TapVis: A Data Visualization Approach for Assessment of Alternating Tapping Performance in Patients with Parkinson's Disease

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Abstract

Advancements in telemedicine have been helpful for frequent monitoring of patients with Parkinson's disease (PD) from remote locations and assessment of their individual symptoms and treatment-related complications. These data can be useful for helping clinicians to interpret symptom states and individually tailor the treatments by visualizing the physiological information collected by sensor-based systems. In this paper we present a visualization metaphor that represents symptom information of PD patients during tapping tests performed with a smartphone. The metaphor has been developed and evaluated with a clinician. It enabled the clinician to observe fine motor impairments and identify motor fluctuations regarding several movement aspects of patients that perform the tests from their homes.

CCS Concepts

***•Human-centered computing** → **Information visualization; •Applied computing** → **Health informatics;** Health care information systems;*

1. Introduction

Measuring patients' individual symptoms and treatment-related complications is one of the major challenges for the clinical management of Parkinson's disease (PD). Many of the patients are far away from clinics and due to the age and the progress of disease frequent travels are not feasible. Sometimes there is a lack of available clinicians to meet and examine patients which makes the abovementioned tasks even more complicated. Standard way of measuring symptoms and disease stage in PD is by using paper diaries and clinical rating scales. However, these approaches have limitations such as inability of the patients to recall their health status and the low inter- and intra-rater variability of the scales [PMdB*05]. Therefore, telemedicine-based systems for collecting, processing and visualizing symptom data for assessing and monitoring PD patients have been developed to improve the symptom assessment and facilitate disease management [EBN*16]. Such systems have been previously developed using data collection schemes ranging from smartphones [WGM*10] and motion sensors [TWA*17].

One of the common test exercises that patients need to perform in such telemedicine settings is the alternate tapping test [MKG*13]. They should perform alternating taps between the left and right buttons as fast as possible and try not to miss the boxes in a period of twenty seconds first with the right, and then with the left hand. Figure 1 shows how such an interface looks like. From clinical perspective, finger tapping is a motor task included in the motor section of the Unified PD Rating Scale where speed and amplitude are rated on a scale from 0 (normal) to 4 (extremely severe) [GTS*08]. In our previous work we have introduced a valid and reliable machine learning methods to rate the severity of PD motor symptoms during upper limb motor tests using data from a smartphone [MKG*13]. In the same study, we have developed a visualization paradigm, which displayed certain movement kinematics to clinicians during the tapping tests. However, the visualizations had certain limitations such as inability to visually depict fatigue and accuracy. In addition, since machine learning methods are black boxes, meaning that it is difficult to explain the decisions for the outcomes that they make, it is imperative to develop visualization tools that represent movement anomalies in a better way as shown with spiral drawing tests [JNM14]. In this paper we intro-

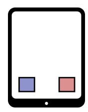

Figure 1: *An example of how an alternate tapping exercise user interface looks like. Patients have to perform alternating taps starting with one of the boxes, left or right.*

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duce a visualization metaphor designed to aid clinicians in analyzing their patients tapping data gathered by a smartphone.

The rest of the paper is organized as follows. Initially a real world dataset that has been used during the design and testing of our approaches is described. We continue with a minor but valuable contribution for domain experts in a form of improvement of the existing approaches to visualize tapping results. Next, we present our main contribution, i.e., introduce a new metaphor that visualizes motor deficiencies of patients during the tapping tests performed with a smartphone. Finally, we present the results of our informal evaluation and conclude the paper with the discussion section.

2. Data collection

During the development and evaluation process of the visualization approaches we have used data collected during an open longitudinal study that lasted for 36 months in nine clinics around Sweden [PDH*12]. The subjects performed repeated measures using a smartphone in their home environments in periods of one week in duration. On each test occasion, they performed tapping tests by alternately tapping two buttons as fast and accurate as possible. The data consisting of position (x and y coordinates of the screen), *correct/incorrect* tap, and *timestamp* were transferred to a central server where they were stored and processed off-line [WGM*10].

3. Visualization approach

The main aim of the alternating tapping exercise is to investigate different movement aspects, which could be used to indicate the upper limb motor performance of the patient. For this purpose, five movement aspects were identified according to the Unified Parkinson's Disease Rating Scale (UPDRS) [MDS03]:

- *Rhythm* – is patient able to perform the tapping test with a consistent delay between taps?
- *Speed* – is patient able to perform the tapping test fast enough?
- *Accuracy* – is patient able to tap at the predefined areas with precision?
- *Fatigue* – is patient's tapping performance declining during the test in terms of speed?
- *Hesitation* – is patient experiencing sudden delays, i.e., hesitating to perform the next tap?

This list of tasks can directly be translated into visualization tasks. Therefore, our aim was to develop an approach that would take into account the above-mentioned movements. In the following subsection we discuss the existing common approaches used to explore the data.

3.1. Enhancing Existing Tapping Visualization

In our previous work we have used up to four different views to explore the tapping movements by two clinicians [MKG*13]. In Figure 2 we present our improved versions of such views. We added color-coding to denote the tapping accuracy in each one of the views, but other than that the design was kept the same. The correct taps are represented in blue, misses in red, and incorrect taps are shown in pink. By adding the color-coding we have improved

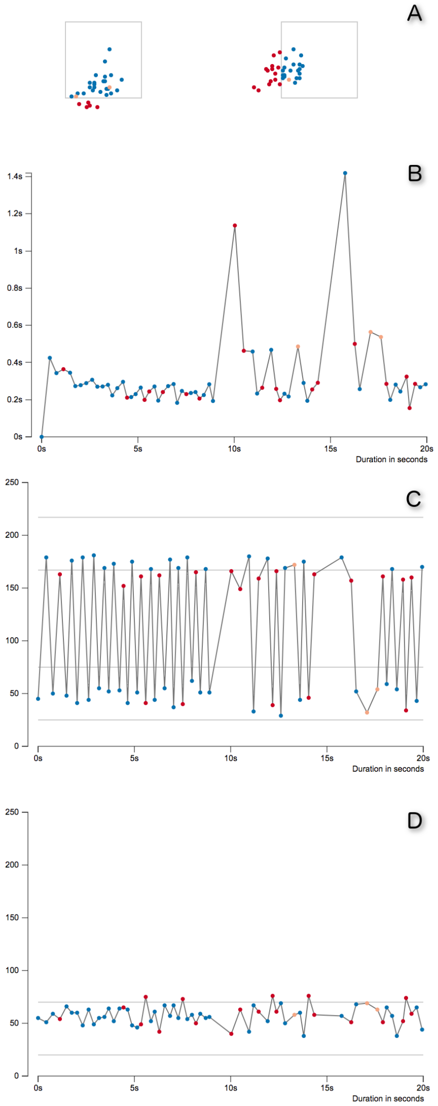

Figure 2: *Enhanced version of common charts used to analyze tapping movement patterns. The colors were added to represent correct taps (blue), misses (red) and incorrect taps (pink). (A) represents the taps as they happened in the pre-drawn boxes. (B) represents the delays between taps during the test trial. (C) is showing the horizontal displacement between taps, while (D) is showing the vertical one.*

many of the drawbacks of the existing approach. In Figure 2 (A) we can now identify number of wrong taps as they are marked with pink color, thus improving the perception of accuracy. Note that this is alternating tapping exercise and patients might make a mistake and tap one or more times in the same box while they should have tapped in the other one. Even without colors, this information can be found by looking at other charts, namely Figure 2 (C) and (D) that show horizontal and vertical displacement, but in this case the user has to shift context from one view to a couple of others to get a complete insight. Without the color, it would be impossible to identify such occurrences in a single chart.

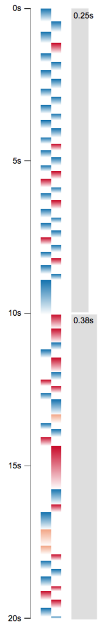

Figure 3: *TapVis metaphor. Vertical axis represents the time where each colored rectangle shows a patient's tap. The blue color represent correct taps, misses are shown in red and incorrect taps in pink. The height of the rectangle represents the time spent between the corresponding tap and the next one. The horizontal position denotes whether a right or a left tap has been performed. The two gray rectangles on the right side show the average times between taps in the first and last ten seconds.*

3.2. TapVis Approach

The main requirement in this paper is to develop a visual metaphor that would identify all movement aspects in a single view. There are several benefits for having such approaches. One advantage would be avoiding multiple coordinated views that require additional cognitive efforts to map the data in many views [WBWK00]. Another benefit would be a more compact visualization that could make comparing multiple instances of exercises easier as well as easier integration of the visualizations on smaller screens.

Our metaphor uses the same color-coding as the extension presented earlier (cf. Figure 2) and its main purpose is to give insights into the tapping performance *accuracy*. Figure 3 shows a screenshot of the proposed metaphor. Each tap is shown as a rectangle called *tapbox* that is placed on vertical axis representing the time. The vertical layout was chosen in order to depict left and right taps more intuitively. The height of the tapboxes corresponds to the time between the corresponding tap and the next tap performed by the patient. We used the gradient colors here to give the impression of time passing between consecutive taps, i.e. the color fades out after the tap occurred. There are several movement aspects that can be perceived by using this approach. A good *rhythm* score is achieved if the tapbox heights are uniform. The *speed* score is shown by the total number of tapboxes or consequently the height of the tapboxes. The smaller average tapbox height shows a better *speed* score. The tapboxes that have uncharacteristically tall height denote *hesitation*. Tapboxes are placed in the corresponding horizontal positions to provide a better perception of *accuracy* and horizontal movement of the patient in cases when patients do not alternate the tapping between the left and right boxes.

The *fatigue* is calculated as the average time per tap in the first ten seconds compared to the last ten seconds. Patient is fatigued if she/he is taking longer time between taps in the later part. We decided to show a gray bar chart in the right side of the tapboxes. Figure 3 shows a patient who is fatigued as seen by the gray bar chart. Of course this can be perceived also by analyzing and comparing the heights of the tapboxes in the top and bottom of the TapVis visualization, but that would require additional mental efforts to achieve. Also, there are cases when patient experienced *hesitation* and this will influence the perceived *fatigue*. That is why we believe the added bar chart is more effective.

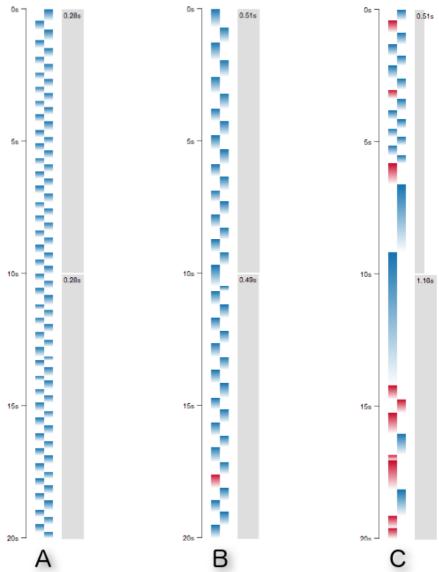

Figure 4: *(A) represents the alternate tapping exercise data by healthy adult person. (B) shows the tapping exercise data by healthy elderly person and (C) represents a PD patient with severe symptoms.*

Figure 4(A) is depicting the tapping exercise performed by a healthy adult. One can notice the steady rhythm and the lack of hesitation by uniform height tapboxes. The accuracy is at 100% as all tapboxes are blue. The relative high tapping speed can be perceived by the short height of tapboxes and their high count. Finally, there is no fatigue as the gray bar charts are of the same sizes in both initial and last ten seconds. Figure 4(B) shows the data collected by a healthy elderly person. The symptoms resemble the ones from the healthy adult with a slight change in speed (taller tapboxes mean this individual was slower) and accuracy (one red tapbox means this individual was a little less accurate). A patient with severe symptoms is shown in Figure 4(C). The patient's rhythm only holds for the initial six seconds, after which there are longer periods of hesitation. Accuracy is very low as seen by the high count of red tapboxes and fatigue is high as seen by the variance in gray bar charts.

4. Evaluation

We performed an informal evaluation of our TapVis approach with one clinician. The clinician who participated in the evaluation is a PD specialist who works with PD patients daily and is involved in related research projects. The clinician had not seen the proposed approach prior to the evaluation session. The main aim of the evaluation was to explore if the given approach has the potential to be at least as good as the previously used approach to visualize such data [MKG*13]. If true, our TapVis metaphor will be more useful in cases where screen real-estate is lacking due to its compactness. Informal evaluation with one clinician is limited to say the least and cannot prove our point, but it is a good indicator about the potential of the approach. However, we believe that our design decisions explained above together with the feedback of the clinician will show the benefits of our proposed approach. Moreover, clinicians' times are very important as they are usually overbooked. Thus an informal evaluation is important step towards refinement and design of an expert evaluation that will be carried out in near future.

A web page was created that guided the clinician through different steps. We showed several visualizations of the dataset that the clinician was familiar with. Instances of the dataset were chosen by us to represent each categories, ranging from tests by healthy persons to patients with severe movement symptoms. The clinician saw our TapVis approach together with our improved common visualization at first in a couple of instances and then we presented one case without the additional views to see if the clinician felt confident to identify the movement aspect accordingly. Later we added the other views as well so that they could reflect on the choices they had made, i.e., if the perceived movement aspects were any different if they were offered only the TapVis approach compared to the case when they had the additional views as well. In the end, the clinician had to answer five questions that correspond to the perception of movements aspects. The question were asked in the following format: *"Do you think the introduced visualization approach is as good or better than the combination of the commonly used data visualization approaches for identifying tapping rhythm? Elaborate your answer if possible."*

The clinician was additionally asked to provide general comments which were positive as were the overall comments about each question. For all the movement aspects, except *hesitation* for which the clinician answered: *"At least as good."* the feedback was that TapVis is better at perceiving the given aspect. The clinician felt that long hesitations were easier to be noticed in the previous data visualizations than the TapViz, but shorter hesitations were more noticeable with TapViz. Regarding *rhythm*, the clinician was very positive towards TapVis noticing that looking at tapboxes is much easier to get the insight about rhythm: *"... you get a good impression just by looking rapidly at the new visualization."* Similarly, the *speed* perception is better as well. One of the comments about the speed was: *"The new approach shows a clear slowing towards the end compared to the beginning."*. With regard to *accuracy*, TapVis was preferred as it was easier to notice larger tapboxes than small circles in the enhanced previous approach. Perhaps if larger circles would be used in the previous approach there would be no significant difference between the two approaches. Finally, the clinician felt that *fatigue* is also perceived better with the TapVis, *"especially with the gray bars"*.

Two more extensions to TapVis and previous visualization approaches were introduced, but not discussed in detail for this paper. The first one is brushing and highlighting between all the views (including combination of TapVis with the previous approach). The clinician regarded it as an interesting feature, albeit a feature that would be rarely used. The other extension was animation where dots and tapboxes would appear as if the patient was performing the tapping test. It was deemed unnecessary as seen in the comment: *"animation is not really needed – you get a good impression just by looking rapidly at the new visualization."*

5. Discussion

The improvement of the previous visualization approaches for alternate tapping results is trivial from the information visualization point of view. However, for domain experts it provides better clarity at least when it comes to the *accuracy*. Another important aspect of this improvement is that it should be rather easy to integrate into the existing visualization systems.

The main contribution of this paper is the TapVis approach. Based on the informal evaluation and subsequent meetings with a clinician, TapVis is more desirable for symptoms rating when compared to the previous approach. It was clear that the TapVis helps in detecting main differences in motor deficiencies of patients at different disease states. Additionally, one can show multiple instances to aid comparison of different test instances. Patients rarely perform only one exercise. They have to do at least two, one for each hand. Also, it might be important to show the historical data to gain insight into disease progression. The compact design of TapVis allows for such comparisons to be possible by showing multiple instances of TapVis in a timeline. Such visualizations could not only be used by clinicians but also by patients themselves. This could help them to better understand the symptoms and take actions at proper times, for example take medicine. This would lead to engagement of the patients and empower them in managing their disease [SSF15].

Two main steps for future work development were identified. During the evaluation, the clinician noted that the gray bar charts used to track *fatigue* could be also added to the previous visualization approaches. Conceptually, bar charts are a separate part of TapViz. Our initial idea was to provide something familiar to the domain experts. Considering the feedback, the plan is to adapt TapViz in such a way that the width of the tapboxes is mapped to the average time per tap for the initial and last ten seconds. The second future work point is to perform an experts' evaluation involving at least three clinicians and possibly data visualization experts with cases from patients experiencing different motor states (under- and over-medicated) and healthy controls.

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