COGNITIVE FUNCTION MONITORING PLATFORM BASED ON A SMARTPHONE FOR ALTERNATIVE SCREENING TOOL

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ABSTRACT
Neurological assessment is a commonly mental screening evaluation for initial neurological disorders in patients. Mild Mental Status Examination is a standard screening test which is used as one of the tools for diagnosis. In Thailand, Thai Mental Status Examination was used to screen the Thai-patients.

This preliminary study aims to provide an alternative screening and monitoring tool for dementia. The tool is focused on both processing and analyzing choice reaction time with a smartphone application. The application was composed of ‘TouchTap’, ‘MindCal’, and ‘MatchTap’. Three tasks have calculated new indices indicating the level of cognitive function in the form of game. The application was tested by 3 groups of player including young adults, middle-aged adults, and older adults.

This results showed that older adults were significantly different from other groups in terms of score in ‘MindCal’. All results indicated a relationship through linear equations and correlation coefficient. For the correlation, ‘MindCal’ was a strong positive correlation (r = 0.83) but other games were a weak positive correlation (r = 0.5) indicated influencing factors; such as age and educational background as similarly the conventional method.

In conclusion, smartphone application would be an alternative screening tool for the measurement of reaction time.

KEY WORDS
Neurological Assessment, Touchscreen Device, Cognitive Function, Mobile Application, Neurological Disorders, Telemedicine

1. Introduction
Dementia is a brain dysfunction which brain abnormally performs in perception, memory, decision processes and executive functions. Common symptoms are identified by the change in behavior and personality. Normally, the general screening of this dysfunction is Mild Mental Status Examination (MMSE) [1]. The examination implies that gender, educational background, social and environment influence the result. After screening, the patients are advanced diagnosed by Computerized Tomography (CT) and Magnetic Resonance Imaging (MRI) modalities to confirm abnormal brain regions. This dysfunction does not have exact treatment procedures; therefore, the physicians apply rehabilitation processes to relieve symptoms and improve brain function.

According to statistical record in Thailand, the prevalence of this dysfunction is approximately 3.4%. However, the MMSE is not suitable for Thais because of language and culture issues; consequently, Thai Mental Status Examination (TMSE) is adapted from the MMSE [2]. The TMSE is wildly used as a standard screening tool in Thailand. As mentioned, several factors influence the results of the screening examination but the factor that influences maximum score is educational background. Higher educational background also leads to a top score. Both TMSE and MMSE indicate the same results in Thailand. Besides TMSE, there are other standard tests used in Thailand; for example, Chula Mental test (CMT) [3] and clock drawing Test [4]. A clock drawing test is a screening tool for dementia and mental retardation. For the drawing procedure, the patients are asked to draw the clock in different conditions. This drawing test depends on education, age, and emotion. The result tends to be lower in elders with low educational background and negative emotion [5]. However, the examinations are conducted by handwritten questionnaire and procedures. These analog systems have several drawbacks including loss and incorrect data. The drawbacks lead to unstable monitor for early detection process to continuously follow up their mental health. In the case of inaccurate data, the physicians cannot provide an efficient treatment plan for the patients.

This study proposes a smartphone application and touchscreen devices to be an alternative screening and monitoring tool for dementia and develop a patient monitoring system.

The scopes of this study are to determine a trend of the reaction time of all games, to generate a mathematical model in each game, and to gather data recording. Three games included in this study was ‘TouchTap’, ‘MindCal’, and ‘MatchTap’ evaluating cognitive functions and analyzing risk assessment with new indices.

The system of games requires reliable, valid, and accurate methods. The study used, therefore, choice reaction time [6], Stroop test [7], mental calculation [8,9] and Symbol Digit modalities [10] as neurological
assessments and developed a mobile application for acquiring raw data and visualizing the results. Furthermore, the advantages of using a smartphone are convenient to manage and monitor individual records effectively. As a consequence, telemedicine system is going to be implemented by utilizing the analyzed results.

1.1 Reaction Time

Reaction time is the main principle for basic cognitive function test to measure speed of brain process. The timeframe indicates processing rate of sensory – motor pathway controlled by central nervous system. [22] In addition, the reaction time can be categorized into three experiments which include simple reaction time (SRT), recognition time and choice reaction time (CRT). Components of reaction time are determined by subtraction method. The method classifies SRT into perception, stimulus discrimination and motor response. For CRT, it is categorized into 4 components; signal perception, stimulus discrimination, response choice and motor response.

All of these experiments relied on stimulus response in various conditions. [11,12] The response of choice reaction time (mean CRT = >0.384 sec) was slower than recognition (time = 0.384 sec) and simple reaction time (mean RT = 0.22 sec). In case of SRT, A comparison between result of auditory and visual conditions demonstrates that auditory stimulus (mean RT = 0.16 sec) leads to SRT faster than visual response (mean RT = 0.19 sec). Men also provide SRT faster than women within the same conditions [13].

1.2 Factors Influencing the Simple Reaction Time

Woods et al. (2015) investigated factors influencing SRT. They observed time period of data transferring between hardware and software. It is necessary for initial phase to eliminate some errors. After analyzed data were transferred, the data were set as a baseline. They informed that elders provided slow reaction time because of motor output response. Gender, age, and dominant handed – left or right – are the most influence factors. Their results also associated with fatigue, stress, and intelligence with the reaction time. However, mentioned factors do not affect reaction time if there are enough population [14,15].

1.3 Interaction for Older Adult Using Touchscreen

Motti et al. (2013) showed that application was used as a database, e-health and game application. The game also motivated memory and concentration process. Elders had curious intention to play a user-friendly game that had large buttons with multi-players. Moreover, the results represented that [16] using touchscreen is alternative input to evaluate cognitive function through touch, click, and slide. [17]

1.4 Reaction Time enhancing Dementia diagnosis

Pirozzolo et al. (1981) demonstrated that RT of normal elderly subjects is faster than elderly people with dementia of the Alzheimer’s type (DAT) in all RT tasks. All tasks also included simple auditory RT, simple visual RT and 4-CRT. Moreover, standard deviation (SD) criteria are used as threshold line to utilize for clinical diagnosis [23]

Storandt and Beaudreau (2004) investigated the response of reaction time to separate nondemented and demented groups by computerized screening tool. Reaction time (RT) regularly are slower in demented individuals than healthy people. However, RT task is unclear when diagnoses early stage of dementia. For early dementia diagnosis, RT task will be applied to predictive variables and compared with a standard test to confirm the results. [24]

2. Materials and Methods

2.1 Game Design and Application

The games in this study were designed based on choice reaction time and neurological assessment, which is inspired by Stroop test, mental arithmetic, symbol digit modalities, and finger tapping test. [18] The tapping test is an upper limb motor unit and collaborates function test for Parkinson disease by counting times when a single finger is pressed. The application was divided into 3 games included ‘TouchTap’, ‘MindCal’ and ‘MatchTap’ to examine the speed of visual-motor response, the process of problem-solving and short-term memory process respectively. Three games were programmed by Unity (Unity Technologies, CA, USA) which is an application engine for game development and android studio providing the fastest tools for building an app. all games were available as an application on android operation system (OS) to gather CRT and evaluate correctness through a touchscreen. Samsung galaxy Grand2 was selected as the touchscreen device for the entire experiments.

2.1.1 TouchTap

TouchTap was designed to evaluate perception, visual-motor control, and speed of response. This game was based on CRT and Stroop test. The rule of the game is to match random color between buttons and display. The result was given as average reaction time and score. It also indicates how fast participants can response when they are stimulated with color.

2.1.2 MindCal

MindCal was based on mental calculation and CRT. This game was utilized to evaluate executive function and
problem-solving process. Calculation stimulates left parietal and left lateral occipital-temporal cortex [19]. In fact, it stimulates short-term memory and long-term memory according to the frequency of the calculation. Common person consisted of child and teenagers take approximately 1-2 seconds in the calculation process. The principle of this game referred to mental calculation both addition and subtraction of mathematics. A result was analyzed by mental calculation time and score. The mental calculation time is shown in the equation below to investigate time when players are in mental calculation.

\[ \text{mental calculation} = \text{calculation time} - \text{response time} \]

### 2.1.3 MatchTap

‘MatchTap’ involved CRT and symbol digit modalities. The Symbol Digit Modalities Test evaluate dementia and learning problem in teenager and adult. The test is matching between symbols and values to stimulate short-term memory [20,21] and concentration. A few factors including age, education, gender and revenue do not impact the result. Rules of this game were focusing and remembering three digits before digits disappear. The result was analyzed in terms of average reaction time and score.

### 2.2 Monitoring and Web Application

A monitoring and web application comprised of a client, server communication, and visualization. A smartphone functioned as a client to send patient data to the back-end server. The server communicated by POST method of Hypertext Transfer Protocol (HTTP) and was implemented by NODE.JS which is back-end framework and add modules for data communication and analysis. The analyzed data were transferred into the database using NoSQL form for information management and web application displaying data summary and monitor.

![Block diagram of the monitoring system](image)

Figure 1. Block diagram of the monitoring system

### 3. Data Analysis

#### 3.1 Participants

Thirty healthy participants were involved in this study. All of the participants were separated into 3 groups by ages which were composed of young adults (20 – 30 years old), middle-aged adults (30 – 45 years old), and older adults (50 – 60 years old). Fifteen participants in young adult group, 8 males and 7 females with average age 23.80; Eleven participants in middle-aged group, 5 males and 6 females with average age 33.45; and Four older group, 3 males and 1 female with average age 53.25.

### 3.2 Procedure

Before an experiment, individual information was asked which are included gender, age, and systemic diseases. All participants were trained with the developed games on smartphones until familiarizing with games. During processes, the participants were asked to test ‘TouchTap’ 10 times for baseline setting. After that ‘MindCal’ and ‘MatchTap’ were tested by 10 times to gather data. the data were recorded in form of reaction time and score. Reaction time of each game was utilized to model a mathematical model by linear regression. Score was used as checking for correction of the answers. Moreover, the data were processed by correlation coefficient to analyze a relationship between the time and age. ANOVA was also performed on reaction time to compare between age groups in all games, which p-value less than 0.05 was significant.

### 3.3 Results

Figure 2 displayed relationship between average response time and age in ‘TouchTap’ using linear regression with the correlation coefficient of 0.57.

Figure 3 showed a percentages’ score of ‘TouchTap’ in each group, it indicated that the most of middle-aged group, approximately 90%, performed full score in ‘TouchTap’. An approximately 73% of the young adult group and 50% of the older group got the full score.
Figure 3. A percentage of ‘TouchTap’ score

Figure 4 displayed relationship between average mental calculation time and age in ‘MindCal.’ Using linear regression, a correlation coefficient was 0.83 demonstrated strong positive correlation for this relationship.

Figure 5 showed the percentage of ‘MindCal’ score indicating that only 21% of the young group received the full score, while other groups were unable to achieve. However, the maximum score of middle-aged group was 9 and that of older group was 7.

Figure 4. MindCal linear equation

Figure 5. A percentage of MindCal score

Figure 6 indicated a percentage of ‘MatchTap’ score that participants in both young and middle-aged groups approximately 80% received the full score. While older group around 75% received a full score.

Figure 6. ‘MatchTap’ linear equation

Figure 7. A percentage of ‘MatchTap’ score

The CRT of each game was shown in figure 8. According to the result from ‘TouchTap’, all group of participants had totally different response time by ANOVA test (p-value < 0.05). In other games, ‘MindCal’ and ‘MatchTap’, a reaction time of young adult and middle-aged groups was a similar result. In case of the older groups’ reaction time was significantly evaluated as the longest when the result was compared with the others.

Figure 8. CRT of each game, ANOVA test was used to analyze difference significantly, * represent a significant
difference from the Young group, p<0.05 with an error bar of the standard deviation.

3.4 Monitoring and Web Application System

All games which were installed on a smartphone transferred data to the back-end server and display data summaries on both the web and mobile application. The web application was shown in figure 9 can access the patient history and conclusion to continuously monitor the activity of the user.

Figure 9. the customized feature on web application

4. Conclusion and Discussion

As shown in this study, a smartphone application was designed to gather the information of each individual and their behavior of usage. By the advantage of digital processing, the test, which was changed from the conventional method to smartphone usage, can reduce the analysis time and cost. Moreover, this study demonstrated that associated factors, including age, gender and educational background, affected the result.

In addition, the application has helped to record, communicate to the back-end server and displayed data for the digital healthcare system [17]. The smartphone system, which manages and monitors digital data to decrease time-consuming and support the doctors’ diagnosis, changes conventional method of screening a person who risks of neurological disorders, recording a raw data and evaluating the analyzed data. All recorded data can be online which can access by the special doctor from everywhere. Therefore, the patient can do the test at home under the normal condition that would be a real condition of patient. The stress of hospital environment should be reduced by smartphone application. Consequently, the smartphone application would be an alternative screening tool for the measurement of reaction time.

The correlation coefficient of reaction time and age from Wood et al. (r = 0.24) [14] and Pirozzolo et al. (r = 0.23 for simple visual RT, r = 0.48 for CRT) [23] demonstrated a weak positive correlation. In this study, ‘TouchTap’ and ‘MatchTap’ results were a weak positive correlation (r = 0.57, r = 0.51) which used the reaction time conditions as similar as Wood and Pirozzolo experiment. All results were the weak positive correlation because age is slightly affected with the reaction time.

For ‘MindCal’, a result is only one showing strong positive correlation (r = 0.83) because an educational background and a career including engineers, general officers, and etc. are affected the result.

All of the games, which expressed positive trendline in term of the reaction time, was compared with age. It is possible to create new indices by choosing age as one of the variables. In addition, a slope of the linear equations would become the variables in dementia evaluation due to different slope and y-axis interception in each game. However, the study would compare the reaction time with the other factors to analyze the statistical relationship.

For the future work, we aim to improve the user interface on a mobile application and a web application to be simple, user-friendly and interactive. The mobile application has developed on iPhone OS and window OS to connect to a server. However, a result would have the large data enough to analyze and generate new indices. The indices would be compared with dementia standard tests and doctors’ diagnosis to validate outcome.

For the server communication, it has been programmed for creating framework module to analyze data from the patient and healthy people.

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