A WEBCAM-BASED ADHD SCREENING TOOL USING EYE-TRACKING AND BEHAVIORAL TESTS

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ABSTRACT

Attention-Deficit Hyperactivity Disorder, commonly abbreviated as ADHD, is a neurological disorder commonly associated with restlessness, difficulty maintaining attention spans, and difficulties maintaining interpersonal relationships [1]. Screening for ADHD is difficult and costly, and a more accessible and affordable option for getting tested for ADHD is necessary. As such, we created the website named NeuroGaze, which offers a non-intensive way to get tested for ADHD [2]. It utilizes the user's webcam to use eye-tracking software across multiple tests. Three tests are employed by the website. First, a visual attention go/no-go test will generate 10 images for a user and they must only interact if they spot a certain image. Second, a continuous inhibition CPT (continuous performance test) will display random characters on a screen and the user is tasked with interacting with all non-'X' characters [4]. Lastly, an interference test will have the user read a passage with distractions intermittently appearing, focusing on eye-tracking movement results. A screening survey follows, and the test concludes with the results screen with a potential diagnosis. To test our website's accuracy, we created an experiment involving 12 individuals, half of which had ADHD [3]. Testing showed that our website is 75% accurate in its diagnoses, which leaves a solid foundation to further iterate on in the future.

Keywords

ADHD screening, Eye-tracking technology, Continuous performance test, Visual attention

1. INTRODUCTION

In recent years, more people, especially among adolescents, have developed Attention-Deficit Hyperactivity Disorder, a mental disorder commonly associated with difficulty maintaining an attention span, hyperactivity, restlessness, and impulsive behaviors. and other learning and attention differences. One issue that arises, however, is that getting their child tested for ADHD can cost upwards of thousands of dollars and requires several intensive hours at a specific facility to complete. Diagnosis rates for ADHD as such may be significantly downplayed or decreased as only a subset of parents have been able to properly get their child checked for ADHD. This problem affects everyone, but is especially impactful towards children; in school, ADHD is a significant detriment to their education. This can make children who are unaware of their differences experience negative impairment at school without realizing it. In adults, ADHD manifests worse symptoms. This includes unstable relationships, impaired interpersonal skills, poor work performance, and issues relating to one's self-esteem. As such, it is incredibly important that methods related to detecting ADHD in adolescents or adults are improved and made more accessible. Solving this problem of accessibility and equity will perhaps improve our ability to recognize traits of and treatment of ADHD.

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Our methodology comparison focused on three research studies which all focused on the use of eye-tracking software to detect ADHD. In “Eye Tracking During a Continuous Performance Test: Utility for Assessing ADHD Patients,” Astar Lev et al. find that eye-tracking software increases the accuracy of traditional ADHD detection tests such as the Continuous Performance Test. The shortcoming of this study is that “ the adult ADHD patients participating in the current study were all undergraduate students, and therefore likely represent highly functioning patients”, and an improvement we made for our experiment is using different age groups for testing.

In “Use of Eye Movement Tracking in the Differential Diagnosis of Attention Deficit Hyperactivity Disorder (ADHD) and Reading Disability”, Pamela Deans et al. find that similar to the last study, the use of eye-tracking software and reading tests resulted in an accurate diagnosis of ADHD. A limitation this study mentioned describes how “Calibration sensitivity and lack of a “bite bar” to keep children’s heads still contributed to lost data and perhaps less valid data in some cases” and our experiment aimed to improve on this by using an eye tracker technology that uses machine learning to keep eye predictions accurate even with head movements.

In “Use of eye-tracker device to detect attention deficits in adults with ADHD,” Adamis et al. find that eye-tracking software in conjunction with a visual or reading-based test like the Stroop test resulted in accurate detections of ADHD among adult subjects.

All of these studies supported the notion that the use of eye-tracking software was sufficient to detect ADHD in children and adults, which lends credence to our website’s main functionalities.

Our app will try to detect symptoms of ADHD for free by tracking a user’s eye movements in various tests of attention. It will use various tests that either distract or focus a user’s attention and measure their reaction times. By making our test a free app, it is much more accessible and affordable so that many more people can be diagnosed with ADHD. Our application relies on eye-tracking, which is something that has been tested, but not used a lot in diagnosing ADHD [5]. In addition, it completely relies on only a browser, meaning a person only needs a computer with a camera to take the test, and it doesn’t require the user to download a separate application on their desktop or phone either. Our app is both free and online, meaning anyone with an internet connection and a device could take it, instead of the much more complex, expensive, and time-consuming process of having to get a full diagnosis by a doctor. Other solutions are more focus-intensive and time-intensive, whereas our proposed approach would be more economical for the end user to take. The hope is that the test results from this website will be accurate enough for this experience and convenience to be acceptable.

Our experiment for this research study involved 10 participants, half of which had ADHD. We had them use NeuroGaze to determine the accuracy of the website’s results system. Overall, the website was 75% accurate in its diagnoses, which is a good start. Of individuals who had ADHD, the website was 83.3% accurate, and of those who did not have ADHD symptoms, the website was 66.7% accurate. Our findings here indicate that the website is off to a reliable foundation when it comes to the accuracy of its ADHD screening systems. We did find, however, that children were disproportionately more likely to be labeled as exhibiting signs of ADHD, even among the children tested who did not exhibit any ADHD symptoms. This may be a fault of the test subjects gathered, the website’s results system, or a combination thereof. In any case, additional test subjects are required to fully understand the potential faults of NeuroGaze’s accuracy.

2. CHALLENGES

In order to build the project, a few challenges have been identified as follows.

2.1. Accessibility

Accessibility is a major selling point of the website but also a significant design consideration. Some may question why the website is not a monetized product but instead an openly available product. We believed that the core of our project was to be accessible for all demographics and financial status. The website is designed to be more as a public service than as a startup product; aside from the test itself, the website includes several articles and blog posts detailing ADHD and aims to increase ADHD awareness [6]. Locking the website behind a paywall would significantly decrease the efficacy of the product.

2.2. The Eye-Tracking Accuracy

The eye-tracking accuracy of the website is also another challenge that we must consider. To put it succinctly – how significantly does the accuracy of the calibration impact the performance of the employed tests, and by extension, the final diagnosis given at the end? It's important that the calibration is not so inaccurate that the website gives an unacceptable amount of false diagnoses to those who don't have ADHD. At the moment, the website employs a recalibration fallback if the first calibration test is inaccurate, and the website utilizes a 75% accuracy threshold before continuing. However, we recognize that this may need to be increased; more tests with real-world users will yield the minimum accuracy threshold needed for reliable results.

2.3. The choice of tests

One of the fundamental challenges in this project was the choice of tests given to users, all of which utilize eye tracking. Some may question this decision, as ADHD symptoms manifest themselves in ways not involving a user's eyesight, such as verbal communication, interpersonal skills, or excessive fidgeting [7]. However, there are several issues with attempting to include those qualities. For one thing, ADHD manifests differently in different people. Secondly, testing for physical symptoms is a challenge not solvable by software, and asking users to order equipment to do so would defeat the purpose of this project. The choice of eye tracking was the most economical choice.

3. SOLUTION

We created a template for each page using Python Flask to keep the pages consistent (every page has a navbar and footer). When you swap pages only the middle content section changes while the navbar and footer do not. This reduces unnecessary repetition in the code and fosters object-oriented code.

The actual portion of the website that administers testing requires several components working in tandem with one another. The jsPsych.js and webGazer.js libraries are used in order to set up eye calibration and eye tracking features.

The website employs several phases of testing. First, a calibration page is given, followed by test 1: visual attention, test 2: continuous inhibition, and test 3: interference. These are followed up by a results screen.

The calibration page uses the jsPsych JavaScript plugin with the WebGazer.js library to track the user's eyes by having them look at specific dots on the screen to get an accurate reading of their eye movement. We do this calibration process before each test to get the most accurate data possible.

The visual attention test will take ten random images from an online database and select one that the user must find [8]. Then the test will randomly show the images and the user will need to press the spacebar when the selected image shows up again.

The continuous inhibition test will show the user a random letter every few seconds. The user is tasked to press the spacebar as quickly as possible whenever a new letter appears, except when the letter X appears.

The interference test will have a user read a passage (with a selection of child, teen, or adult difficulty) and pop up random images in the background as the user reads.

The last testing section of our program is the screening section (with also a selection of three). It consists of a rating scale from 1-5 questionnaires to help the results be more specific. The three specific tests are NICHQ Vanderbilt Assessment Scale (child), The SWAN* Rating Scale for ADHD (teen), Adult ADHD Self-Report Scale (adult).

The results page formats the stored data from the previous tests into a viewable table of test results. The results are divided into test sections, with the first two sections (Visual Attention / Continuous Inhibition) displaying average response time, test result scores, omission, and commission errors. All three tests display the eye tracker points in coordinates as a chart (representing the gaze data on the screen throughout the test) using Chart.js.

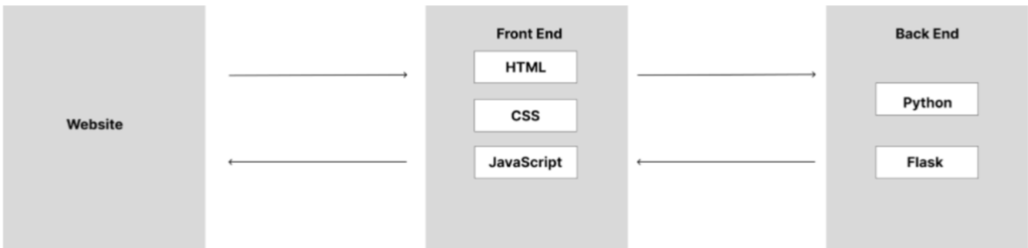

Figure 1. Overview of the solution

The calibration portion of the website is the most important part, superseding even the three aptitude tests that the website gives afterwards. If the calibration process yields a low accuracy, meaning that the user's eyes aren't calibrated, the subsequent tests will be wholly inaccurate and possibly provide a false diagnosis. As such, it is important that we have a mechanism to stop the user from proceeding if their reading is inaccurate.

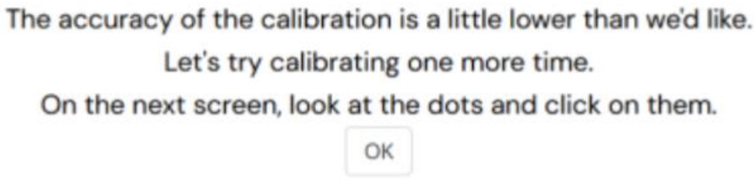

Figure 2. Screenshot of the accuracy test

```
export let recalibrate_instructions = {
  type: jsPsychHtmlButtonResponse,
  stimulus: `
      <p>The accuracy of the calibration is a little lower than we'd like.</p>
      <p>Let's try calibrating one more time.</p>
      <p>On the next screen, look at the dots and click on them.<p>
    `,
  choices: ["OK"],
};

export let recalibrate = {
  timeline: [
    recalibrate_instructions,
    calibration,
    validation_instructions,
    validation,
  ],
  conditional_function: function () {
    var validation_data = jsPsych.data
      .get()
      .filter({ task: "validate" })
      .values()[0];
    return validation_data.percent_in_roi.some(function (x) {
      var minimum_percent_acceptable = 75;
      return x < minimum_percent_acceptable;
    });
  },
  data: {
    phase: "recalibration",
  },
};
```

Figure 3. Screenshot of code 1

This piece of JavaScript code is used for the recalibration process. It involves two objects, the instructions and the setup for the recalibration trial itself. These are ‘recalibrate_instructions’ and ‘recalibrate’, respectively. The jsPsych library is used to set up this recalibration process, which behind the hood is treated as a trial. This occurs if the user’s calibration accuracy score (calculated elsewhere in the code) is too low to properly take the tests with. It performs the same test as the original calibration test. The user is asked to click on various dots and then follows up by using an eye-tracking library to ask the user to look at the various dots appearing on screen instead. A threshold of 75% calibration accuracy is required in order for the process to continue. This recalibration procedure ensures that the participant’s calibration is accurate enough before continuing with the experiment properly.

The continuous inhibition test will show the user a random letter every few seconds. This test is designed as a Go/No-Go Test designed by neuropsychologist Alexander Luria in 1940-50s, used to measure a participant's capacity for switching between several types of behavioral response ("plasticity") and control of adequacy of response (impulse control and sustained attention) [9]. The user is tasked to press the spacebar as quickly as possible whenever a new letter appears, except when the letter X appears. Our program will measure the delay of the user along with tracking their eye movement.

Figure 4. Screenshot of “Y”

```
/**
 * Event listener for keypress event
 */
document.addEventListener("keypress", function (event) {
  if (testingPhase && event.code === "Space") {
    if (ALPHABET[currLetterIndex] !== "X") {
      let endTime = Date.now();
      let reactionTime = endTime - startTime;
      reactionTimes.push(reactionTime);
      corPressedKeys++;
      omissionErrorFlag = false;
      console.log("correct press");
    } else {
      console.log("incorrect press");
      incPressedKeys++;
      comissionErrors++;
    }
  }
});
```

Figure 5. Screenshot of code 2

This piece of the JavaScript code registers on startup and is triggered whenever the user presses the space button on their keyboard. It is employed during this test in order to gauge the user’s reaction time to a letter being shown. When a key is pressed, the event listener checks if the experiment is in the testing phase and if the spacebar was pressed. If the currently shown letter is not an “X”, the server will calculate the reaction time by determining the duration between showing the letter and registering the keypress. It determines the amount of correct key presses and sets ‘omissionErrorFlag’ to false. This variable is responsible for ensuring test trial validity, and setting it to false will indicate to the system that the response was not missed. If the user hits the spacebar when an "X" shows up, the code considers this incorrect, logs an error message, and increments the 'incPressedKeys' variable.

The interference test will have a user read a passage (with a selection of child, teen, or adult difficulty) and pop up random images in the background as the user reads. It also tracks the user's eye movement as they read from left to right and can detect if the user's eyes stray from the passage.

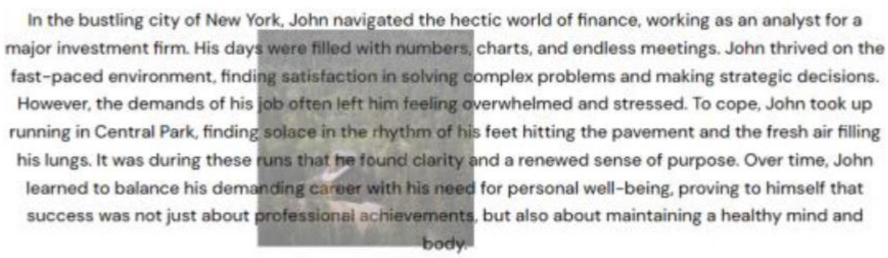

Figure 6. Screenshot of the interference test

```
let trial = {
  type: jsPsychHtmlKeyboardResponse,
  choices: "NO_KEYS",
  stimulus: HTML,
  on_load: function () {
    console.log(HTML);
    console.log("Trial started");
    testingPhase = true; // set testingPhase to true
    showRandomImage(); // call random image function
  },
  on_finish: function () {
    console.log("Finished");
    let eyeTrackingData = jsPsych.data.getLastTrialData().values();
    let trial_json = JSON.stringify(eyeTrackingData, null, 2);
    console.log("Eye Tracking Data:", trial_json);
    localStorage.setItem("attention-eyeTracking", JSON.stringify(trial_json));
    endTest();
  },
  trial_duration: TEST_DURATION * 1000,
  extensions: [
    {
      type: jsPsychExtensionWebgazer,
      params: { targets: ["#currentImg"] },
    },
  ],
};
```

Figure 7. Screenshot of code 3

The portion of the JavaScript code for the image generation page sets a trial configuration for a jsPsych experiment, commonly used in psychological studies to collect behavioral data. The trial type is 'jsPsychHtmlKeyboardResponse,' to denote that this trial will involve displaying HTML content only and requires no user input [10]. The 'onload' function when called will log the HTML content and display a random image on the screen. Eye tracking data is collected using the jsPsychExtensionWebgazer extension, which will determine if the user looks at the image while reading a passage. The test will run for 'TEST_DURATION' seconds. Once it finishes, the server will log the completion of the trial and store the eye tracking data into the user's local storage, which persists even after they close the website. The website will utilize this information later during the diagnosis phase when determining if the user has ADHD.

4. EXPERIMENT

The biggest portion of our project is the ADHD analysis software, administered through three tests. We aim to validate how accurate our software is through experimental testing between ADHD and non-ADHD targets. Through Google Sheets, we will collect user data from the tests and compare the control and test groups to determine how well our website is able to perform ADHD analysis.

In this experiment, we will have several test subjects use the website to detect possible signs of ADHD. They will be split into a control group, and an experimental group. Groups are split into three parts: children, aged under 12; teens, aged from 12 to 18; and adults over 18. The dataset for each user will be the result data outputted by the website and the final diagnosis given at the end. If the website incorrectly diagnoses a user, we deem that diagnosis inaccurate. We tally up all the accurate diagnoses at the end of our experiment and present an accuracy percentage which holistically represents how well our website can detect ADHD among confirmed and unconfirmed subjects. Subjects will be utilizing the same computer, the same web browser, webcam, and the same physical testing environment to ensure that no noise affects the results.

	Age	Intended Diagnosis	Diagnosis
1	Child	ADHD	ADHD
2	Child	ADHD	ADHD
3	Teen	ADHD	No ADHD
4	Teen	ADHD	ADHD
5	Adult	ADHD	ADHD
6	Adult	ADHD	ADHD
7	Child	No ADHD	ADHD
8	Child	No ADHD	ADHD
9	Teen	No ADHD	No ADHD
10	Teen	No ADHD	No ADHD
11	Adult	No ADHD	No ADHD
12	Adult	No ADHD	No ADHD

Figure 8. Figure of diagnosis

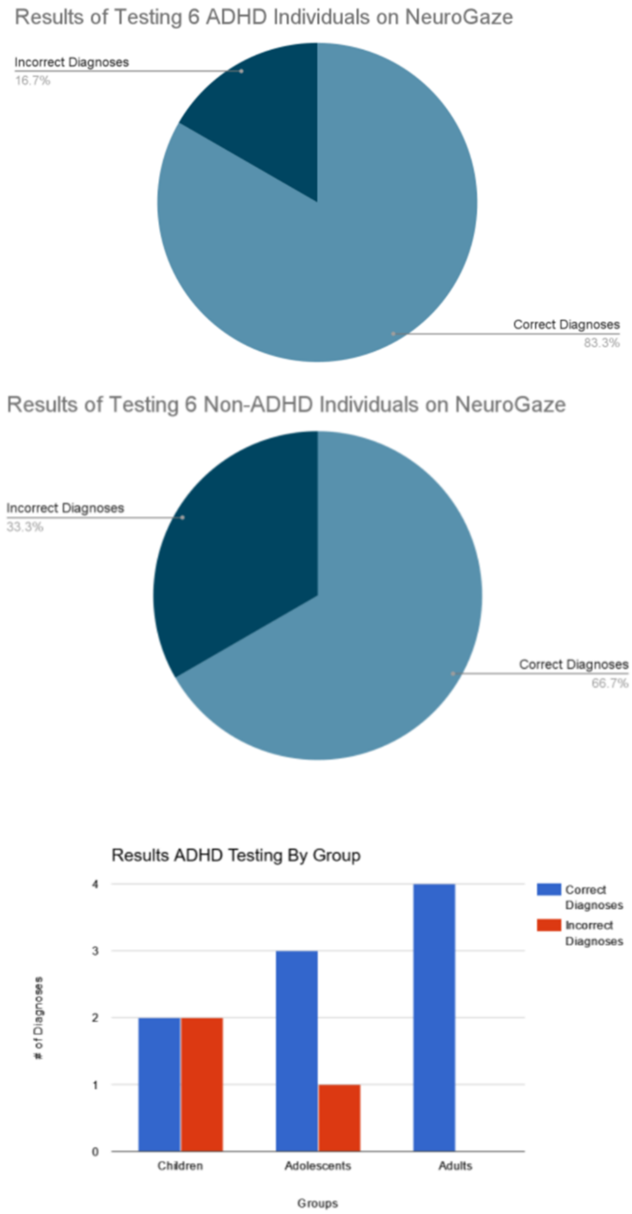

Figure 9. Results of testing 6 ADHD individuals on NeuroGaze

The accuracy score of this experiment was done in two parts. The first accuracy score was calculated from the group of subjects who had ADHD. Of the 6 individuals tested, 1 of them was falsely labeled as not having ADHD, giving an accuracy score of 83.3%. Of the 6 non-ADHD individuals, 2 of them were falsely labeled as having ADHD, giving an accuracy score of 66.7%. Cumulatively, then, the current accuracy score overall for NeuroGaze is 75%, which is a good start. We believe that if we had enough time to further test NeuroGaze on subjects, then the accuracy score would increase. The most notable part of our result data was that the two non-ADHD children tested were falsely screened as having ADHD. We will have to research further as to whether the website's screening system is too sensitive when it comes to children, if the children used in testing were too erratic, or if the children may have actually had ADHD. Regardless, it should be noted that all children tested in this experiment were labeled by the website as having ADHD.

5. RELATED WORK

In the paper “Eye Tracking During a Continuous Performance Test: Utility for Assessing ADHD Patients,” written by Astar Lev et al., the researchers explore whether the use of eye tracking software increases the accuracy and effectiveness of traditional continuous performance tests, which are used to detect ADHD [11]. Research indicated that people with ADHD spent more time looking at irrelevant areas of a given screen. The results of this paper corroborate the findings that we find in this paper with our own project, demonstrating that the use of eye-tracking software is reliable enough to use as a potential ADHD detector.

In the paper “Use of eye-tracker device to detect attention deficits in adults with ADHD,” researchers Adamis, Unal, and Mahony tested the efficacy of eye-tracking to detect ADHD in adult subjects [12]. Specifically, researchers used the Stroop test, a classic test which requires subjects to exert cognitive control and to coordinate reading and visualizing color. In this experiment, the Stroop test was administered with eye-tracking software. Results showed that adults who had ADHD had significantly longer response times with a lower accuracy compared to the control group. Overall, the researchers conclude that eye tracking is a reliable indicator of detecting ADHD. This also lends credence to our website’s claims to detect ADHD in adults.

In the paper “Use of Eye Movement Tracking in the Differential Diagnosis of Attention Deficit Hyperactivity Disorder (ADHD) and Reading Disability”, written by Pamela Deans et al., researchers utilized eye tracking technology in order to differentiate between those with ADHD and those with reading disabilities [13]. Findings showed that those with ADHD had different eye movement patterns than the control group. Overall, the researchers conclude that eye tracking alone is a suitable tool to detect ADHD given the contrast between the experiment and control group. The use of eye tracking software and the success of using eye tracking software is one of several reasons why we elected to utilize eye tracking libraries in our website.

6. CONCLUSIONS

While our website is publicly available and operational, it is a research prototype and is not without need for improvement. The calibration technology used in the website is not wholly accurate and as mentioned previously, its continuation threshold might need to be increased as we continue to test this website on subjects [14]. There are, of course, concerns with wholly using eye-tracking software to detect ADHD. However, for reasons that we outlined in the Challenges section and based on research conducted in the Methodology Comparison, we are confident that the eye-tracking software will be sufficient to detect ADHD in most users of the website for now. If given more time to work on this project, we would expand the project to include more tests and to improve and refine the calibration and analysis process. If possible, we would like to modify this website in order to be mobile compatible or even create a separate mobile app, in order for users to be able to truly take an ADHD detection test anywhere [15]. If we had to start over on the project, we might have used a different development framework or tech stack, as we are currently utilizing vanilla HTML, CSS, and Javascript without a proper frontend or backend library.

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