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A novel risk assessment and screening tool for Learning Disorders in children

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ABSTRACT

Learning disorders (LDs) are neurodevelopmental disabilities with a worldwide prevalence of 5-15%. Lack of awareness paired with heterogeneity in testing methods results in non-identification of LDs in children. Assessment tests presently used to diagnose LDs require the physical presence of a medical professional, are time-consuming and expensive and adopt a non-child-centric approach. DysDiag proposes novel, accessible and easy-to-administer risk-assessment and screening tests (based on DSM-5 criteria), for LDs in children (5-8 years). DysDiag's test for Dyslexia consists of a gamified, visual-based quiz that accesses the child's phonemic, auditory and visual-based skills followed by a pronunciation test and parental questionnaire. The test for Dysgraphia includes 2 Machine Learning Image Classification Models that classify the child's handwritten sample as dysgraphic or normal and further evaluate the sample for 6 diagnostic symptoms. The models recorded F1 scores of 0.785 and 0.964 respectively. The test of Dyscalculia includes a facial emotion recognition model alongside a response-time-based math quiz and a parental questionnaire. DysDiag was tested on 40 children consisting of a case-group of pre-diagnosed children (n=20, mean age=6yrs) and a control-group (n=20, mean age=7yrs). The children were tested by a registered medical professional followed by DysDiag's screening tests. DysDiag recorded a sensitivity and specificity of 90%, a Positive Predictive Value of 94.73% and a Negative Predictive Value of 90.47%. DysDiag was also reviewed and rated by 15 psychologists and paediatricians. DysDiag proved to be a clinically viable tool, that can aid in the early identification and mass screenings for LDs at elementary schools.

Keywords: *learning disorders, neurodevelopmental disorders, dyslexia, dysgraphia, dyscalculia, behavioral and social sciences, learning disabilities, reading difficulties, case-control study on learning disorders, risk-assessment for learning disorders*

1. INTRODUCTION

A learning disability is a neurodevelopmental disorder that affects cognitive processes related to learning.[1] These disorders involve difficulty in one or more basic psychological processes such as input (auditory and visual perception), integration (sequencing, abstraction, and organization), memory (working, short-term, and long-term memory), output (expressive language), motor (fine and gross motor).[2]

Diagnostic and Statistical Manual of Mental Disorders (DSM-5) estimates the prevalence of all learning disorders (including impairment in writing, reading, and mathematics) to be about 5% to 15% worldwide.[3] According to the UNESCO Mahatma Gandhi Institute of Education for Peace and Sustainable Development (MGIEP), at least 10-12% of the school-going population of India suffers from a learning disorder. That number accounts for about 4 children in every average Indian classroom.[4]

Various risk-assessment tests have been developed and designed for Dyslexia. The Western diagnostic methods for dyslexia include

- Intelligence tests like the Wechsler Preschool and Primary Scale of Intelligence, Woodcock-Johnson Tests of Cognitive Abilities, or Stanford-Binet Intelligence Scales. They measure different cognitive processes, such as verbal ability, nonverbal and spatial reasoning, working memory, and processing speed.
- Achievement tests like the Woodcock-Johnson Tests of Achievement and Wide Range Achievement Test. They test the child's performance in academic activities and assessments.

The tests are drastically ill-suited for assessing dyslexia in India as they fail to accommodate its multitude of cultural and ethnolinguistic variables. Moreover, these tests fail to adapt to the Indian education system and curriculum. In India, the 2 widely used scales are the Dyslexia Assessment for Languages of India (DALI) and Malin's Intelligence Scale for Indian Children (MISIC). However, these current assessments for learning disabilities are intrusive, highly expensive, time-consuming, and inaccessible to children from rural areas or from low socio-economic backgrounds as they require several sessions with a qualified clinical psychologist. Moreover, they are also not child-friendly as they lack cohesive storylines and audio-visual content.

Unlike specific learning disabilities and neurodevelopmental disorders that have been more extensively studied, there is no gold standard for diagnosing Dysgraphia. Tests that are used to diagnose dysgraphia include the Ajuriaguerra scale, Concise Evaluation Scale for Children's Handwriting (BHK) for children or teenagers, the Minnesota Handwriting Assessment, ETCH, SCRIPT, Detailed Assessment of Speed of Handwriting (DASH) and Hebrew Handwriting Evaluation (HHE) scale.[5] However, these tests usually involve an expert investigating sentences written by a subject on paper, and, therefore, they are largely subjective, expensive, and scale poorly.

A consensus has not yet been reached on appropriate diagnostic criteria for dyscalculia. Most current-day assessment tests for dyscalculia only include achievement tests that assess the child's arithmetic ability. Tests such as the Mathematical Fluency and Calculations Tests (MFaCTs), and Comprehensive Mathematical Abilities Test (CMAT) only access the child's computational skills and do not take into account the mental and emotional context of the situation. Alternatively, fMRI research has shown that the brains of neurotypical children can be reliably distinguished from the brains of dyscalculic children based on the activation of the prefrontal cortex. However, due to the cost and time limitations associated with brain and neural research, these methods are not incorporated into diagnostic criteria despite their effectiveness.[6]

All the above-stated assessment tests fail to recognise that professional administration of assessment tests for even a preliminary screening is not a scalable solution. There is an acute need to develop newer means of assessing Learning Disabilities through computerised forms of testing with the aim of creating more accessible, time and cost-efficient and accurate forms of screening. Through this study, we have developed one such pre-diagnostic, risk assessment tool (in the form of a computerized web application) for learning disorders that can help perform psychometric evaluations and aid in identifying children who show signs of neurodevelopmental disorders.

DysDiag is a novel risk assessment and screening tool for various learning disorders in children such as Dyslexia, Dysgraphia and Dyscalculia. We hypothesised that DysDiag would be clinically significant, which we would test through a case-control study and experimental review by professionals. As a pre-diagnostic tool, DysDiag would be the first step for individuals to seek more evaluation and treatment based on the risk score.

2. RESULTS

A test run was conducted on a group of 40 children to understand the viability of DysDiag. The test consisted of a case group of clinically pre-diagnosed children (n=20, mean-age=6 years) and a control group (n=20, mean-age= 7 years). Results of the case-control study are as follows:

Table1: Results of Dyslexia risk-assessment test

Study Group	Diagnostic Status	Result: At-risk	Result: Not at risk
Cases	Diagnosed with Dyslexia	13	0
Cases	Diagnosed with other LDs	4	3
Control	Non-diagnosed/neurotypical	1	19

Table2: Results of Dysgraphia risk-assessment test

Study Group	Diagnostic Status	Result: At-risk	Result: Not at risk
Cases	Diagnosed with Dysgraphia	6	1
Cases	Diagnosed with other LDs	7	6
Control	Non-diagnosed/neurotypical	0	20

Table3: Results of Dyscalculia risk-assessment test

Study Group	Diagnostic Status	Result: At-risk	Result: Not at risk
Cases	Diagnosed with Dyscalculia	5	1
Cases	Diagnosed with other LDs	8	6
Control	Non-diagnosed/neurotypical	0	20

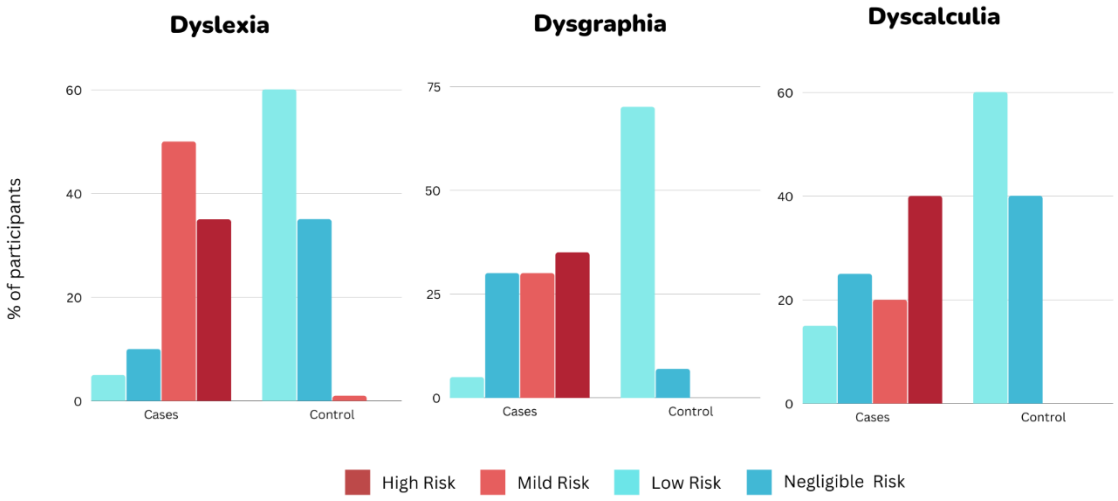

Figure 1: Results of case-control study

Sensitivity: 90%
Specificity: 95%
Positive Predictive Value: 94.736%
Negative predictive Value: 90.476%

These measures of performance were chosen as they are commonly accepted measures in the machine learning community and provide numbers that are easy to compare with other models. 15 professionals (psychologists, pediatricians, and speech pathologists) rated the effectiveness of the tool with respect to current diagnostic methods. The questionnaire contained:

1) 5 questions to be answered using a 10-point scale (1 being the lowest and 10 the highest) comparing DysDiag to current risk-assessment tools on the basis of accuracy, child-centric approach, accessibility, time-efficiency and parental involvement.
2) 5 yes/no answer-type questions answering the project's research questions.

Results of the Professionals' review are as follows:

PART 1:

Table 4: Results of the questionnaire filled out by the professionals

Questions	Responses
Do you believe that digitisation and automation of risk-assessment tests for SLDs is scalable and beneficial?	13 out of 15 said yes
Do you think that the audio-visual elements and gamification increase child responsiveness and reciprocity?	14 out of 15 said yes
Are DysDiag's risk-assessment tests in accordance with the DSM-5 diagnostic criteria for SLDs?	12 out of 15 said yes
Do you believe that the use of Machine Learning models increases the viability of DysDiag's assessments?	11 out of 15 said yes
Do you find DysDiag to be a novel, efficient, accurate and accessible risk-assessment tool for SLDs?	13 out of 15 said yes

PART 2:

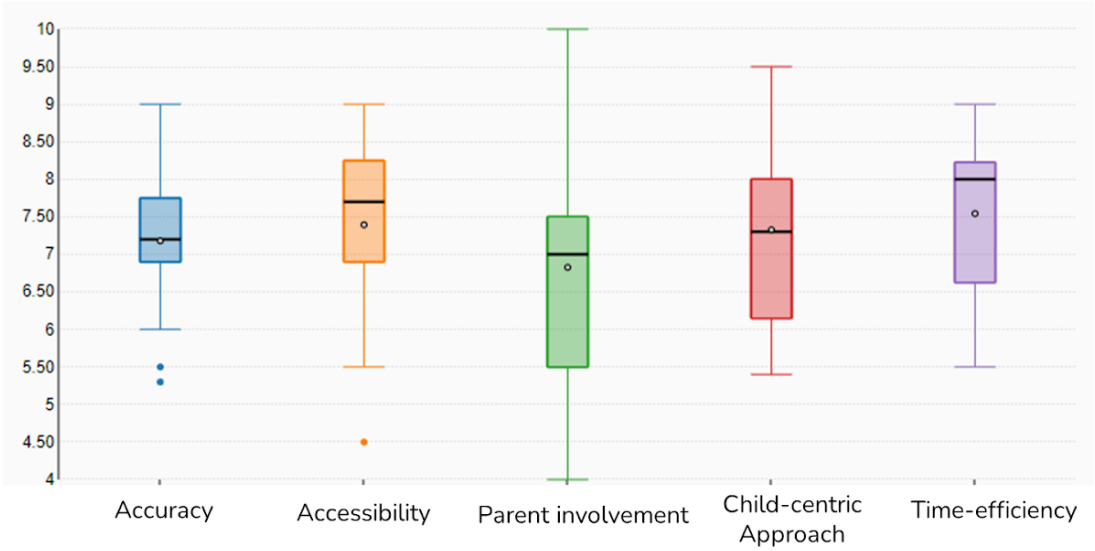

Figure 2: Box plot graph showing the ratings given to DysDiag by the medical professionals for different domains

3. MATERIALS AND METHODS

3.1 Digitization of current risk-assessment tools

Dysdiag digitised the current risk-assessment and screening tools for Learning Disorders into gamified, visual-based quizzes. The quizzes incorporate increased audio-visual content and animations in order to increase the child-centric design of the tool.

3.1.1 Risk-assessment test for Dyslexia

The quiz contains 7 multiple-choice questions based on the Dyslexia Assessment for Languages of India (DALI) developed by the National Brain Research Centre. It judges the child based on the child's phonemic, semantic, auditory and visual-spatial abilities. It checks whether the child is able to:

- correlate words with real-world objects and actions
- recognise word pronunciations
- understand alphabet orientations
- understand spatial directions

- differentiate between similar words

The quiz makes use of visual content and animated figures to make the process engaging and interactive for children. This child-centric approach aims to increase child responsiveness and reciprocity by ensuring that the process does not feel overwhelming for the child. The quiz is judged based on the answers provided by the child and the response time for each question.

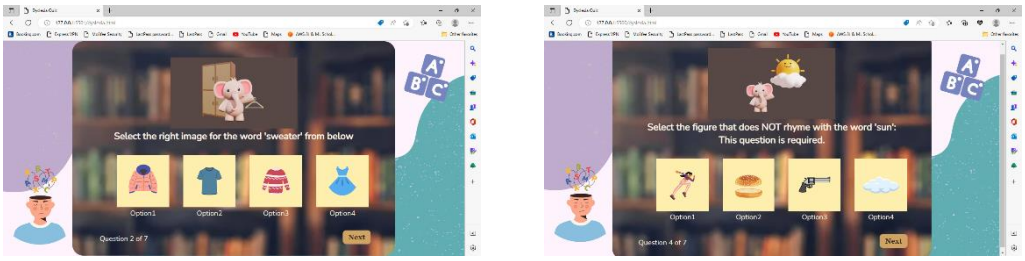

Figure 3.1 and 3.2 : Dyslexia risk-assessment Test

3.1.2 Risk assessment tool for Dyscalculia

The entire assessment is focused on detecting and diagnosing anxiety related to math in the child. The quiz contains 10 multiple-choice arithmetic and logical questions. It tests the child's ability to:

- understand the relationship between mathematical symbols, numbers and quantities
- Understand basic concepts such as addition or greater than/lesser than
- solve multi-step mathematics problems

The quiz makes use of visual content and animated figures to make the process engaging and interactive for children. The quiz is judged based on the answers provided by the child and the response time for each question.

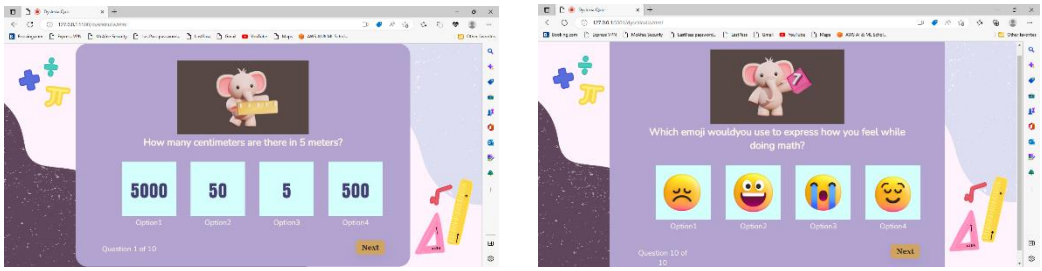

Figure 4.1 and 4.2 : Dyscalculia Risk-assessment Test

3.2 Increasing Parental Involvement

The screening tools for Dyslexia and Dyscalculia utilize a parental/teacher questionnaire containing questions regarding the child's developmental milestones and everyday behavioral traits.

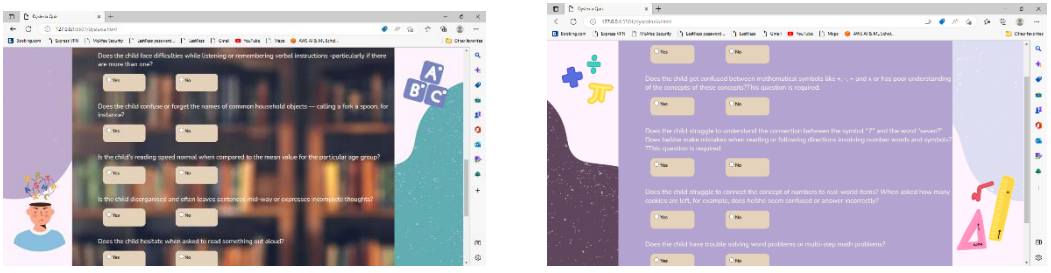

Figure 5.1 and 5.2 : Parental questionnaires

3.3 Developing novel screening Methods

3.3.1 Dyslexia Risk-assessment tool

DysDiag uses a novel audio-based pronunciation test to further assess the child for signs and symptoms of Dyslexia. In this part the parent/teacher/guardian is required to play an audio clip for the child. The audio clip contains the pronunciation of

a particular word. The child should then be asked to repeat the same word. The parent/teacher/guardian is then required to grade the child's pronunciation in accordance with the audio clip.

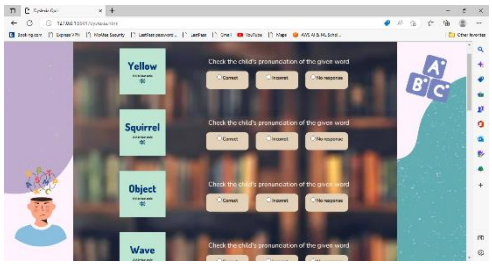

Figure 6: Dyslexia Audio-based pronunciation Test

3.3.2 Dysgraphia Risk-assessment Tool

The dysgraphia risk-assessment test consists of 2 novel Machine Learning Computer Vision models that detect signs of dysgraphia using samples of the child's handwriting. The models were trained using Google Cloud AutoML and were imported as tensorflow.js files. The assessment for dysgraphia has two steps.

The first Machine Learning Image Classification model distinguishes between dysgraphic and normal handwriting using a random sample of the child's writing. It is a single-label classification mode. The ML model was trained using 116 labelled samples of dysgraphic and normal handwriting (normal: n=58, dysgraphic: n=58). The dataset included samples written in pen and pencil on both ruled and unruled paper. Some samples were also taken in dim and coloured lighting in order to increase efficiency. The dataset was labelled with the help of a certified professional. The model was trained using Google Cloud AutoML Vision. At a confidence threshold of 0.5, the following evaluation scores were recorded:

a) Precision : 78. 57%
b) Recall: 78.57%
c) F1 Score: 0.93415

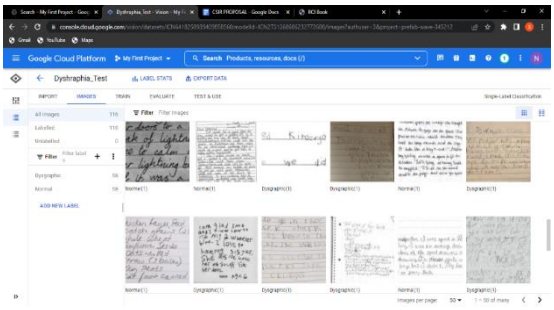

Figure 7.1: Labelled data points of machine learning model used for dysgraphia assessment

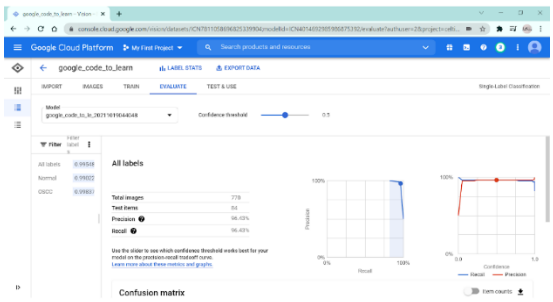

Figure 7.2: Precision-recall graph

If the first Machine Learning model classifies the child's handwriting as 'dysgraphic', users are required to proceed to step 2. In this phase, DysDiag uses a Machine Learning multi-label Image Classification model to detect specific signs of dysgraphia in the child's handwriting. The model was trained using 104 samples of dysgraphic writing. For the purpose of testing, the child would be required to write a particular sentence, "*the quick brown fox jumps over the lazy dog*" (a sentence that contains all 26 alphabets of the English language) for accurate analysis. The ML model scans this sample of the child's handwriting for diagnostic signs such as

a) illegitimate writing
b) poor spatial planning
c) inconsistent size
d) inconsistent case
e) incorrect orientation
f) unfinished alphabets

This step aids in the detection of the specific strengths and weaknesses of each child. Upon testing this model at a confidence threshold of 0.5, the following evaluation scores were recorded:
a) Precision: 96.43%
b) Recall: 96.43%
c) F1 Score: 0.99548

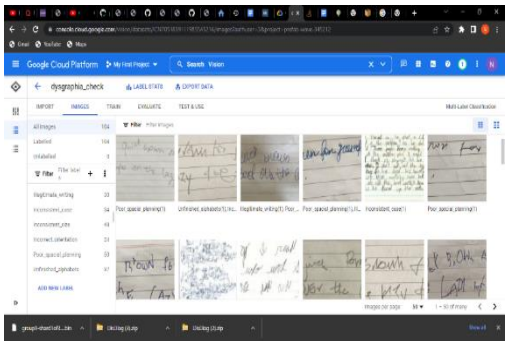

Figure 8.1: Labelled datapoints of machine learning model used for dysgraphia assessment

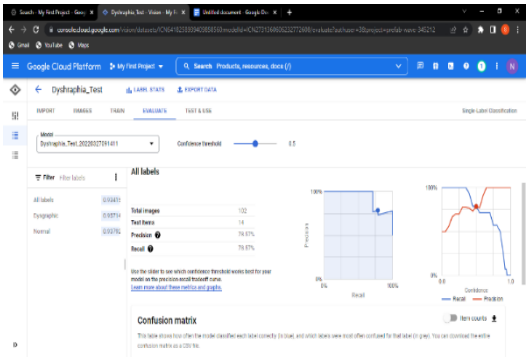

Figure 8.2 Precision-recall graph

3.3.3 Dyscalculia Risk-assessment Tool

DysDiag uses an Image Classification model for facial emotion recognition to detect signs of fear, stress, anger, sadness or anxiety in the child while attempting the quiz. Video footage of the child is captured during the duration of the quiz, which is then further analysed. The model was trained using 497 labelled images sourced from open-source datasets. The model classifies the facial emotion under 5 categories:
a) happy (n=100)
b) neutral (n=99)
c) angry (n=98)
d) sad (n=100)
e) fear (n=100)

The model was trained using Google Cloud AutoML Vision. At a confidence threshold of 0.5, the following evaluation scores were recorded:
a) Precision: 89.5%
b) Recall: 34%

c) F1 Score: 0.594

Figure 9.1 and 9.2: Precision-recall graph and confusion matrix

3.4 Case-Control Study

A test run was conducted on a group of 40 children to understand the viability of DysDiag. The test consisted of a case group of clinically pre-diagnosed children (n=20, mean-age=6 years) and a control group (n=20, mean-age= 7 years).

3.4.1 Population:

School-going children (English Medium) residing in Indian metropolitan cities aged 5-7 years

3.4.2 Inclusion Criteria:

Aged (5-7) years, attending English Medium, Elementary, Private schools (NCERT and ICSE board), residing in Indian metropolitan cities (New Delhi, Mumbai, Hyderabad, Bengaluru), Parental Educational level: Undergraduate or higher, diagnosed with SLDs by a certified Medical professional.

3.4.3 Exclusion Criteria:

Children diagnosed with other neurodevelopmental disorders such as Autism or ADHD, family history of Learning disorders, self-diagnosed or assessed using tests other than certified assessments such as the NIMHANS index or MISIC, children who failed to receive quality education during the COVID-19 pandemic. The case group consisted of 7 children with Dyslexia, 4 children with Dysgraphia, 3 children with Dyscalculia, 3 children with both Dyslexia and Dysgraphia and 3 with both Dyslexia and Dyscalculia.

3.4.4 Methods:

Both case and control groups were first assessed by the Qualified Scientist/mentor (registered medical professional). Participants were then screened for all three learning disorders, that is Dyslexia, Dysgraphia and Dyscalculia using DysDiag's risk assessment tests. Respective results were recorded. The results of the procedures conducted by the Qualified Scientist/mentor (registered medical professional) were then obtained by the student researcher for analysis.

Table 5: Test run group distribution by gender

	Male	Female
Controlled	10	10
Experimental	12	8

Table 6: Test run demographics summary

	Mean+S.D	p- Value
Controlled	6.723 + 0.43	0.43
Experimental	6.238 + 0.86	0.86

3.5 Professionals' Review of DysDiag

15 professionals (psychologists, pediatricians, and speech pathologists) rated the effectiveness of the tool with respect to current diagnostic methods. Each of them was sent a questionnaire in order to access DysDiag.
The questionnaire contained:
a) 5 questions to be answered using a 10-point scale (1 being the lowest and 10 the highest) comparing DysDiag to current risk-assessment tools on the basis of accuracy, child-centric approach, accessibility, time-efficiency and parental involvement.

b) 5 yes/no answer-type questions answering the project's research questions.

3.5.1 Participants
Certified Medical professionals, both male and female, expertise related to pediatrics and child neurodevelopmental psychology.

3.5.2 Recruitment
Participants were recruited either from nearby hospitals and healthcare centres or contacted telephonically (using contact details provided online).

3.5.3 Methods
Participants were asked to visit DysDiag's website, review the proposed risk-assessment tests and digitally fill out a related questionnaire containing 10 questions. The first five questions required the participants to rate DysDiag in comparison to the current risk-assessment tools in terms of accuracy, time-efficiency, parental involvement, child-centric design and accessibility. Time commitment sought from participants: 20-30 minutes.

4. CONCLUSION

Early diagnosis is recommended for the effective management and treatment of learning disorders, especially in young children. Often, particularly in rural areas, wherein the incidence of these learning disorders is statistically higher, it becomes difficult to identify developmental delays by conducting screening tests due to a lack of resources in primary and secondary care settings. In such scenarios, DysDiag can prove extremely beneficial. DysDiag's facility can be accessed anywhere, anytime and by anyone. It would facilitate the mass screening of young children for learning disorders and will lead to early intervention measures such as a comprehensive diagnostic evaluation of at-risk children.

Present diagnostic methods present the need for a certified clinical professional. They are also extremely time-consuming ranging from 15 minutes to 3-4 hours. This makes them extremely inaccessible to the general public at large. Moreover, usually, such assessments are conducted upon recommendations from teachers based on the child's performance in the classroom and co-curricular activities. But due to the lack of proper teacher training, the poor pre-referral procedures result in over-referral, thus wasting time and resources or under-referral which prevents children with learning difficulties from receiving necessary help.

DysDiag's assessment tests are simple, time-efficient and can be administered at home/school by anyone without prior experience. This acts as a solution to the prevailing problem of lack of teacher training and awareness. Also, as the child is engaged throughout the process and is not interviewed by someone they have not known beforehand, social inhibition is reduced, the child is more cooperative and comfortable and hence testing is more reliable. Lastly, as DysDiag's risk assessments are automated, they contrast the contemporary diagnostic methods which are dependent upon the individual expertise, judgement and bias of the evaluator.

Despite DyDiag being a clinically viable tool as proved by the case-control study and the professionals' review, DysDiag does have some limitations. All the current assessment tests are available only in English. In a multilingual country like India, where several children have a regional language as their first language, testing children through English assessment tests might yield an incorrect estimation of the child's abilities. Moreover interpreting the app and answering the observer questionnaire requires a certain degree of training, which may be limited in rural areas. Lastly, to use DysDiag, one needs access to a mobile phone, tablet, or computer with sufficient capabilities in terms of memory, graphics, etc. An internet connection is also initially required to run the web-application.

The current study can be expanded on in the future by conducting beta testing on a larger research group. Additionally, expanding our study to include more feedback from other related health workers involved in the LD diagnosis process, such as social workers or pediatricians, can make our diagnostic tool more effective. In the future, we hope to improve upon the identified limitations. Additionally, we hope to expand our diagnostic tool by including levels, multilingual assessment tests and age-based modules. Finally, we plan on partnering with healthcare professionals, especially those involved with LD patient care, to make DysDiag accessible throughout the country.

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6. APPENDIX

Table 1: Scoring rubric for Dyslexia (the numbers in brackets represent the score assigned)

Criteria	Low-risk	Moderate-risk	High-risk	Very High-risk	Total
Correct quiz responses	>6 (35)	4-6 (25)	2-4 (15)	0-2 (0)	35
Response delay (sec)	<5 (20)	5-10 (15)	10-15 (10)	>15 (5)	20
Audio-based pronunciation test	>4 (15)	2-4 (10)	1-2 (5)	0-1(0)	15
Observer's questionnaire	22-30	15-22	7-15	0-7	30
				TOTAL	100

Table 2: Scoring rubric for Dyscalculia (the numbers in brackets represent the score assigned)

Criteria	Low-risk	Moderate-risk	High-risk	Very High-risk	Total
Correct quiz responses	>8 (30)	5-8 (20)	2-5 (10)	0-2 (0)	30
Response delay (sec)	<5 (20)	5-10 (15)	10-15 (10)	>15 (5)	20
Facial Emotion Recognition Model	20	15	10	5	20
Observer's questionnaire	22-30	15-22	7-15	0-7	30
				TOTAL	100

Table3 : Result prediction criterion for Dyslexia and Dyscalculia risk-assessment tests

Score-range	Corresponding analysis
75-100	Negligible Risk
50-75	Low Risk
25-50	Mild Risk
0-25	High Risk

SAMPLE OF PROFESSIONAL'S QUESTIONNAIRE

PROFESSIONAL'S QUESTIONNAIRE

DysDiag is a novel risk-assessment and screening tool for Learning Disorders in Children in the age group of 5-8 years. The following questionnaire is to be filled out after reviewing DysDiag's risk assessment tests. The responses to this questionnaire would be used for understanding the clinical viability of DysDiag as a risk-assessment tool for Learning Disorders in children.

Name: _____

Age: _____

Educational Background/ Degrees: _____

Email Id: _____

PART I

The following question needs to be answered in either 'Yes' or 'No'.

1. Do you believe that digitisation and automation of risk-assessment tests for SLDs is scalable and beneficial?
Yes / No

2. Do you think that the audio-visual elements and gamification increase child responsiveness and reciprocity?
Yes / No

3. Are DysDiag's risk-assessment tests in accordance with the DSM-5 diagnostic criteria for SLDs?
Yes / No

4. Do you believe that the use of Machine Learning models increases the viability of DysDiag's assessments?
Yes / No

5. Do you find DysDiag to be a novel, efficient, accurate and accessible risk-assessment tool for SLDs?
Yes / No

PART II

Rate DysDiag in comparison to the current diagnostic/screening/risk-assessment tools for Learning Disorders using a 10 point scale (1 being the lowest, 10 being the highest) in terms of:

1. Accuracy:

1	2	3	4	5	6	7	8	9	10

2. Parental Involvement

1	2	3	4	5	6	7	8	9	10

3. Time-efficiency

1	2	3	4	5	6	7	8	9	10

4. Child-centric approach

1	2	3	4	5	6	7	8	9	10

5. Accessibility

1	2	3	4	5	6	7	8	9	10

I hereby acknowledge that the above questionnaire has been filled out after reviewing DysDiag - without any bias, to the best of my abilities.

Date:
Name:
Signature:

