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Research Article

Cognitive activity detection and tracing system

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ABSTRACT

Cognitive problems like Dementia and Alzheimer's are usually challenging to diagnose but can be noticed by some signs of their symptoms. The most common symptoms are confusion, trouble finding the right word, memory loss, and difficulty concentrating. This study aims to design a cognitive activity detection and tracing system that contains games and analyzes users' performances then displays detailed statistics to the users. The proposed Cognitive Activity Detection and Tracing System (CADTS) is software that contains different kinds of games from different categories inside its body that aims to measure cognitive activity by utilizing formulations in the context of the games and give feedback to users concerning the performance analyses done. The purpose of these analyses is to catch the signs of symptoms. An insight into a possible scoring system is provided, and as our results, several descriptive statistics are shared based on the tests conducted.

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INTRODUCTION

Dementia, Alzheimer and other cognitive problems are encountered too often, and early diagnosis may be necessary for the treatment to be more effective. Diagnosis of cognitive problems is usually difficult, but there are symptoms that can be a sign of one of those cognitive problems.

The purpose of this work is to create a desktop application that is suitable for all people of all ages to play and evaluate them with their scores in the background compared to other users. Each game is built to evaluate a specific attribute, and the evaluation of a user performance of that game is done related to specific indicators. Low scores do not represent a diagnosis of any cognitive problem since these games aim not to diagnose any disease [1]. The detection and screening processes of cognitive diseases are complex, and the screening tool's accuracy is disputable [2]. However, these low scores might be a sign of a problem that may be diagnosed as a cognitive illness with the further investigation since the labeling process of the scores is based on comparisons with other players.

Games selected that fit into categories are developed by the Unity Game Engine [3]. Firebase [4] database is used

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for keeping the statistics then those statistics are analyzed. For this paper, a literature review and research of similar studies, software, and hardware specification, determining the four-game categories, developing a game for one of the categories, and interpreting the saved scores are done. After that, the development of the games for the other categories, some improvements to these games, and the user interface are implemented. After the study's goal is achieved, an application that provides people, especially people at risk of neurological conditions, with detailed reports of their performance is actualized. Users are evaluated in four different age ranges defined by the United Nations [5]. Each user is compared to other users in their age range for the specific game they played.

There are a lot of other applications that try to do the evaluation task in different ways; what sets our work apart from others is the feedback mechanism. This feedback mechanism allows users to track their past performances through a line chart, which can be e-mailed to them or their relative.

REVIEW OF LITERATURE

There are many studies conducted that show the relation between games and cognitive activities [6,7,8,9,10]. One study [6] is conducted on middle-school students with stealth assessment embedded into Plants vs. Zombies 2. In this study, the researchers created a model to test problem-solving skills and implemented this model into the game with Bayesian networks. To validate the stealth assessment, they ran a pilot study on middle-school students to collect data, analyze it and update the model. This loop continued throughout the process to measure students' problem-solving skills more accurately each iteration. They stated that their study shows a correlation between the game and problem-solving skills. Another study [10] also aims to measure problem-solving skills by utilizing stealth assessment in a game called Use Your Brainz. The researchers focus on two external problem-solving tests, Raven's Progressive Matrices [11] and MicroDYN [12]. The observation was done on 55 7th-grade students, and each played the game for about three hours across three consecutive days. The researchers state that the problem-solving estimates derived from the game correlate with the external measures. Therefore, their stealth assessment is valid.

There are a lot of existing methods and tests for measuring attention. Posner cueing task [13], Attention Network Test (ANT) [14], and Conners Continuous Performance Test [15] can be given as examples. This study focuses on visual search tasks under the attention category. In studies around visual search tasks, there are many mentions of the term "selective attention" [16]. Two visual search task examples are given in Figure 1. The example on the left side asks the user to find the number of green or red lines whereas the example on the right asks the user to find the number "2" that is blent into several numbers "5"s.

The brain is exposed to vast amounts of sensory information throughout the day. Nevertheless the brain, especially in focus, cannot fully process all of this information (i.e., traffic noise, music in the background). "Selective attention" can be defined as the brain ignoring certain stimuli (noise) to focus on an object or task. This function of the brain has been studied along with visual search tasks to be integrated into our study in the form of a mini-game under the attention category [18].

Memory is acquiring, storing, retaining, and retrieving information. Encoding, Storage, and Retrieval are the main processes of memory. On the other hand, working memory is a function that allows humans to simultaneously store and process information in immediate consciousness for a limited duration [19].

According to the studies available, there are two kinds of tests on memory. These are direct and indirect memory tests. Direct memory tests use the subject's personal experiences and aim to see whether or not the subject can give behavioral evidence on that subject. With indirect memory tests, the subject is asked to complete some cognitive or motor memory-related activities.

Indirect tests fall under four categories [20]:

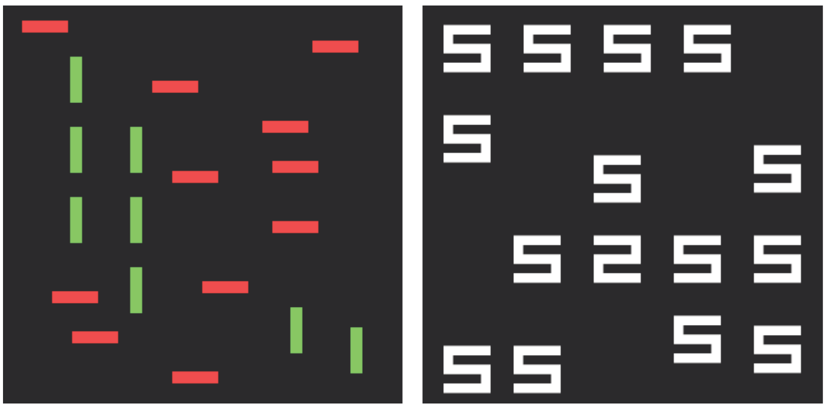

Figure 1. Visual search task (adapted from [17] with permission Visual Attention Lab).

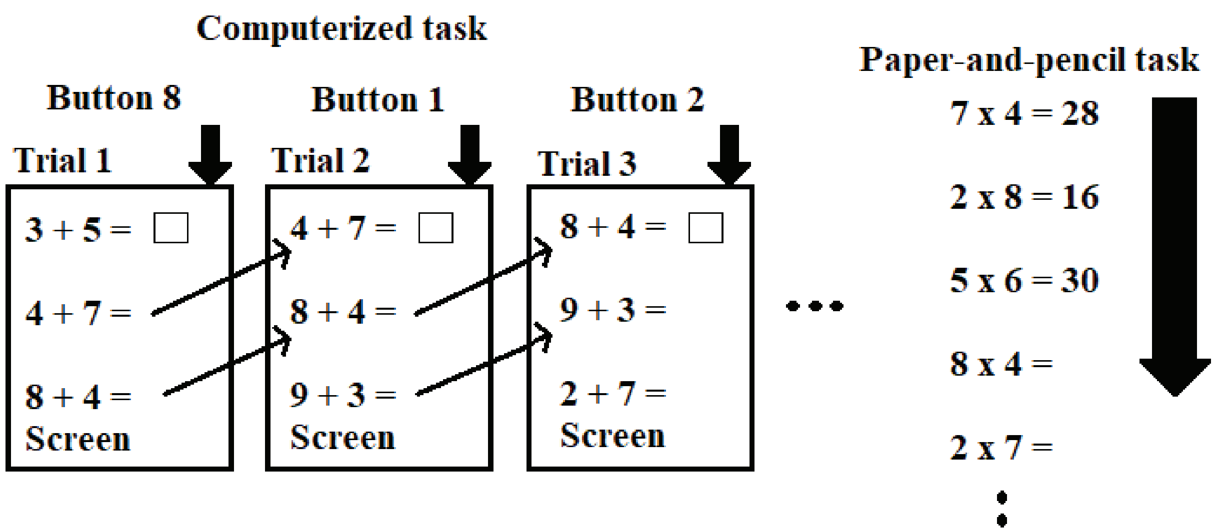

Figure 2. Schema of examples of training tasks used in this study. Training tasks consisted of computerized (addition, subtraction, and multiplication) and paper-and-pencil (addition, subtraction, and multiplication) tasks (adapted from [21], under the Creative Commons Attribution License).

- Tests of conceptual, factual, lexical, and perceptual knowledge
- Tests of procedural knowledge
- Measures of evaluative response
- Other measures of behavioral change

Suppose the tests of conceptual, factual, lexical and perceptual knowledge (especially factual) are examined in detail. In that case, it is seen that tasks that fall under this category focus more on the retrieval of information. In factual domains, the subject is asked to answer questions of general knowledge, react to certain stimuli, and categorize them [20].

In these kinds of tasks, the measurement parameters are accuracy or the latency of a correct response. The more the prior exposure to stimuli increases, the more the accuracy or latency decreases. This is called Direct/Repetition Priming [20]

Another study has been made to observe the effects of fast simple numerical calculations (FSNC) on neural systems. In this study, simple mathematical problems are asked of participants, like single-digit addition, subtraction, and multiplication, as shown in Figure 2. The ability to complete an FSNC task correlates with processing speed, quantitative ability or knowledge, and general intelligence. Previous studies of psychological interventions showed that cognitive interventions involving arithmetic or FSNC tasks lead to improvements in performance on untrained cognitive tasks (transfer effects) among the elderly as well as dementia patients. Besides the effects on the performance improvement, FSNC is used to trace the brain activity and measure participants' performance.

Studies have shown that fast simple numerical calculations (FSNC) can be used to measure a person's cognitive skills. According to a study that researches the effects of FSNC training in neural systems, by the changes on levels of regional gray matter volume (rGMV) and regional cerebral blood flow (rCBF), the effects of FSNC training can be observed [21]. Changes in rGMV and rCBF provide direct evidence that FSCN can measure cognitive skills.

Other studies are not mentioned in this section but can be accessed in [22]. Besides the studies done in the academic field, there are also a lot of commercial applications like Lumosity, Elevate, etc. These commercial applications have advertised or are still advertising themselves as "cognitive training" applications. There have been studies on the effectiveness of these applications, and there have been conflicting results. Brain training exercises can be effective in the long term [23]; however, a study that focuses on Lumosity in its experiments concludes by stating that Lumosity lacks strong evidence for improving the cognitive skills of the players [24]. In a study conducted [25], it is shown that a group of players who played Portal 2, which is a puzzle game with no intention of improving cognitive skills, outperforms the other group of players that played Lumosity on some tests.

CADTS STRUCTURE

CADTS structure is divided into four games and a feedback mechanism. The categories those games belong to are memory, problem solving, maths and attention. The use-case diagram of the system is explained in Figure 3.

Memory

The game that has been developed for the Memory category contains four buttons in four different colors. These

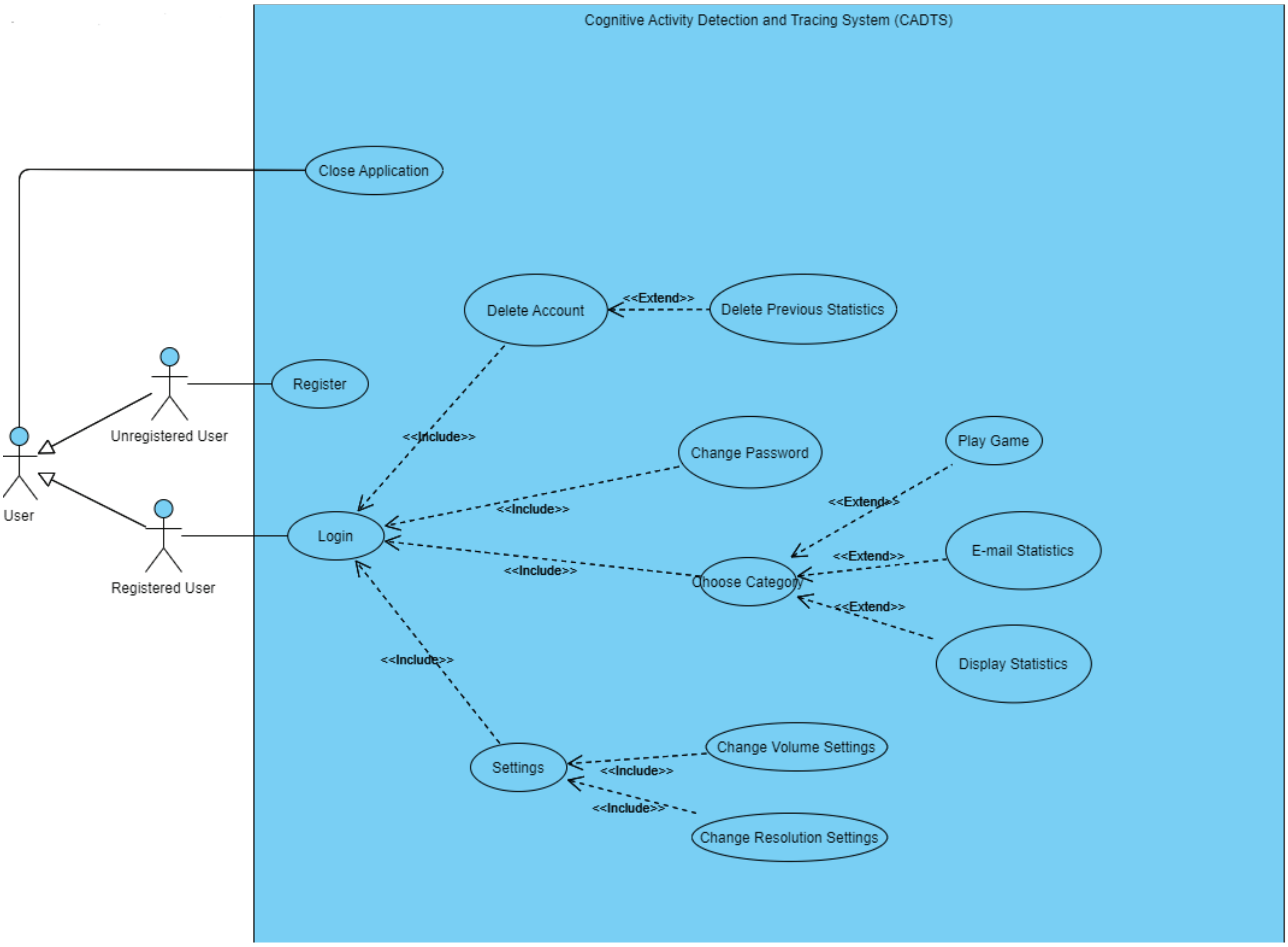

Figure 3. Use case diagram of CADTS application.

buttons start to light up in random orders three times in the beginning. After the sequence is given, the user is expected to push the buttons in the same order. After every level the user manages to provide the correct answer, another random button is added to the initial sequence. If a wrong button is pushed, the game ends. A visual from the memory game is given in Figure 4.

Figure 4. Buttons of the memory game.

This game falls under the category of indirect tests and, more specifically, tests of conceptual, factual, lexical, and perceptual knowledge. In these kinds of tests, the measure parameters are the accuracy and latency of a correct response. According to this information, the scoring of this game is calculated using the number of buttons correctly pushed (b_j) and the time (t_j) in which the level is completed. Ten points are added for every correct button push (b_m) , and at the end of the level, the total score is divided by 1% of the time passed and then multiplied by the level coefficient (l_j).

For the playthrough i with n levels, the memory score (ms_i) is computed as follows:

$$ms_i = \sum_{j=0}^{n}(b_j \ b_m \ /(t_j \ t_m))l_j \quad (1)$$

where b_j is the number of correct button pushes, t_j is the total time passed in level j, and l_j is the level index (i.e 1 for the first level, 2 for the second). The multipliers b_m and t_m in Equation 1 is set to 10 and 100, respectively, for our experiments.

Problem Solving

Problem-solving game design is based on the definition of problem-solving skill. Problem-solving is usually explained in four steps [26]:

1. Defining the problem
2. Generating alternative solutions
3. Evaluating solutions and selecting the best solution among the alternatives
4. Implementing the solution

The developed game aims to build a path from the pipe connected to the valve to the exit. Users can interact with two types of pipes, and each click rotates them 90 degrees in clockwise direction. The visuals of the pipe types are given in Figure 5. Water starts flowing from top to bottom, and rotating the pipes changes the direction the water is flowing.

Figure 5. I type and L type pipes.

The game consists of three levels with different pipe counts for each level. Pipe types and their rotations are randomly generated at each level's start. That design choice aims to evaluate every player almost reasonably since every level is randomly generated, and some people can encounter manageable levels while others can encounter challenging levels. The first level is a 4x7 map, the second level is a 5x8 map, and the final level is a 5x12 map; with that design, there is usually an average difficulty for each gameplay cycle.

A few variables are tracked during the gameplay to evaluate players' problem-solving skills when all the levels are completed. A model is created for the problem evaluation mentioned:

The model mentioned in Table 1 consists of two main attributes: planning the solution pathway, and efficient usage of given resources. If a player turns on the valve and the water flow cannot reach the exit, the player could not generate a solution and loses points. The time and length of the path are evaluated as resources, and less those values, the higher the score players earn. A final indicator of efficient usage of given resources is the rotation count for each pipe. Each pipe has four states, and the starting state of every pipe is randomly generated as mentioned before. Rotating a pipe three times yields every state a pipe can be in an order. Rotating a pipe for the fourth time results in a cycle (c_i), and the pipe goes back to its starting state, which is evaluated as non efficient, and players lose points for performing that.

For the playthrough i, the problem-solving score (ps_i) is computed as follows:

$$ps_i = t_i^{-1} t_m - w_i w_m - c_i c_m - p_i p_m \qquad (2)$$

where t_i is the total time passed, w_i is the number of wrong attempts, c_i is the total number of cycles, and p_i is the total number of pipes in the solutions. The multipliers in Equation 2 t_m, w_m, c_m and p_m are set accordingly for the scores to be balanced between players. For instance, in our experiments, players are punished more for the wrong attempts (w_m=15) than the pipe cycles they perform (c_m=5). The utilized values of the other multipliers t_m and p_m are 2500 and 1, respectively.

Maths

While designing the game, it is considered that the games should be playable for all ages. This brought a challenge since older gamers generally have difficulty playing games with certain boundaries like time, game speed, etc. According to the research, the games quickly become overwhelming for elders because of the decline in processing speed and reaction time [27]. In order to prevent this, the game's design was kept simple. Instead of using complex mathematical problems, simple numerical calculations are used. The numbers used in those calculations also kept small to decrease the player›s cognitive load.

Balloons are used to visualize the calculations. All balloons in the game have simple calculations written on their bodies, as given in Figure 6. The players need to enter the result of those calculations into the input field to blow up

Table 1. Indicators used to evaluate score in problem solving game

Measured attribute	Example(s) of indicators
Planning the solution pathway	- Water reaches the exit when the valve is turned on
Efficient usage of given resources	- Number of pipes that water passes through from start to exit (p_i)
	- Total time passed from start to the end of all levels (t_i)
	- Rotate count for each pipe should be <4 in order to avoid cycles

Figure 6. Balloon with calculations.

the balloons and earn points. There is an obstacle at the top of the game screen; if the balloons touch the obstacle, the balloons blow up. The game ends if the balloons blow up by touching the obstacle five times. The users need to blow up the balloons by entering the correct result for the balloons. The overall structure of the game is given in Figure 7.

The difficulty scaling is achieved by increasing the speed of the new spawning balloon. Considering the playthrough for the elders and younger players the balloon's speed increases by 0.25 units/seconds according to the speed of the last balloon. According to our user tests and feedback, 0.25 units/second is optimal for all the players. After a certain level which can differ for every player, the player cannot calculate the results since the balloons become too fast for the player. This is the ending condition for the math game since there is not any time limit used in this game.

Players earn 10 points for every correct answer and lose 3 points for every wrong answer. Entering the wrong answer does not blow up the balloon; the player still can enter the correct answer for that balloon before the balloon touches the obstacle. The scores of the players are compared among themselves according to a range of ages. The players get motivated to play the game when they see that their peers get better scores; they also get motivated when they see their scores increase over time. The feeling of progress is the key to the motivation of the players.

For the playthrough i, the math score (mas_i) is computed as given in Equation 3,

$$mas_i = co_i\, co_m - w_i w_m \tag{3}$$

where w_i is the number of wrong answers, and co_i is the total number of correct answers. The multipliers co_m and $_{wm}$ are used with the values of 10 and 3, respectively.

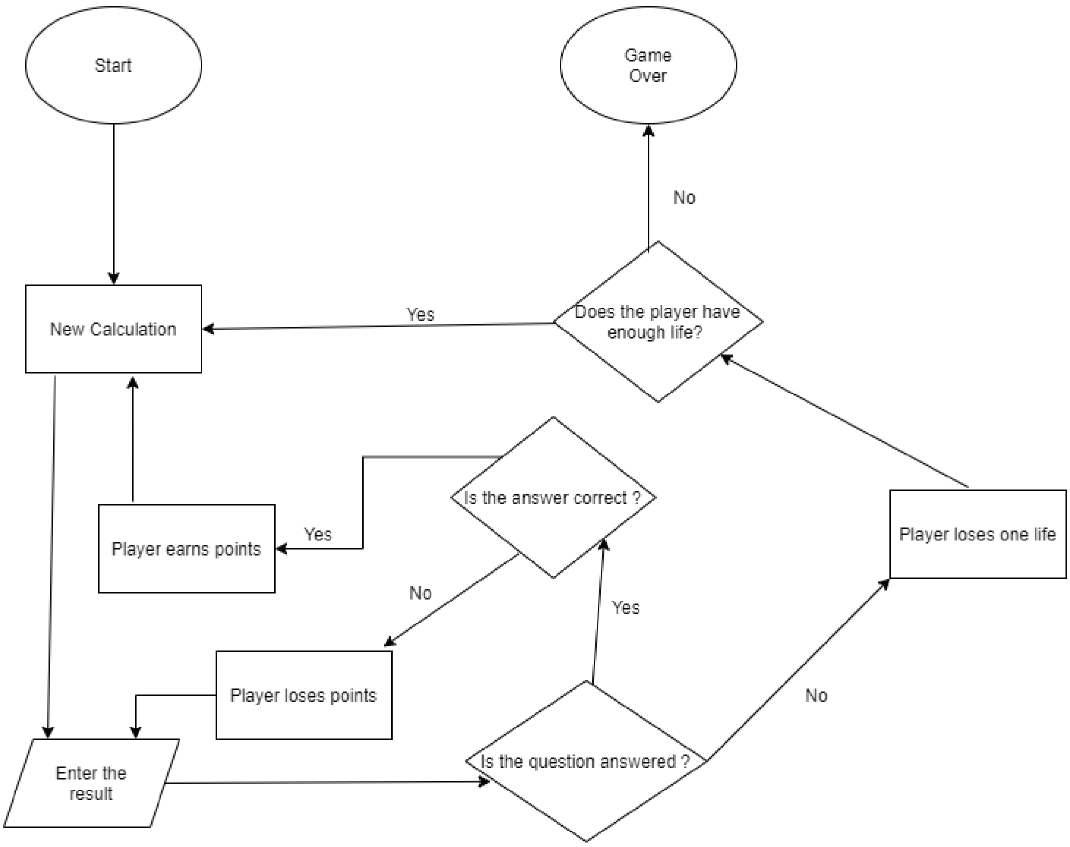

Figure 7. Flowchart representation of the math game.

Attention

The attention skills of a person can be analyzed in different branches. The design process of the game in the attention category focuses on the "selective attention" branch. In the game view, two pasteboards and two different random generated strings are written on both. Players are expected to select the pasteboard with left and right arrow keys which contain the uppercase letter string written on it. After the player chooses a pasteboard, new random strings are generated and written on the pasteboards again, this cycle continues until the time is up, which is displayed on the top right. If a player makes five mistakes back to back, the game will be ended directly to limit the player and increase the quality of the data collected; on the other hand, three seconds will be added to the time limit for every five correct answers given back to back. The main goal of the game is to spot the string that includes the uppercase letter and select the postcard that the string is written on with the correct arrow key as fast as possible for each iteration. An example in-game visual from the attention game is given in Figure 8.

Figure 8. In-game screenshot of two postcards with strings written on them.

The parameters used in evaluating players' performance in visual search tests are the number of correct/incorrect answers and the reaction time given to these answers separately. Reaction time (r_i), is the time passed between the appearance of the strings and the input taken by the player. In the evaluating the player score, the arithmetic mean of those reaction times (ar_i) is used.

For the playthrough i, the attention score (as_i) is computed as given in Equation 4,

$$as_i = ar_i^{-1} r_m + co_i co_m - w_i w_m \quad (4)$$

where ar_i is the average reaction time (arithmetic mean of r_i values), w_i is the number of wrong answers and co_i is the total number of correct answers. The multipliers r_m, w_m, and co_m are used with the values of 2.5, 2.5, 5, respectively.

Feedback Mechanism

The feedback mechanism is a simple yet informative system. It is divided into two sub-mechanisms where one is visible to the user in the statistics menu. At the same time, the other is based on an e-mail system to inform the relatives responsible for the user.

The first sub-mechanism is percentage-based comparisons displayed individually in the statistics menu for every game. Three statistics are displayed to the user in this branch. The first statistic compares a user's last score to the average of their previous scores. An example message is "Your last score is 21.4% better than your average score". The second statistic is similar, but instead of comparing to the user's past scores, the last score is compared to other users' average scores in the same age range. The final displayed statistic is a comparison between the user's average score and the average of the other users' scores within the same age range. These messages help users see if they are performing better or worse compared to themselves and others in their own age interval.

The second sub-mechanism, which discriminates our study from the others, is a function that creates a line chart using all past scores of the user in the selected game category and sends an e-mail to their registered relative. It provides an easy-to-interpret visual to see whether the user's performance decreases or increases.

PRELIMINARY RESULTS

Preliminary tests were conducted on eight individuals between ages 25-64 and have no confirmed diagnosis of any cognitive problems. A developed application was sent to those individuals, and there were no restrictions for accessibility to any game; players could play each game in their

Table 2. The data collected during the preliminary tests

	Attention	Math	Memory	Problem solving
Highest score	350.38	407	55157.5	270.93
Lowest score	34.42	118	1182.14	79.11
Average score	112.96	244.23	21383.84	139.38
Total games played	35	47	25	71

environment for an unlimited number of times to produce more data. Table 2 is divided by category names since there is only one game for each category.

Although each game has its tutorial section, it is not possible to know if users followed the tutorial on their first playthrough to get an understanding of the game or not. To take problem-solving game as an example, it is not correct to say the person who scored 139.38 might be showing a sign of a cognitive problem from statistics at first glance. This low score might be the individual's first game, and the individual might have spent time understanding of the game or made a mistake while trying.

It is incorrect to bind a score to a sign of a problem in short-term statistics observation. This study requires regular data collection with minimum technical issues by the users' side in the long term to interpret the data.

CONCLUSION

This study proposes the CADTS system, which includes a game under the categories of memory, problem solving, mathematics and attention. For each game, the game's structure and the scoring function is explicitly described in detail. CADTS has been tested by people of various ages, and a small collection of data is recorded in the target database, which gives a clue about skill distribution in categories and ages. In commercial applications similar to CADTS, in terms of the structure of the games, the scoring systems are not explicitly stated. Thus, with this study, an insight into a possible scoring system for different types of games is contributed. Our results show that the scores of people with no known cognitive illnesses are relatively close. However, for a generalized conclusion, more data is required. The controversy over the efficacy of brain training applications [24,25] is known and is expected to remain a research area.

With the consultation of neuroscientists, current games can be further improved for more accurate results, and new games can be implemented. The current comparing system relies on the users' performances and makes comparisons between them; this system can be further improved with a detailed classification mechanism that uses more data.

Based on these data, this study could be progressed into a product that can catch signs of dementia and some of the other issues related to those skills and also keep track of the diagnosed people. With all the improvements mentioned, this study could be used in professional applications in the future.

AUTHORSHIP CONTRIBUTIONS

Authors equally contributed to this work.

DATA AVAILABILITY STATEMENT

The authors confirm that the data that supports the findings of this study are available within the article. Raw data that support the finding of this study are available from the corresponding author, upon reasonable request.

CONFLICT OF INTEREST

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

ETHICS

There are no ethical issues with the publication of this manuscript.

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