Exploring Micro-Movements for Diagnostics of Neurological Problems

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ABSTRACT
Tremor can be as a symptom of such neurological diseases as Parkinson’s disease, multiple sclerosis, and damage to the cerebellum. A successful screening method could open the way for earlier treatment that may delay the progression of presently incurable diseases. The goal of this project was an exploration of the pen-based technique for early diagnostics of the deterioration level in a person’s ability to control micro-movements. Eight subjects of different age groups took part in the pilot test. The method was based on a comparison of the personal immediate handwriting performance in copying the graphical patterns. The performance of the subjects in game-like testing was evaluated in terms of the stylus deviation and correlation of the scan path to the graph on X-axis and Y-axis separately and the task completion time when output-to-input ratio was non-less than 4. The results of a pilot testing are analyzed. They reveal that coordination problems can be registered even when the problems have not previously been detected by the person himself. We guess that further exploration of the pen-based technique for screening hand-eye coordination problems can increase selective sensitivity of the method regarding verified symptoms of neurological problems.

Author Keywords
Eye-hand coordination, tremor, micro-movements, scale-factor, diagnosis of neurological problems.

ACM Classification Keywords
H5.2. User interfaces. Input devices and strategies.
I.3.6 Methodology and Techniques. Interaction techniques.

INTRODUCTION
Rhythmic, involuntary shaking of the body parts is the most common movement disorder known as tremor. Neurological origin is linked to the occurrence of such causes of tremor as Parkinson’s disease and Essential Tremor. At such a physiological state, neurons (cells in the central nervous system) that are being activated once can be activated repeatedly and spontaneously and provoke unintentional spastic muscle activity, which is considered as a tremor phenomenon. Subtle changes caused by the disease are not visually distinguishable at the beginning of the disease. The extent of deterioration in a patient’s ability to control micro-movements should be detected as early as possible to open a way for treatment that improves the quality and productivity of the patient’s life in spite of the disease.

Movements and gestures analysis has a great potential in development of non-invasive diagnostics and screening methods of neurological disorders. There are several approaches for tremor simulation and recording. Various techniques have been proposed, most of them with complex test procedures and specialized hardware [1-5]. For example, the Precision Image-based Motion Analysis System (PRIMAS) [2] has been tested for recording movement patterns. The PRIMAS system was based on the video/digital conversion method and was able to determine the 3D position of markers in real-time at a 100 frame/s rate. The test procedures have been the following of the predefined movement patterns, such as pinching, circling and tapping, where the patient lifts all the fingers except the thumb, and then hits the table with their fingertips in the order of little-, ring-, middle- and index finger, imitating the piano-playing movement. It has been shown that Parkinson’s disease affects the test performance detectably in this kind of test setting.

We carried out an empirical study of a different technique based on an evaluation of the personal immediate handwriting performance in copying the graphical patterns when stylus movements are displayed with output-to-input ratio non-equal to 1. Eye-hand coordination in such a condition cannot compensate enough motor dysfunction, and behavioral artifacts can be detected and recorded. The “Finger Dexterity Test and Training” (FDTT) game-like application used in the pilot testing records the stylus tracking in two dimensions (X, Y) on a standard pocket PC equipped with touch screen. The advantage of a mobile device employed for screening-test of neurological dysfunctions is a very simple technique and a conventional interaction style compared to the stationary haptic devices, or multi-channel recording of micro-movements through accelerometers attached to each individual finger, or methods based on video-tracking of the tags/markers. The

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goal of the pilot testing was to assess whether we can gain data to detect differences between normal and extra or hyper activity in fingers, which decreases performance of an eye-hand coordination in people who suffer from various medical conditions. We present the results of the pilot testing with the pen-based technique and discuss whether relevant information can be retrieved from the recordings. We guess that a further exploration of the pen-based technique for screening hand-eye coordination problems could increase selective sensitivity of the method regarding verified symptoms of neurological disorders, as visible tremors and muscular rigidity appear only at a later stage in the progress of the disease.

**BACKGROUND**

The two main symptoms of neurological diseases, we aimed at detecting, are tremor and the muscular rigidity causing problems in hand-eye coordination. According to statistics from Louis et al. [6], one out of every 150 to 200 persons contracts Parkinson’s disease during their life. There are from a million to a million and a half cases in the United States alone. In healthy people a set of reflexes accompany the most basic actions: getting up, walking, turning, stopping, and smiling. In Parkinson’s patients, many of these reflexes are absent or require intentional efforts. In addition, short, alternating movements, as used when somebody brushes their teeth, are hard for them. Their handwriting usually gets small and cramped after the first few words. They tend to sit and stare, moving the eyes rather than the head to look somewhere else, even though these outward symptoms in no way indicate any degrading of mental capacities in the patient. Muscles and joints get stiffer and may become rigid. Blood circulation suffers, which may lead to other illnesses. A tendency to become withdrawn and eventually totally dependent on others may develop.

Initial symptoms of the disease are ambiguous: deep aching in joints and muscles and difficulty in carrying out tasks such as brushing teeth. The patients do not yet have any idea they have Parkinson’s disease. It can take months or even years of visits with various medical techniques to be correctly diagnosed. As symptoms settle in, walking, speaking and carrying out daily activities becomes more difficult. James Parkinson, whose name was given to the disease, described the condition in 1817. His description remains remarkably accurate: *Involuntary tremulous motion, with lessened muscular power, in parts not in action and even when supported; with a propensity to bend the trunk forward, and to pass from a walking to a running pace, the senses and intellects being uninjured.* [7]

Slow, rhythmic tremor, especially of the hands, is the most widely discussed and most obvious symptom associated with Parkinson’s disease. Tremors can be classified according to parameters of the symptoms, which are amplitude/magnitude and frequency of body vibration, or other periodic physiological signals that accompany a muscular activity. A clinical rating scale can be used for the assessment of the severity of tremor-induced disability. Another way of measuring tremor is the frequency of unintentional micro- and macro-movements of the body parts.

Table 1 shows a simple classification of the tremor according to the severity of a movement disorder.

<table>
<thead>
<tr>
<th>Degree</th>
<th>Magnitude of movements deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>No tremor</td>
</tr>
<tr>
<td>1</td>
<td>Slight tremor</td>
</tr>
<tr>
<td>2</td>
<td>Moderate tremor (less than 2 cm excursion)</td>
</tr>
<tr>
<td>3</td>
<td>Marked tremor (2 cm to 4 cm excursion)</td>
</tr>
<tr>
<td>4</td>
<td>Severe tremor (more than 4 cm excursion)</td>
</tr>
</tbody>
</table>

Table 1. Classification of the tremor according to the severity of disease. Adopted from [8].

Tremor can be classified according to body involved or according to the movement or position typical to the occurrence of tremor as rest tremor, postural tremor and intention tremor. Rest tremor occurs when without any voluntary movement, and is common in Parkinson’s disease. Intention tremor occurs during voluntary movements. Typical causes are multiple sclerosis, Parkinson’s disease and Wilson’s disease. Postural or physiologic tremor occurs when a position is maintained. Abnormal postural tremor occurs during withdrawal from addiction to drugs and alcohol. Normal postural tremor occurs during fatigue and stress. Table 2 shows a classification of tremors according to the frequency and occurrence of tremor, giving indications of the likely origin of tremor.

For some unknown reason a significant percentage of patients suffering from Parkinson’s disease never get visible tremor. In others, tremor is the main symptom and an indicator of the disease’s progress.

Our study aimed both at detecting the effects of tremor and the effects of deterioration in hand-eye coordination. In Parkinson’s disease, the severity of the tremor is slight in the beginning. A more severe tremor would affect a person’s level of test performance more. Our aim was to assess to which extent the pen-based technique could be used to detect different degrees of tremor severity. As the results showed, the effects of tremor could be detectable but additional software options should be used to increase efficiency of the method for detecting micro-movements and vibrations in hands.

Below we will discuss whether the attention should rather be focused on the problems of hand-eye coordination for developing an efficient and inexpensive screening method. The effects of proper treatment and support upon patients who have neurological diseases causing movement disorders can be impressive at the best. The research has been encouraged by patients who have frozen into practical immobility by Parkinson’s disease, but have been helped by the proper treatment including the emotional support, resulting into a release of a measure of ability to move again.
<table>
<thead>
<tr>
<th>Type of tremor</th>
<th>Frequency</th>
<th>Amplitude</th>
<th>Occurrence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rest tremor</td>
<td>3-6 Hz</td>
<td>High; decreases with target-directed movement</td>
<td>Limb supported against gravity, muscles are not activated</td>
</tr>
<tr>
<td>Example: Parkinson's disease. Initial symptoms include resting tremor beginning distally in one arm at a 4- to 6-Hz frequency. It worsens with stress and diminishes with voluntary movement.</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Action tremors</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Postural tremor</td>
<td>4 to 12 Hz</td>
<td>Low; increases with voluntary movement</td>
<td>Limb maintains position against gravity</td>
</tr>
<tr>
<td>Examples: physiologic tremor; essential tremor; metabolic disturbance; drug or alcohol withdrawal</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Simple kinetic</td>
<td>3-10 Hz</td>
<td>Does not change with target-directed movement</td>
<td>Simple movements of the limb</td>
</tr>
<tr>
<td>Intention &lt;5 Hz</td>
<td>Increases with target directed movement</td>
<td>Target directed movement</td>
<td></td>
</tr>
<tr>
<td>Examples: Cerebellar lesion (stroke, multiple sclerosis, tumor); drug-induced (lithium, alcohol)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Isometric tremor</td>
<td>~6 Hz</td>
<td>Variable muscle contraction against stationary objects</td>
<td></td>
</tr>
<tr>
<td>Example: Holding a heavy object in one hand</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Task-specific tremor</td>
<td>4-10 Hz</td>
<td>Variable occurs with specific action</td>
<td></td>
</tr>
<tr>
<td>Examples: Handwriting tremor; musician's tremor</td>
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<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 2: Classification of the tremor according to the frequency of body movements. Adopted from [9].

**METHOD DESIGN**

**Participants**

An empirical study was carried out with 8 right-handed participants (5 male, 3 female). Age of the subjects varied from 10 to 60 years. All test subjects had normal visual acuity or wore prescription glasses. None of them had previously complained on any motor or coordination problems in hands or fingers though 2 of the participants had been suffering from other more severe medical conditions.

**Hardware**

Hardware platform used in the experiment was an iPAQ pocket PC 3800 series with touch screen and stylus input. The fixed screen resolution of the device was 240 by 320 pixels. The advantage of FDTT software is a standard and affordable platform. There is also a standard desktop pc version available, where the input can be given with a mouse or stylus (digitizer). In our experiment, we tested the subjects with a device that fitted well on the subject’s hand and where the input was given with a stylus. We guessed a pen-based method adds to the sensitivity of measuring any possible problems in the subject’s game performance, and at the same time, makes the test more mobile and easier to be set up.

**Software**

The “Finger Dexterity Test & Training” (FDTT) software was originally designed to measure finger dexterity in hand-eye coordination tasks. The software application was developed in Microsoft eMbedded Visual Basic 3.0. The software allows estimation and measuring an individual’s ability to move the fingers and to control fine micro-movements when the user draws or copies predefined graphic images using a stylus input [10]. We applied FDTT software to explore a possibility to use micro-movements and behavioral artifacts for earlier diagnostics of neurological problems in children and adults.

**Training**

Before testing, the subjects were given a brief training on how to give input to the device. The training session was not fixed in length. The subjects were given basic instructions on how to copy the tracks indirectly on the screen. Special attention was drawn to handling stylus. Lifting the stylus could cause orientation problems, because after lifting the person could loose the knowledge of the location for a while. When the participants apparently could handle the task, the application was reset and the recording started. Usually, 2-4 inputs were enough to learn the application well to start the test. The application was surprisingly easy to adopt even with persons over 50 years old with normal vision (or corrected to normal).

Every time the person plays the game, s/he will usually become more and more skilled. As none of the participants had previous experience with the application, this factor did not interfere with comparisons between the subjects.

**Setting**

Test setting was a normal room, with silent background music to release any tension and concern for how results might be evaluated. During the testing, the subjects could choose a position they felt the most comfortable. The room was kept quiet. Subjects used their preferred hand in giving input. A session of about 10-15 minutes was usually enough to complete the test. Each of the 20 participants entered the total of 20 graph tracking inputs with a stylus. The input was given in successive order with only brief pauses intervening. Any breaks were allowed between blocks if the participant so wished, but all input sessions were completed during the same sitting in successive order. A visual estimation was carried out whether any extraordinary difficulties occurred in using the device during the test.
Graphs used in testing

Five graphs as a game-like scripts were designed to provoke and record micro-movements and behavioral patterns. The graphs were predefined as shown in Figure 1. The Start zone and End zone are shown with different level of gray color. 5 graphs appeared in a random order during the 20 trails done by each of the participants.

To provoke any possible problem in hand-eye coordination, the input is not done in the game field directly over the graph, but through indirect copying via reduced gestures within the input field with amplified gestures. A further provoking of unintentional micro-movements is achieved by using a different scale factor between stylus movement and scan path produced within the game field. The minimal scale factor used is equal to 4. To complete the game the player needs to cross the red rectangle (end zone). During the tracking of the graph, the application measures and records accuracy and performance of the player in terms of average deviation on X and Y-axis regarding the test graph.

The test results achieved justify the choice of the graphs’ shapes. Figure 2 shows that the graphs’ sampling was homogeneous enough in the average deviation both on X-axis (120 pxls, SD=3.6 pxls) and Y-axis (45 pxls, SD=1.1pxls).

As shown in Figure 3, at the startup of application, two fields appear: a big square - game field restricted with the black (white originally) square border (180 by 180 pixels), and the small gray (green originally) field (45 by 45 pixels), where all input is given. The bigger field has a start zone (green rectangle originally), and the end zone (red rectangle). When player moves the stylus within the small gray field and the black (yellow) track is moved to the small green box in the game field. When “primary” scan path has entered the starting zone, the game field is cleared and recording of player movements begins.

RESULTS AND DISCUSSION

We had the following three main research questions on mind when analyzing the data. Does tremor have an impact on a personal game performance? How do coordination problems show themselves in the recordings? Can relevant information be gained from the recordings to estimate whether the technique could be used as a screening method?

The performance of individual subjects was usually very close to the mean value. This observation was meaning as it makes it relatively easy to distinguish between ‘normal’ and ‘abnormal’ game performance if the test technique was applied to any person.

On the test completion the time spent and correlation factors are calculated and the results are stored in a log file.

Figure 4 shows the total averaged scores (correlation on XY-axes) and the individual results for participants 1 and 7. To find out what is the level of tremor needed to affect the results, participant 1 tested the application with simulated tremor. The recordings suggest that subtle deviations caused by invisible tremor affects the results slightly but detectably: the results are slightly poorer (corr. = 0.810) with tremor than without tremor simulation (aver. corr.=0.844). However, participant 1 performed better than the average (corr. = 0.780) both with and without simulated tremor. The differences between individuals’ performances are thus greater than the effect of slight tremor.
Figure 4. Subject 1 (with and without tremor) and Subject 7 singled out.

Figure 5. The effects of hand-eye coordination problems in Subject 7.

There is additional software option to change scale factor in a wide range. That could increase a sensitivity of the method especially in detecting the tremor effects.

At the same time, coordination problems show themselves very clearly in the data even though they no problems had been previously detected by the person himself, and they could have the greater diagnostic power. For example, coordination problems in Parkinson’s disease include difficulty in carrying out such tasks as brushing teeth, walking, speaking, and writing, and worsening rigidity.

Figures 4 and 5 show the scores of participant 7, who gained exceptionally low results in the test. The participant seven performed remarkably poorer than other subjects. Supported by the evidence from other recent symptoms, the participant 7 has in high risk of displaying the symptoms of a disease of neurological origin. A wise course to follow is to consult one’s doctor for further advice.

According to our experience with testing the FDTT application, more graphs requiring small circular movements with reverse directions have the higher diagnostic meaning. Difficulties in using computer-aided equipment usually rise with age. Unlike we had assumed, gathering tracking information from aged people proved be relatively simple. The only requirement for the testing was a normal vision (or corrected to normal with eye glasses.) Age itself did not have much impact on the results. The best results were collected with the Subject 2 (belonging to the age group 50-60). But the population sample under current investigation was restricted to make any final decision. The test might be applicable for people of various ages.

FUTURE WORK

The software used in the testing was still under development. There were a couple of known issues, but according to the visual estimation, they did not change the relative order of results between the participants. When entering the final, the red rectangle, the software could freeze for a couple of seconds, before given a chance to start a new game. Because this could confuse the user, the advisor stood near and asked the participant to wait patiently until the game proceeds to the next level. Sometimes getting into the red rectangle was unsuccessful if the box was not in the right angle. The user needed to do the entering again. These issues were caused by the inadequacy of the device’s processor (200 MHz) to perform steadily with this prototype version of the FDTT. Calculation of correlation took additional time once an input had been finished. It also seems that the software did not always display the last pixel before entering the red rectangle, so the user thought not to have yet entered the rectangle. The problems were caused by the display performance and the bugs and restrictions of an embedded display controller.

It is not enough only to measure the tremor amplitude and frequency and the hand-eye coordination performance accurately, but there must be a way of interpreting and evaluating the results effortlessly to detect the cases where the deviation from what is normal is apparent. Devices detecting tremor should aim at converting the amplitude and frequency of tremor into an electrical signal indicative of tremor and then interpreting the results in a way that is easily understandable. In our pilot testing, the results were first processed with statistical analysis and then with an estimation of the visual representations of the results. Evaluation programs and scripts could be developed for the immediate analysis of the results.

Detecting the tremor is a challenging task. There are widely different amounts of tremor, which requires consideration of measurement scales. Normal postural tremor can be of the order of 10 times greater than normal rest tremor. Tremor in Parkinson’s disease in turn can be 10 more times greater. What we now tried to do was more similar to handwriting; therefore, the small movements and screen size are currently used. A larger, full screen window might be used for more complicated tasks. The future possibilities to discern the effects of tremor by using additional software options could be tested. There is additional software option to change scale factor in a wide range. That could increase a sensitivity of the method especially in detecting the tremor effects.
CONCLUSIONS
With proper care given started as early as possible in the progress of a neurological disease the vast majority of sufferers were able to manage quite well. A test that is inexpensive, mobile and easy to use is needed. The test we experimented could be done in 10 minutes. The proposed technique could possibly be further developed progressively into a screening method to be applied after an operation, or even as a simple method to be used privately by persons who have a higher risk for neurological diseases typical to a certain age group.

The performance of individual subjects was usually very close to the mean value, but severe problems in hand-eye coordination show themselves clearly in the data. According to our experiment, actual problems in hand-eye coordination are relatively easy to detect. Graphs requiring small circular movements with reverse directions demonstrate the higher diagnostic power. We suggest setting focus on the effects of deterioration of sensomotoric skills, as they are more likely to be detected than the first invisible signs of tremor.

The study was carried out in the field of human-computer-interaction. Further research should be done under medical supervision. Recordings among people suffering from various neurological diseases might be carried out to estimate the values of deviation from the normal.

It has been suggested that various other factors such as a smoking habit could affect the results in exploring the tremor and finger dexterity. The effect of other factors could be evaluated in more thorough testing of larger samples of population.

REFERENCES