supersets dyslexia. Therefore, for the sake of clinical accuracy, the term dyslexia and reading disabilities will be used interchangeably. International Dyslexia Association recognizes the term *Evaluation* as a more accurate word to describe the process of determining if someone has dyslexia. The word evaluation encompasses identification, screening, testing, diagnosis, and all the other information gathering involved when the student, his or her family, and a team of professionals work together to determine why the student is having difficulty and what can be done to help. Evaluation conventionally involves a three-stepped process of information-collection from parents and educationalists, screening and testing; and intervention plan leading to conclusion and recommendations.

[1] https://dictionary.apa.org/dyslexia#:~:text=n.,words%20and%20sometimes%20in%20arithmetic.

[2] https://unstats.un.org/sdgs/report/2019/The-Sustainable-Development-Goals-Report-2019.pdf

CURRENT DIAGNOSTIC CRITERIA

The American Psychiatric Association has created the international diagnostic criteria for learning disabilities in DSM-5. The diagnostic criteria used for specific learning disorders are four:

Criterion a) the persistency of the symptoms for at least 6 months, despite specific interventions;

Criterion b) the impairment of single or more abilities, with negative effects on school achievement;

The second diagnostic criteria refers to the specific affected academic skill (one or more than one), that must be substantially and quantifiably below those expected, based on the chronological age, and it negatively influences academic achievement, or occupational performance, or activities of daily life. With reference to the impairment in a single or more abilities, from a psychometric point of view the cut-off that is to be used is one and a half deviation standard below the expected mean in each single evaluated ability (or even one standard deviation in some cases, or under the 5th percentile for some measure) [18].

Criterion c) the onset in a school-age, even if the disorder could fully manifest later;

With reference to the age of onset, there is an agreed awareness that the clinical manifestations of learning disorders can change during the individual's life and that they are a lifelong condition [6]. Generally they are discovered in the first years of schooling, but it is also possible that they could be discovered later in the individual's schooling history. In order to take into account the clinical manifestations in different phases of life, there is a clear reference to the schooling history and the clinical history, to the integrated use of standardized tests and the documented history of learning difficulties, most of all for individuals aged 17 and older, where the use of standardized tests could not be valid, sensible and specific enough to describe the quality and the quantity of the learning disorders [16]. Some Years ago, UtaFrith, one of the most known scientists in the field, stated "diagnosis based on behavioural criteria will always be problematic, as behavior is strongly influenced by comorbidity, motivation, age, and ability" and "Adults with dyslexia and adults with autism who show good compensation can sail through standard diagnostic tests. Have they ceased to be dyslexic or autistic? Of course not. They themselves tell us about their persisting problems, and we can reveal these problems with more subtle tests.

criterion d) last but not least, there are different exclusion criteria.

The first exclusion criterion refers to absence of intellectual disability.

The second refers to the exclusion of a fragmentary and inadequate instruction.

The third refers to linguistic proficiency in the language used for academic instruction.

The fourth refers to absence of sensory problems high enough to justify the learning difficulties (visual and auditory sensory problems) [16,17,19].

2. LITERATURE REVIEW

Current diagnostic tools:

In India, the standardized procedure involves DALI, tools for school teachers and psychologists in Indian Languages to identify dyslexia. It works by asking a series of questions related to reading and word decoding abilities. DALI as an

assessment tool was created by the National Brain Research Centre, India in South Asian languages with the primary aim of acting as a bridge for dyslexia diagnosis in a multilingual country of India to identify dyslexia in indigenous languages like Hindi, Marathi, Kannada and English. Despite its dire necessity, it is very subjective and relies on a child's/mentor's interpretation of his/her own symptoms, which can make children self-conscious of their "problem". the systems using a computer-based battery of tests or questionnaires without introducing a new algorithm on top. They are just the digital transcription of human expert tests, and predictions are usually based on statistics.

Several studies have been conducted internationally in the hopes of diagnosing dyslexia with the help of Artificial Intelligence, a much awaited catalysis for this topic of research in the neuroscience community. Currently, validated diagnostics are delivered by accredited professionals based on scoring of a diverse battery of tests. Artificial Intelligence and Machine learning have been utilised to provide accurate results at a faster rate and easier convenience.

EYE_BALL TRACKING

Eye-tracking is a process more recently used in Artificial Intelligence as a measure of either the point of gaze or the motion of an eye relative to the head. An eye tracker is a device for measuring eye positions and eye movement. Previous research (xxx) has indicated that dyslexia may be correlated to a dysfunction in the oculomotor process for which two main independent variables of eye fixations and saccades were sourced as information data-points to determine to what extent is a person at risk of developing dyslexia.

A study by Benfatto et al indicates, "Eye tracking can be an efficient means to identify children at risk of long-term reading difficulties' '. The method involved originates from KronobergsProjektet, a research project on reading development and reading disability in Swedish school children. The project ran between 1989 and 2010. Eye-tracking during reading was conducted on children in 3rd grade, and reading difficulties were assessed until adulthood. What makes the KronobergsProjektet study unique is: 1) children were monitored over a long period of time and 2) the integrity of the recorded eye movement data.

Methods and Results: The experiments are based on eye tracking data from a cohort of 185 subjects participating in the project. Each participant (all Swedish speakers) has to read one and the same text presented on a single page of white paper with high contrast. For each session, using eye-trackers, the authors record a lot of numerical parameters among which, for instance, the duration of the event, the distance spanning the event, the average eye position during the event, the maximum range between any two positions, etc. Having gathered all these data and properly preprocessed their data set, the authors have implemented a standard classifier showing a high degree of accuracy (around 96%). It is important to note that the model also takes into account the results from a battery of other common tests, such as rapid automatized naming, reading of non-words, etc. One interesting feature of the process is that the prediction can occur after as little as 30 seconds of reading for the user.According to the study, "Using statistical cross-validation techniques on a sample of 97 high-

risk and 88 low-risk control subjects, they achieved a classification accuracy of 96%." Thus, in this study we will be using these as our literature values for comparison.

Necessary definitions: A saccade is a quick simultaneous movement of both eyes between two or more phases of fixation in the same direction.

According to Castles et al, from the phonological deficit hypothesis, several parameters can be derived. A study conducted by lead researchers at Dystech focused on utilising audio recordings of participants reading out words as a method of discerning dyslexic readers from non-dyslexic readers. For every audio record, they considered 2 parameters:

- The Reading Reaction Time (RRT) which is the interval between the initial display of the word and the start of the reading.
- The Reading Time (RT) which is the time it takes for the participant to read the corresponding word.
- RRT and RT evaluation is done via a computer (no human in the loop). Consequently, from a session of 32 audio records, we extract 6 numbers which will be used in our ML experiments:
- average RRT for 32 words, average RRT for 16 real words, average RRT for 16 nonsense words
- average RT for 32 words, average RT for 16 real words, average RT for 16 nonsense words

It is to be noted that poor reading performance is not an ultimate marker of dyslexia, but Dystech results demonstrate that a dedicated machine learning algorithm associated with proper audio signal processing can extract patterns that are not accessible to a human expert. Hence, we decided to use a factor of both eye-ball tracking and phonology testing as variable markers for dyslexia.

We look for backtracking,

Based on this research, we hypothesized a phonological speech analysis solution, which could be correlated with eyeball tracking to improve accuracy.

Figure 1: Parameters for the Project

It is important to move from a deficit to a preventive model of education.

3. DYSLEXIA

Dyslexia is not caused by poverty, developmental delay, speech or hearing impairments, or learning a second language, although those conditions may put a child more at risk for developing a reading disability (Snow, Burns, & Griffin, 1998).

Children with dyslexia will often show two obvious difficulties when asked to read text at their grade level. First, they will not be able to read as many of the words in a text by sight as average readers. There will be many words on which they stumble, guess at, or attempt to "sound out." This is the problem with "fluent word recognition" identified in the previous definition.

Second, they will often show decoding difficulties, meaning that their attempts to identify words they do not know will produce many errors. They will not be very accurate in using letter-sound relationships in combination with context to identify unknown words. These problems in word recognition are due to an underlying deficit in the sound component of language that makes it difficult for readers to connect letters and sounds in order to decode. People with dyslexia often have trouble comprehending what they read because of the great difficulty they experience in accessing the printed words.

4. EARLY AGE DETECTION DYSLEXIA

For many years, the importance of early identification and intervention for children with dyslexia has been stressed. Accordingly, much research has been directed towards establishing precursors of dyslexia in the preschool years in international studies of children at family risk of reading problems.

This is the major reason being our problem statement was taken into consideration, as per reports Once children begin to think reading is difficult, they develop a resistance to it and lose confidence. Developing this attitude toward reading during the formative years makes it difficult to reverse later. To prevent this, teachers need to reach these students in kindergarten and first grade. Studies show that there is little to no difference between the reading abilities of average children and dyslexic children when intervention occurs early.

5. INNOVATION

We are designing an objective and quantifiable screening of dyslexia for children at an early age so that the literacy rate of children is not hampered. This project aims to use rapid and holistic machine-learning-dependent assessment with parameters of

If one effectively processes the input parameters of both READING *(fixation/px·ms^{-1}& saccade/px·ms^{-1})* and SPEECH TESTS *(reaction time/s, reading time/s, backtracking/Boolean & pronunciation/Boolean)* of a young child, THEN it is possible to quantifiably measure the degree and level of dyslexia using machine-learning algorithms. Our solution uses eyeball tracking and phonological testing because the combination of the two provides a holistic and more intricate analysis of dyslexia by improving the data set and accuracy of predictions.

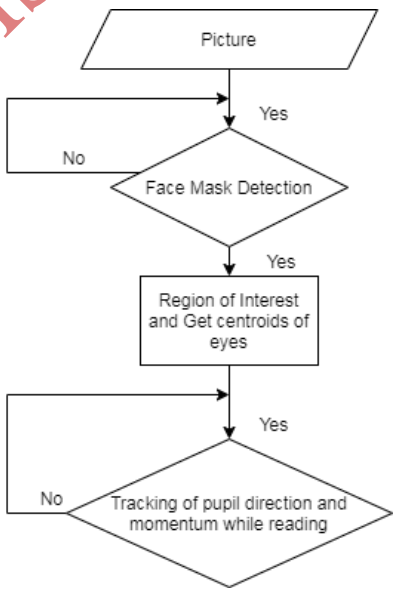


Figure 2: Block Diagram for Eye Ball Detection, Explanation, and final output,

And this test is computer based and it takes 20 minutes to complete and give you the results of dyslexia.

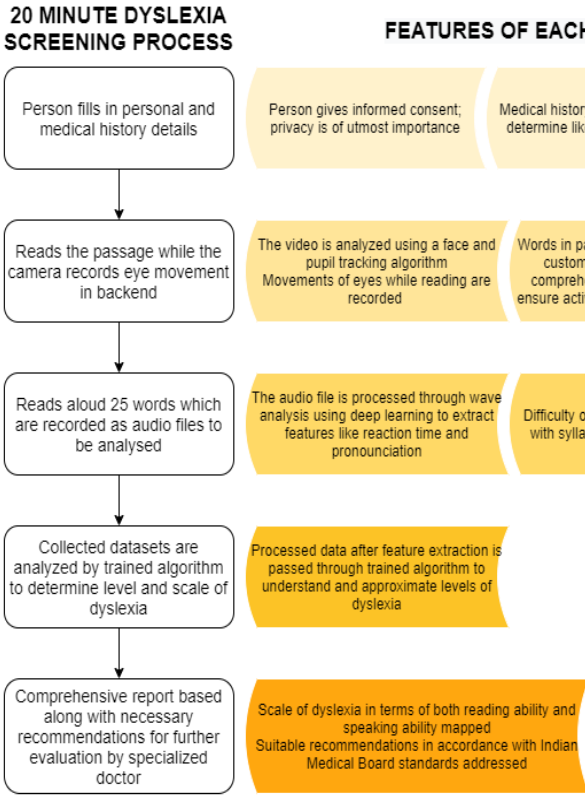
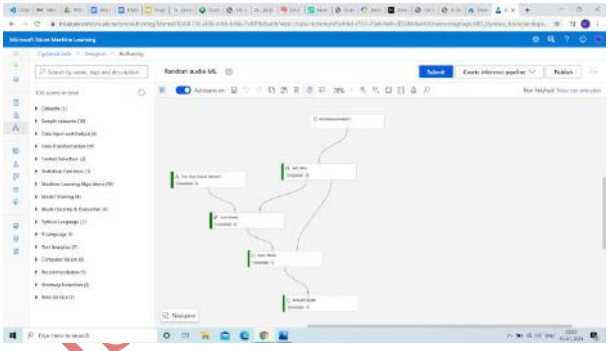


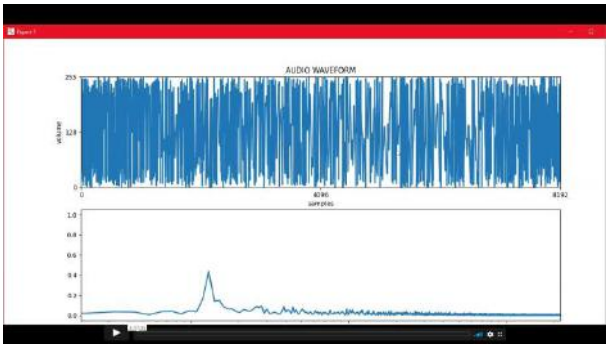
Figure3: The flow of the screening dyslexia process

6. ALGORITHM

All aspects of the algorithm rely on image processing and speech to text software. This is facilitated by Python and its plenitude of libraries and easily-accessible server. The data collection happens through the connected camera and microphone.

Imageio library, which provides a platform to read and write image data, was used to locate pupils of the eyes. OpenCV Library, which is utilized for image processing, was used to trace eye coordinates and perform the motion tracking. Moreover, Numpy (array and numerical matrices) library was used to convert the vision pupils to array coordinates that the programming language can understand. Matplotlib, which functions on an object-oriented API, was used for face plotting. SciPy optimizes curve fit machine learning that helps to track the eye while reading. Video Stream (imutils.video.VideoStream()) was used to give a live stream of the video without any break of the loop. Dlib is a toolkit containing machine learning algorithms and tools for creating complex software such as for this algorithm. The SpeechRecognition library was used to convert speech to text for the speaking test.





7. METHODS

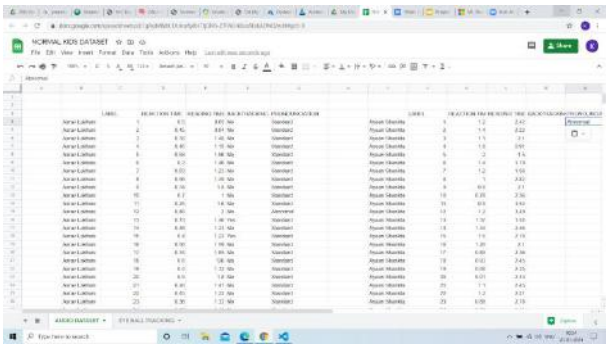
Our solution works on 2 main measures: Eye tracking & Phonology.

The Image Processing & Eye Land marking algorithm captures and locks the pupil coordinates on the screen by using the python library Imageio that provides an easy interface to read and write a wide range of image data. These coordinates are

like a 2-dimensional x-axis and y-axis points on screen that can be pin-pointed. These coordinates are converted into a text file for the eyeball tracking mechanism, and are used with the dlib module. OpenCV library and its classifiers gauge distance between eyes and the border of the face. Thus track the eyes movement specifically using CV2 by creating a mask using matplotlib.

The fixations and saccades are recorded by the motion of the eyes while reading. Bresenham's algorithm, which works on the principle of incremental scan conversion, relies only on integer calculations for accurate tracking of eye movement. The curve fit function of the SciPy library is utilized to create a mathematical function to model the data points into text which are then statistically compared to determine the extent to which the child is dyslexic.

Speech recognition software uses py-audio and pyttsx3 libraries to capture the speech of the user and identify patterns or characteristics commonly associated with dyslexia such as backtracking and grapheme mispronunciations. Furthermore, we incorporated additional filtering processes of font and size of texts which were specific to age categories. Thus, the reading and speaking tests will furnish customized feedback to the child.



GENDER	Male		Female		Total
DYSLEXIC	3	(65 audio sets)	1	(18 audio sets)	4
NON-DYSLEXIC	5	(125 audio sets)	7	(154 audio sets)	12
TOTAL	8		8		16

RESULTS AND CONCLUSIONS

After conducting numerous trials and consistently improving the efficacy of the machine learning program, it was found that both the reading and speaking tests were possible and provided valuable information about the levels of dyslexia. The reading test, when taken by dyslexic children, was extremely effective in identifying them as such with an accuracy as high as 86%. The speaking test did have a few errors in the program running at first. But once they were resolved, it functioned well, although the accuracy of the algorithm needs to be improved.

The combined run of the two tests led to 91% accuracy with SVM model and 90.9% accuracy with logistic regression. The speaking test did have a few errors in the program running at first. But once resolved, it functioned well. Compared to literature values, results are lower but very competitive. With expanded datasets and increasing accuracy in feature extraction algorithms, this can be surmounted

MODEL EVALUATION(%)	Two-class neural network	Two-class decision forest	Two-class logistic regression	Two-class support vector machine
Accuracy	81.8	81.8	90.9	91
Precision	100	100	100	98
Recall	33.3	33.3	66.7	68
F1 Score	50	50	80	79
AUC	92	68.7	95.8	100

Moreover, the tests were effective for each age-category as they used passages of varying fonts, sizes and spaces to allow for the reading ability of that age. The OpenCV library and Bresenham's algorithm significantly improved the accuracy of the results, however larger and more extensive data sets are required to further improve the accuracy of the algorithm. Screener that effectively screens for early literacy milestones- tablet based, self administered, scientifically validated and ready for scaling. Data analytic for customized resources support for coaching- data back to solutions

- Distribution- schools need for test scores, screening legislation
- AI technologists

8. FUTURE SCOPE

A major strength of this prototype is that it is highly standardized in equipment yet personalized in feedback to every child. This ensures that the prototype can be scaled to numerous schools and platforms through state associations such as the Maharashtra Dyslexia Association and national associations such as Dyslexia Association of India. A factor that must be improved is its accuracy and potential economic feasibility for rural schools but with persistent evaluation and detailed procedures, this too can be accomplished.

Our prototype-the newest and most effective assessment method for dyslexia- will be scalable and accessible to the young generations of our country.

9. ACKNOWLEDGEMENTS

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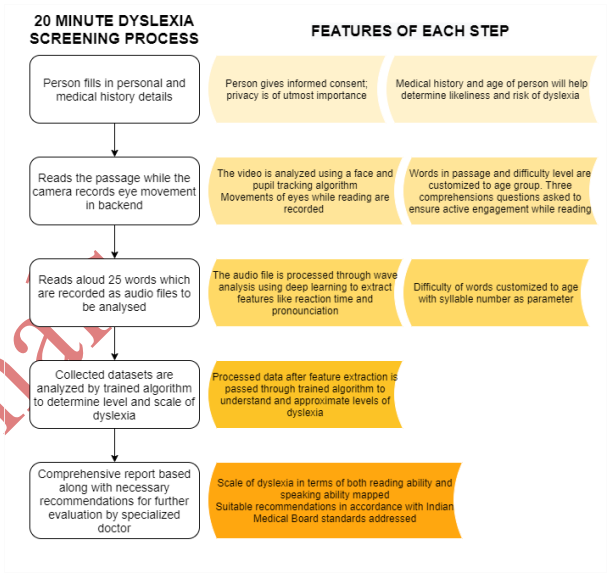

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