On-line Computer Test System for Remote Assessment of Neurological Patients: Part A Standard Computer Interface Application

Peter Dabnichki, Dilshat Djumanov

Abstract- The work presents a development of an on-line system for neurological tests. A variety of congruent, non-congruent and bradikinesia tests are described. The system is aimed at patients with a variety of neurological disorders and has been tested on Multiple Sclerosis and Parkinson Disease sufferers. The current implementation uses standard PC/laptop/tablet interface and is considered appropriate for conducting unsupervised in house tests. The main aim of this development is to facilitate a link between patient, personal clinician and specialist neurologist to allow speedy assessment of treatment effectiveness and on-time interventions. The main achievement is improved accuracy of time measurement allowing for the better differentiation in the disease progression assessment and/or earlier diagnosis.

Keywords:- presents, development, disease progression assessment and/or earlier diagnosis.

I. INTRODUCTION

Multiple sclerosis (MS) is an inflammatory predominantly autoimmune disease of the Central Nervous System (CNS) showing ever increasing rates across the globe. MS mostly affects brain cores leading to muscle deficiency through demyelination, i.e. degradation of the interface between muscle and nerve. MS frequency varies depending on population characteristics and geographic location. It is most prevalent in the white population of northern European descent and in populations living in temperate climates affecting females more (≈2:1). The underlying reasons for this difference are still unknown. The existing research suggests that both genetic and environmental factors influence the frequency. The highest prevalence of MS occurs in the Orkney Islands of Scotland at a rate of 250 cases per 100,000 population while 2 cases per 100,000 in Japan and is exceedingly rare in Africa [1].

MS progression follows different patterns reflected in the classification of distinct types of MS. Four distinctive varieties occur: primary progressive, relapsing remitting, relapsing progressive and secondary progressive phenotypes. There is a wide range of symptoms neuropsychological from visual impairment to cognitive issues up to depression and even in extreme cases bipolar disorder or physical such as ataxia (inability to coordinate the movements of muscles), hemiparesis (weakness on one side of the body) or paraparesis (partial paralysis of the lower limbs). Very frequently occurring is weakness and incapacitating fatigue [2, 3]. Diagnosis of MS is not always straightforward especially by medics not specialising in neurological disorders that may result in delay and inefficient treatment. However, the online technologies allow to link computers and medical devices and this way facilitate the interaction between the general practitioners and relevant specialists. Here we present a software developed for patients with neurological disorders as focus is placed on Stroop tests that could be shared regardless of the physical address of the relevant parties. Although the work was initially focused on MS patients, additional development is being conducted for other conditions.

II. METHOD (ONLINE COGNITIVE TESTS, DATA COLLECTION AND ADMINISTRATION)

Cognitive impairments in information processing, attention and executive functioning are widely reported in patients with MS [4]. The words listed in table one represent the congruent and non-congruent test. Naming the font colour of the first group of colours is easier and quicker than the second. The performance measured by certain temporal parameters demonstrates the Stroop effect.

Test 1	Test 2
Green, Red, Blue, Green, Blue, Red	Green, Red, Blue, Green, Blue, Red

Table 1. Stroop test effect

J. Ridley Stroop, in his experiment, administered several variations of two main tests. Stroop referred to his tests as RCN, to stand for "Reading Colour Names", where participants were required to repeat the written meaning of words with differing coloured fonts, and NCW, to stand for "Naming Coloured Words", in which participants were asked to orally identify the colour of each printed colour name. Additionally Stroop tested his participants at different stages of practice with each task, to account for the effects of association [5]. The original paper is one of the most cited papers in the history of experimental psychology, leading to over 710 replications [6,7].

The Stroop test has been utilized to investigate a variety of psychological disorders. EEG and fMRI studies of the Stroop effect have revealed selective activation of the anterior cingulate cortex during a Stroop task. According to Kujala et al [8], cognitive functioning evolves over time in patients with MS. The Stroop test can be used to analyse the current state of such patients in

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addition to other cognitive tests [9] since, progressive cognitive deterioration should be considered as one of the characteristics of multiple sclerosis. Edith Kaplan's group (developer of the Delis-Kaplan neuropsychological test battery) developed the task further by separating the task into four different stages: naming colour fields, congruent colour words, incongruent colour words, and combined. The additional strain on the executive function of the brain allows for a more precise diagnosis [9].

A number of studies showed that MS patients have attention problems i.e. slower cognitive process [10]. Cognitive process is a psychological process involved in acquisition and understanding of knowledge, decision making and problem solving and is distinct from emotional and volitional processes. MS patients have been found to be consistently slower when performing Stroop tests [10,11]. Results presented in [10] are replicating some previous findings [10-12] suggesting that the MS patients may have a specific impairment in selective attention. The extent to which MS slows cognitive processes has been reviewed in [13] where speed tasks were administered to 22 participants with and without MS. On all tasks, patients with MS responded more slowly than comparison subjects.

III. SOFTWARE DESIGN USING A KEYBOARD/TOUCH INTERFACE

As a result of research, the Stroop test software has been developed utilizing ordinary computer keyboard. The system was built with three tier architecture separating logical layer from storage. Three different Stroop tests were pre-programmed allowing comparison of results between their outcomes.

Test 1. Three equidistant keyboard keys should be marked with stickers (or equidistant spots for tablets represent keys). For a standard key board

Key "C" = Red; Key "M" = Green and Key "Y" = Blue

For **Test 1**, Black & White text is used for a random flash of a series of three words Red, Green and Blue once a Space key is pressed. The flashing of a word on a screen is a stimulus to react to. The time that it takes from the stimulus to lift a finger from the Space key to hitting the appropriate target key is measured.

Test 2 differs from Test 1 by using coloured words which represents the word meaning i.e. word Red is displayed in red colour and word Blue is displayed in blue colour. The same parameters and variables are measured during the test.

In Test 3, the above mentioned words are displayed in random colours. The user has to ignore the printed word and respond to the colour of the word, which involves a cognitive task. Similar to the previous tests the reaction times are measured and the procedure is listed in table 2 below. The block diagram is shown in Appendix 1.

Table 2. Test Structure and Execution Sequence

	Test procedure for each step	Outcome and parameters obtained
1.	Subject presses the space bar and holds	Starts the test generator
2.	Visual stimulus is displayed	Randomly within 0.5 to 4 s from beginning of step 1
3.	Subject releases the space bar as fast as possible	Reaction time is obtained
4.	Target key hit	Step completed

IV. PERFORMANCE PARAMETERS

The following performance parameters have been introduced:

- **a.** Time difference between 3 and 2 is called Central Reaction Time.
- **b.** Time difference between 4 and 3 is a Peripheral Reaction Time.
- **c.** Time difference between 5 and 3 is a Total Reaction Time.
- **d.** Accuracy is the number of correct/incorrect keys hit during each test.

The parameters described above were jointly developed with specialist's neurologists and implemented in the software presented in this work. **Error! Reference source not found.** represents a block diagram of the software. The application was build using .NET environment with a dedicated storage server for use from any location with internet access. A login system was implemented to prevent unauthorized access. After the application is started a password prompt window is displayed. Two types of users are defined: admin and ordinary user as shown in Fig 1 below. An admin user has access to all features of the software as well as the user management window.

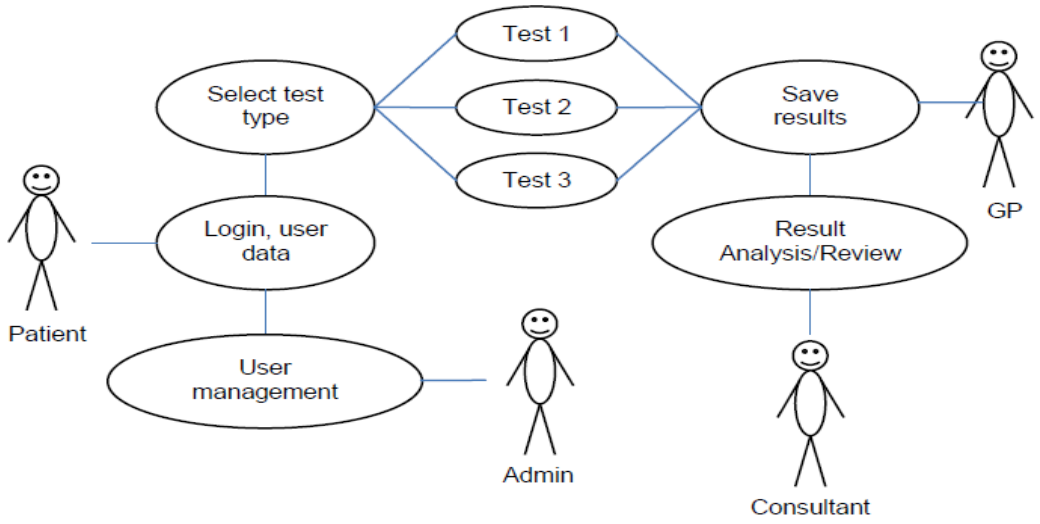

Figure 1. Diagram for Stroop test software structure (keyboard version).

Once the correct username and password combinations are provided then the test number can be selected. Currently 3 different tests have been developed. In the first test the colour word is displayed in black and white and the user has to react to the meaning of the word, by pressing the appropriate coloured key on a keyboard. In the second test the colour words are displayed in different colours and the user has to react to the meaning of the word rather to its colour. In the third test the colour words are displayed in random ink colour and the user reacts to the colour of the word ignoring the meaning. The results of each test can be reviewed using the Results window. It contains several filters such as test date, test type and displayed values. One can monitor the progression of tests observing several calculated parameters: Central reaction time, Peripheral reaction time, Total reaction time and Accuracy (Fig 2 below). Compared to Test 1, the second test is slightly more complex as words are displayed in random ink colour and the user should react to the meaning of the words only. The results of each test vary depending on personal abilities of a user. The second test results are displayed in Fig 3. It can be seen that the user achieved better performance towards the end of the test.

The third type of test window and associated results are displayed respectively in Fig 4 and Fig 5. In this test the user should react to the colour of the word while ignoring its meaning. When the word "Brown" is displayed in yellow colour, the user should press the yellow key rather than the brown key. When the number of set repeats is achieved the software saves all data into a database on an external server. This is to avoid data loss due to unstable connection that occurs when data is sent in packets. Every single key-pressing is recorded and confirmed once recorded. If connection is lost a local copy of the data is created, and sent to the server when connection to the internet is restored.

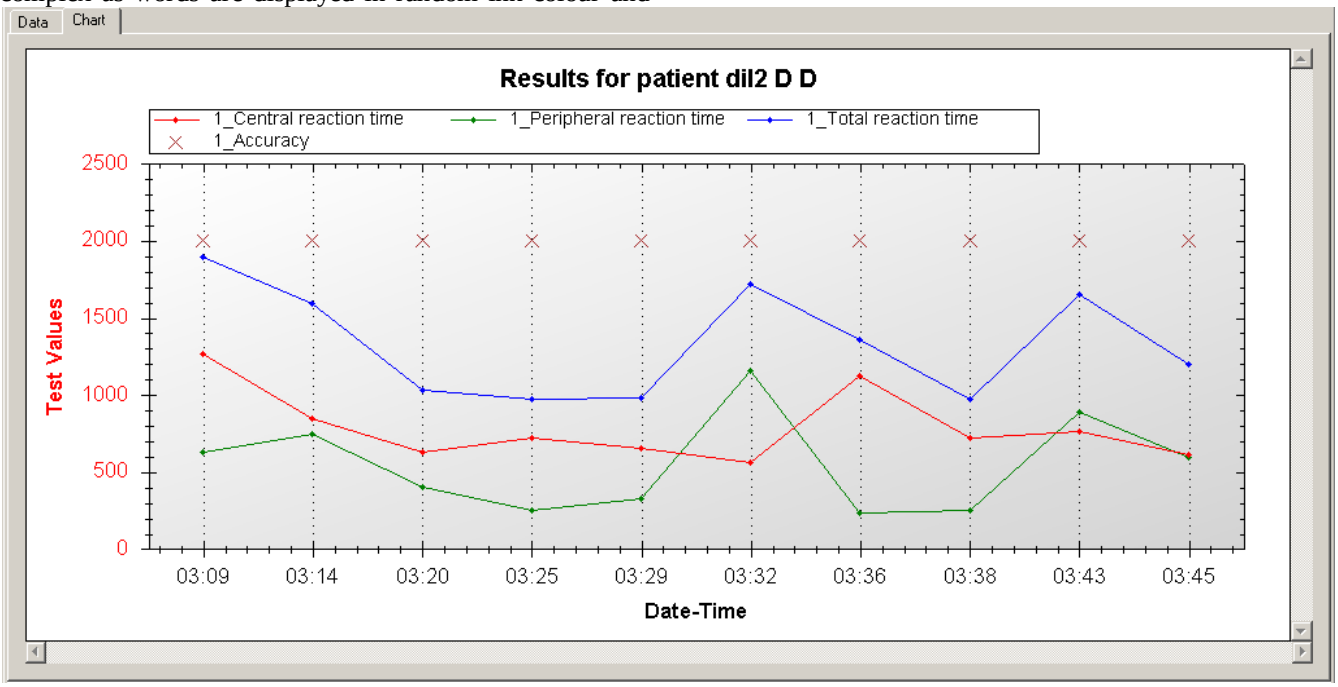

Figure 2. Software results for a Stroop test software using Keyboard (Test1).

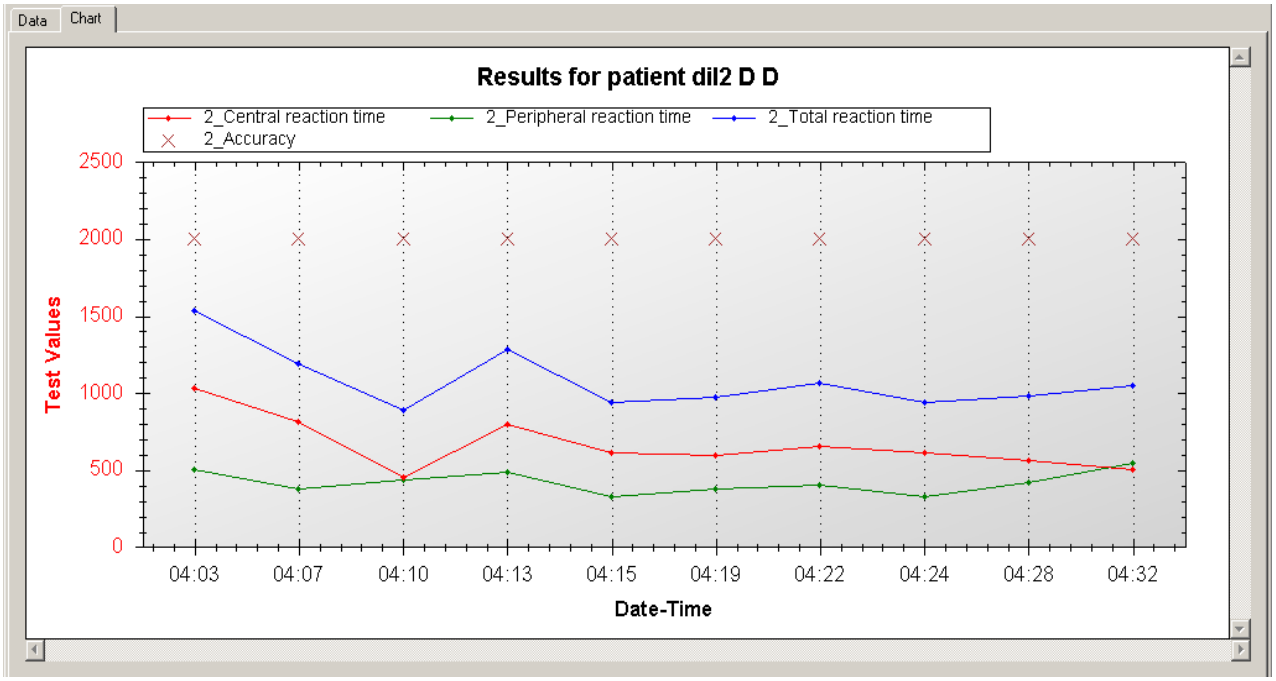

Figure 3. Software results for a Stroop test software using Keyboard (Test2).

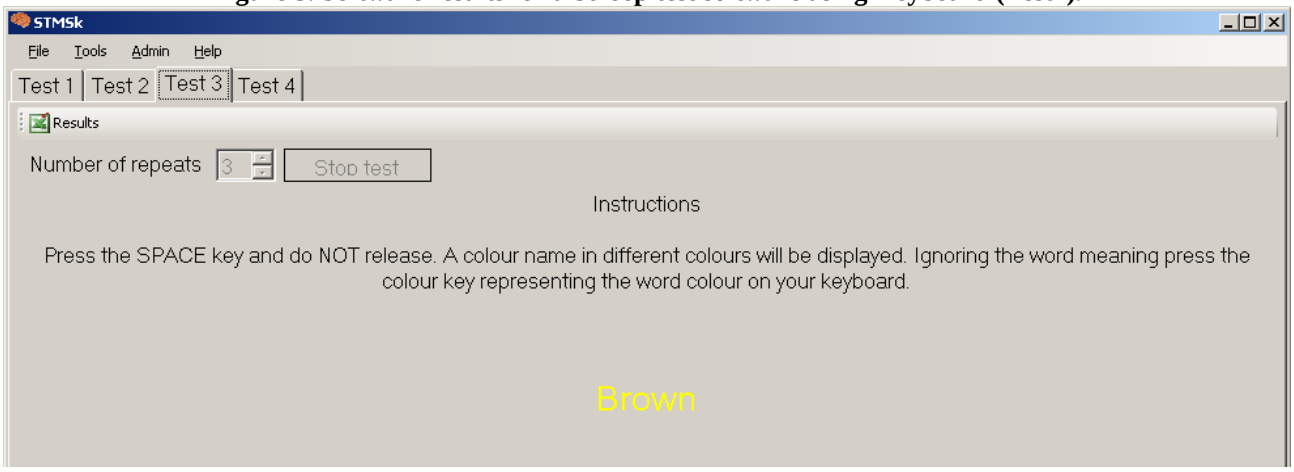

Figure 4. Software for a Stroop test software using Keyboard (Test3).

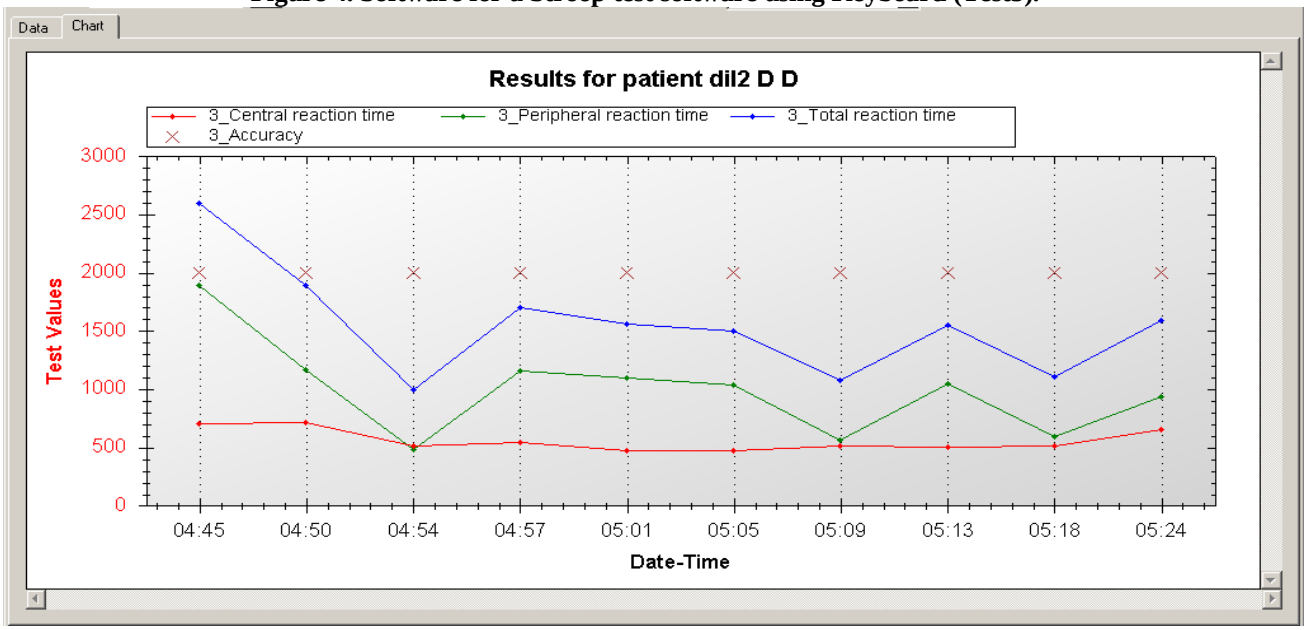

Figure 5. Software results for a Stroop test software using Keyboard (Test3).

In order to identify disorders in the rate and accuracy of upper limb movement a fourth test was developed. It involves consecutive taping of two keys located at about 15 cm from each other. The test is performed first with the right hand for 60 seconds and then repeated with the left hand which is adopted for diagnosis of Parkinson Disease (PD). Six parameters are calculated after the test including total number of keys, the number of keys pressed correctly, Kinesia Score - the number of keystrokes in 60 seconds, Akinesia Time - cumulative time that keys are pressed, Dysmetria score - a weighted index calculated using the number of incorrectly hit keys corrected for speed and Arrhythmia score - a measure of rhythmicity which corresponds to the variance of the time interval between keystrokes. These parameters correspond to disease severity. Since the values of different parameters vary substantially, scaling is introduced while drawing results. Each parameter can be scaled or un-scaled to match to the rest of the graph lines. Users can perform custom calculations by using raw data in the Data tab. These parameters are illustrated in

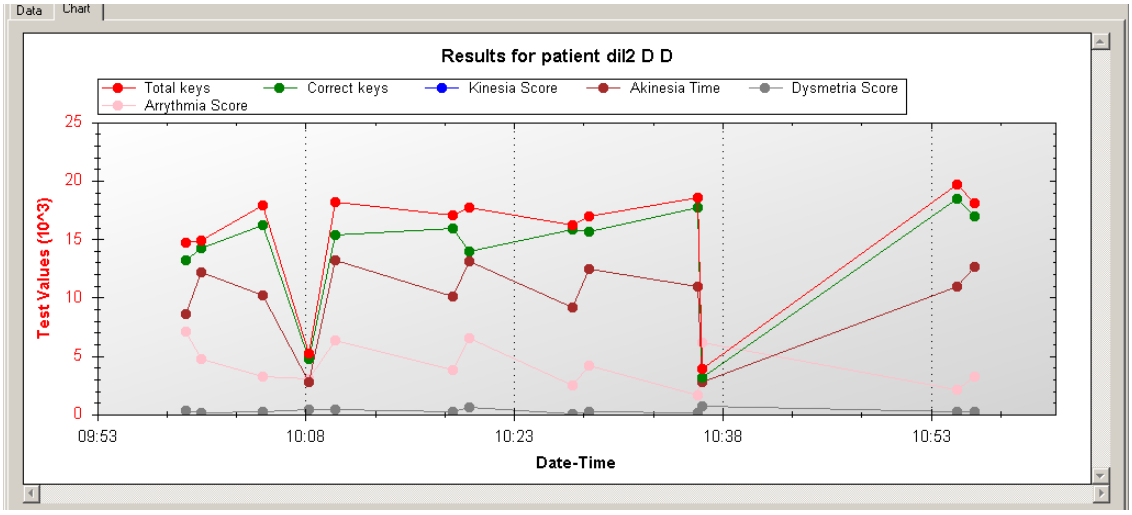

Figure 6. Graphical presentation for Kinesia test results (Test4).

Key msec	Time Diff	Key Supposed	Key Value	Key Down
953	0	0	186	1
15	62	0	186	0
343	328	83	83	1
437	93	83	83	0
781	343	186	186	1
859	78	186	186	0
171	312	83	83	1
250	78	83	83	0
578	328	186	186	1
656	78	186	186	0
968	312	83	83	1
46	78	83	83	0
390	343	186	186	1
468	78	186	186	0
796	328	83	83	1
859	62	83	83	0
187	328	186	186	1
265	78	186	186	0
578	312	83	83	1

Figure 7. Recorded data results for Kinesia test (Test4).

V. RESULTS AND DISCUSSION

The presented software was implemented as a suite of tests has been implemented and is run on non for profit basis to enable development of early diagnosis methods and procedure for effectiveness of treatment and assessment of patient status. As such the software allows to both build patients profile and provide targeted treatment with a constant involvement of the specialised neurologists and allow to enhance our understanding of the disease accompanying symptoms their progression. It builds on an earlier work [14]. It allows to avoid complex physical testing procedures such as those presented earlier [15,16] where extensive lab facilities are used and more importantly. The use of the software showed that its biggest advantage is its flexibility, ease of use and virtually no requirements re equipment specification. However, its usability for research purposes is more limited as the actual accuracy is about 60 ms on average as keyboards and tablets have built-in delay prior to accepting the signal. This reduces the ability of clinicians to differentiate between the different cases. After numerous tests, we embarked on the development of a dedicated interface for use under

supervision to complement and address some deficiencies of the presented software main ly due to the utilised standard computer interface.

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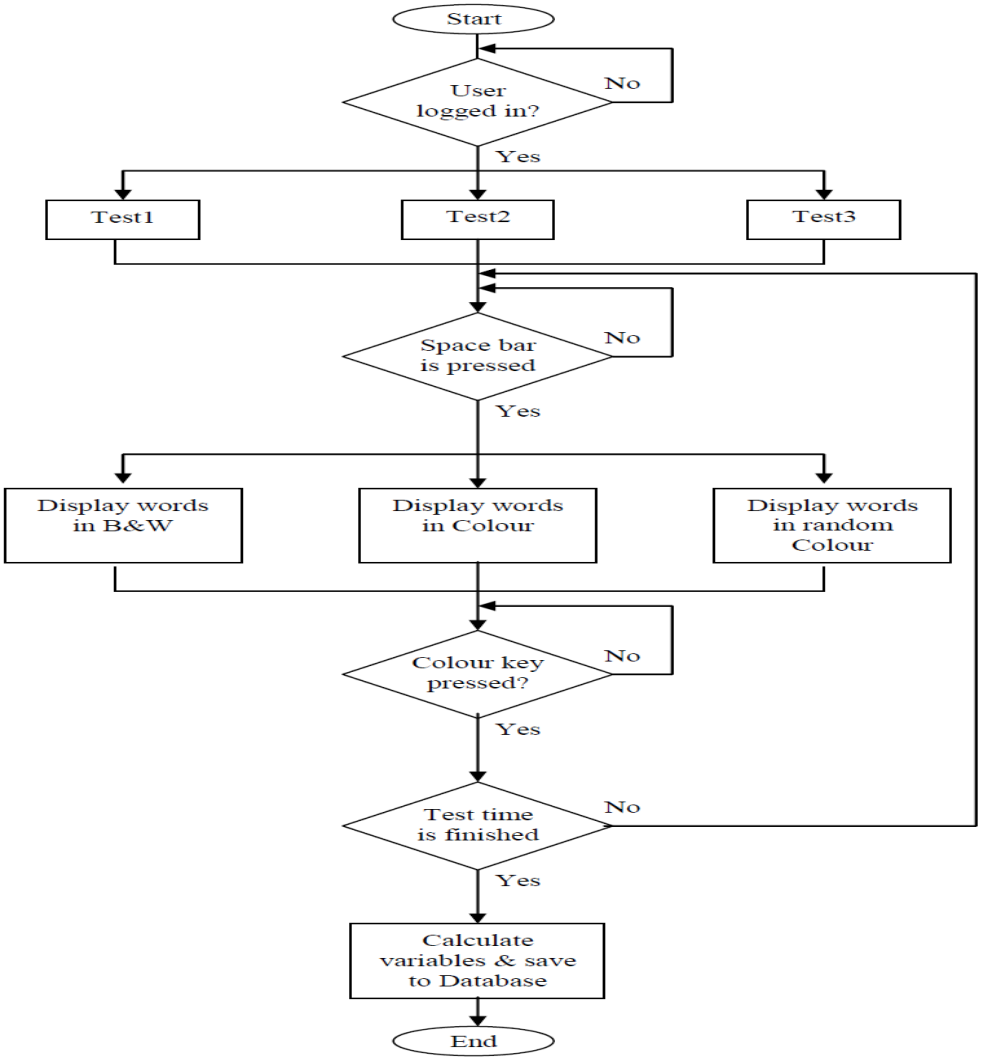
APPENDIX 1

Block diagram of the Stroop test software using Keyboard.



APPENDIX 2

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User directions for performing Stroop test using Keyboard (Test4). Welcome to the Bradykinesia/Akinesia Incoordination (BRAIN©) Test.

This is a short, simple, software-based medical device that is used to pick up disorders in the rate and accuracy of upper limb movement.

Now that you have successfully downloaded and installed the test to your computer, you should read the instructions below. The data collected from this test will be uploaded to a secure online database and analysed by experts in the nervous system and movement disorders. The full patient information sheet is available on the Predict PD Website, and should be read before agreeing to undertake this test.

At the bottom of this window you will see two boxes: agree and disagree. If you wish to undertake this short test, having read the patient information sheet, please click on 'agree'. If you do not wish to take the test, click 'disagree'. If you click 'agree', you will pass to the next window, which requests a unique username and password. You should use the username and password allocated to you on registering with the Predict PD website.

In the interests of ensuring best-quality data, try to do the following:

- Sit comfortably directly in front of your computer.
- Place a single red sticker (provided) on both the 'S' key and the ';' key. These are approximately 15cm apart on a standard desktop keyboard.
- Adjust the seat/computer height (if possible) to ensure that your arms are just above the keyboard when your elbows are flexed to 90 degrees.
- When the timer starts, use your index finger of your right hand to alternatively strike the two keys marked with a red dot.
- Do this as fast and accurately as you can.
- The test will last for 60 seconds.
- Repeat the test for the left hand, again using the index finger.