Investigating the Effects of Age and Parkinson's Disease on Touch-based Selection and Scrolling Tasks

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ABSTRACT

Detection of Parkinson's disease at the early stage is important to prevent the progression of the disease. However, it requires repeated assessments of a person's motor abilities, and such repeated assessments are not always feasible. Thus, I am interested in exploring how to incorporate assessments into interactions which users frequently have with computer devices. In particular, I focus on mobile devices because the personal nature and regular use of mobile devices today makes it an ideal platform for collecting data to be used for repeated assessments of motor problems. To that end, I investigated the user performance of two common tasks on mobile touch-screen devices—target selection and scrolling— with three participant groups: young adults, older adults and adults with Parkinson's disease. My results indicate several differences in user performance between users with Parkinson's diseases and the other user groups. I discuss research and design implications taken from this work for how the assessment of the user's motor abilities can be incorporated into mobile-touch screen devices.

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I dedicate this thesis to my parents. To my father, who has always been an icon of correctness and honesty, and who taught me that success is not reaching a certain status in life, but it is feeling of joy inside found while pursuing a productive life and by becoming a better person. And to my lovely mother, who has always taught me to not surrender even at the hardest times of life, and to be patient and live a life devoted to others. And finally, to my brothers who helped and supported me even from thousands of miles away.

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1. INTRODUCTION

Ubiquitous healthcare technology allows professional healthcare providers to monitor patients' health status and facilitates the treatment process. With physicians able to remotely monitor patients and provide general health advice, patients do not need frequent trips to their doctor's offices, which is particularly useful for motor-impaired patients and many elderly people.

However, diagnosis a disease at its early stage is more desirable in comparison to just monitoring its progression. Early awareness of the signs of a disease can help to delay its onset and potentially reduce health-related risks by enabling proper treatment at an appropriate time. Particularly for Parkinson's patients, by the time a physician diagnoses an individual's motor disabilities, s/he already may be displaying a 60% degeneration of the nigrostriatal neurons and treatment initiated at that stage would already be too late to suppress the disease effectively [3]. To that end, early detection of Parkinson's is highly desirable.

Early detection requires early and regular assessments of a person's motor abilities. Unfortunately, such assessments may not be affordable or convenient for all patients. I argue that a personal device which is common and used frequently (*e.g.,* mobile phones) could be leveraged to provide regular assessments. In particular, a technique could be deployed on a user's mobile phone to evaluate her performance of common tasks as a way of detecting the symptoms and potentially the onset of Parkinson's disease.

I am interested in exploring how feasible it would be to design a system to detect Parkinson's disease by analyzing common user interactions, such as selection and scrolling, on mobile touch-screen devices. The performance of such interactions by users with Parkinson's disease has not been well explored in the context of touch-based user interfaces, despite the fact that mobile touch-screen devices are widely available today. Thus, my work examines the effects of age and Parkinson's disease on user performance of target selection and scrolling tasks on mobile touch-screen devices.

In this thesis, I first review models and measures used to assess the performance of target selection and scrolling tasks. I discuss how these models have been used in prior works for comparing the performance of users with and without motor disabilities. I then present my experimental design and results. Finally, I conclude by discussing the design and research implications of my results.

1.1 Contributions

Many assistive technologies have been designed to help users with a variety of abilities interact with modern technologies [14, 31, 33]. In addition, a considerable number of research studies have investigated the effect of aging on computer interaction and accessibility. Specific to my research interests, some of these experiments have investigated the effect of motor system disabilities like Parkinson's or Cerebral Palsy on common computer interactions [20, 28]. Despite these efforts, there is no research that investigates the user performance of common tasks on touch-screen handheld devices by older adults and individuals with motor impairment. This research fills this hole. In particular,

I conducted an experiment to study the differences in the performance of three user groups with different levels of motor ability, and compared their movement patterns while performing selection and steering tasks.

In the first experiment, users of each type completed a set of targeting tasks. In the second experiment, I assessed the participants' performance in scrolling tasks. I compared the performance of each user group in order to determine if any significant differences exist. Specifically, I examined differences between the groups along measures such as movement time, error, and average velocity.

The goal of my study was to answer the following research questions:

- Is there a significant difference in the completion time of target selections between different groups of younger adults, older adults and individuals with Parkinson's?
- Is there a significant difference in the number of target selection errors (cases where participants failed to touch the target) between the three groups of users?

- Is there a significant difference between the three user groups' ratio of divergence from a straight scrolling path?
- Is there a significant difference in the average scrolling velocities between the user groups?

In pursuit of answering those questions, I uncovered the following:

I found that individuals with Parkinson's were more likely to perform inaccurate target selections than the two groups of able-bodied adults, because the number of errors they made was higher. They were also slower than two other user groups. Based on results of the scrolling experiments, I found that individuals with Parkinson's had more trembling movement patterns in a straight scrolling task in comparison to the young adult groups, and their slowness in interacting with the device was confirmed again, by having a lower mean velocity in comparison to the able-bodied participants.

In short, the experimental results showed that there are measurable performance differences between these three user groups (*i.e.*, young adults, older adults and older adults with Parkinson's disease). I believe that this study can be seen as preliminary research for more detailed follow-up studies that explore the movement behaviors of users with different motor functionalities.

2. BACKGROUND & RELATED WORKS

Motor disabilities caused by aging and Parkinson's disease may affect an individual's performance of common interactions with graphical user interfaces such as pointing and scrolling. In this section, first I present some basic information about Parkinson's disease. Then I discuss the models often used to predict the performance of target selection and steering tasks. Finally, I review prior projects which have used these models to compare the user performance of such tasks by individuals with and without motor disabilities.

2.1 Parkinson's disease

Parkinson's disease is on the rise. It is estimated that the cumulative life-time risk of an individual developing this disease is 1 in 40 [24]. Parkinson's disease, known also as paralysis agitans, results from widespread destruction of the substantia nigra (the pars compacta) that sends dopamine-secreting nerve fibers to the caudate nucleus and putamen. Parkinson's disease is mainly characterized by motor disabilities, such as involuntary tremor [12].

Detection of Parkinson's disease at its early stage is often difficult because its signs and symptoms are often subtle, and may be confused with aging effects. As it was mentioned earlier, before physicians are able to diagnose individuals with Parkinson's disease by their motor system symptoms, patients already may be displaying a 60% degeneration of the nigrostriatal neurons. Needless to say, starting any therapy at such a stage can not result in a considerable effect on the suppression of disease [3]. Therefore, an early diagnosis of Parkinson’s disease is often highly desirable. However, physicians often need repeated assessments of the symptoms that patients have over time in order to produce an accurate diagnosis. For that reason, a system which continuously monitors and assesses for Parkinson’s disease from a user’s daily activities potentially could help in the diagnosis and treatment of the disease. Some representative motor-related symptoms caused by Parkinson’s disease are:

- *Bradykinesia*: This refers to slowness of movement [17]. Bradykinesia encompasses difficulties with planning, initiating and executing movement, and with performing sequential and simultaneous tasks. It often appears as slowness in performing activities of daily living, and slow movement and reaction times.
- *Akinesia*: This refers to a loss of physical movement, particularly, inability to initiate movement. A person with Akinesia needs the highest degree of concentration even for simple movement [12].
- *Dyskinesia*: Dyskinesia means abnormal movement, which include athetosis (slow and writhing motions) and chorea (rapid and randomly irregular jerky movement) [12].
- *Tremor*: Rest tremor is the most common and easily recognized symptom [17]. Tremors are unilateral, occur at a frequency between 4 and 6 Hz, and generally are

apparent in the distal part of the body. Rest tremor in patients with Parkinson's disease can involve the lips, chin, jaw and legs, but, unlike essential tremor, rarely involves the neck, head or voice.

These motor symptoms may affect users with Parkinson's disease in their performance of common interactions with graphical user interfaces. Unsurprisingly, researchers have begun to examine the effect of motor disabilities on user's interaction with their personal computers [15, 16, 19]. Because people interact with their PCs regularly, their interactions can be used for repeated assessment to detect specific motor issues. Similarly, handheld devices, such as mobile phones, have become an everyday technology that people interact with. Because of the personal nature of mobile phones, they can also be used for repeated assessments of motor problems resulting from aging and Parkinson's disease.

2.2 User Performance on Selection Tasks

Fitts' law is a model for predicting movement time in a pointing or target selection task [9, 22]. Fitts' law states that the movement time (*MT*) to acquire a target with width *W* and distance *A* from the cursor can be predicted by the following equation:

$$MT = a + b \log_2(A/W + 1),$$

where *a* and *b* are experimentally determined. The logarithmic term (*A/W* + *1*) is called Index of Difficulty (*ID*) of the pointing task

2.3 User Performance on Steering Tasks

Steering is another task users often perform on graphical user interfaces. Accot and Zhai established a model for steering task derived from the Fitts' law model [1]. The movement time in a steering task depends on the shape of the path the user needs to follow. If the path is a straight line, the movement can be predicted as follows:

$$MT = a + b * A/W,$$

where A is the length of the path, W is the width of the path, and a and b are experimentally determined. Similar to the Fitts' law, A/W is called *ID* of the steering task.

2.4 Studies on Effects of Age and Motor Disorders on User Interactions

In this section, I provide a review of the related work on investigating the effects of age and motor disabilities on user interaction. I begin with a review of research studies focused on the effects of aging on the user's performance. Then I discuss projects in which the effects of motor impairments on interactions with computer devices were studied. Afterwards is a short summary of some assistive technologies invented to provide greater accessibility for users with different types of motor disability. Finally, I present a users performance assessment model that was created to provide adaptable interfaces for users with motor disability.

2.4.1 Studies related to the effect of age on a user's performance

Investigating and resolving the difficulties in human computer interaction caused by age-related problems is an increasingly important issue. This is not only because there have been growing number of older adults using digital technology in their everyday life, but also due to the growth of the population of elderly adults, which is predicted to be about two times greater than the number of young adult computer users in about three decades [27]. Consequently, there have been a large number of research studies aimed at exploring the effect of aging on human performance when interacting with modern technological devices; motor-related deficiencies are one of the most known barriers [14, 19, 20].

Investigating the validity of the Fitts' law formula on modeling older adults' performance has been the topic of many studies. For example, Bakaev [2] examined older adults' performance on targeting tasks using the mouse as an input device. He found out that although older adults' movement time could be predicted using Fitts' law, the coefficient of determination of the elderly adults' performance was lower than that measured for the young participants. Results of his experiment showed that senior adults had higher accuracy in targeting, however they were slower and their movement times were about two times more than the movement time of younger participants. In addition, older adults had a higher error rate when acquiring small target sizes, but a longer distance seems to have no significant effect on the error rate. Siek *et al.* [26] also investigated the performance of elderly adults using PDAs to explore the effects of age-related problems (e.*g.*, visual impairment or deterioration) in motor skills. They showed there are no major differences in the performance of older and younger users when using a PDA. Although reduction in muscle strength and fine motor movement was reported in prior research studies, they found older participants were able to perform tasks requiring fine motor controls (such as targeting a specific button while holding the PDA) with the same accuracy as younger participants.

Other types of interactions (such as pen-based) have also been a topic of a variety of research studies. For example, Hourcade and Berkel [13] explored the user performance of different aged participants on a pen-based selection and steering task experiment. Their results showed that the performance of senior users were comparable to that of younger users.

Among the variety of studies that could provide a greater understanding of the effect of aging and disability on user interaction, Jin *et al.*'s research was the most helpful [18]. They examined the performance of users from different age groups in a touch-based interaction technique. In two different experiments, participants were asked to perform a set of selection tasks on a touch-screen LCD. In the first experiment, participants had to select a single target, which appeared in a random position on screen in different sizes and in the second experiment, they were required to target a specific button from a 3x3 matrix of buttons on the screen. They were exposed to different target sizes in this experiment, as well.

Jin *et al.* found that in both experiments older adults had shorter (*i.e.*, faster) reaction times when larger targets was presented. However, except for one button size, providing larger buttons in the second experiment did not help older participants hit the target with higher accuracy. In the second experiment, in addition to the target size, the authors studied the effect of inter-button spacing on performance and discovered that the larger spaces between the buttons caused the longer (slower) reaction times, yet there was no enhancement on older adults' performance with respect to accuracy. Still, they reported that zero spacing between the buttons resulted in the lowest accuracy.

Although Jin *et al.*'s results support the validity of the Fitts' law formula for predicting the performance of different age groups, their experiment had users perform the tasks on a 17-inch LCD monitor, so it does not provide knowledge generalizable to handheld device use and the need to hold it steadily while interacting with it.

Size, weight, and many other physical and ergonomic factors have important effects on users' performance. In the Siek *et al.* study, they observed that older adults used both their hands to hold a PDA and younger participants used just one hand, which could suggest that age has an effect on grip strength [26].

As a result, exploring users' performance while interacting with a handheld device is more crucial when they have any kind of motor impairment (*e.g.*, hand tremors) caused by aging. Specifically, holding a device steadily is not a trivial job for them. For this reason, I believe that examining the movement behavior and performance of users of different ages and different motor abilities is important and could be a beneficial contribution in this area.

2.4.2 Studies related to the effect of motor-impairment on a user's performance

Motor impairments are not only an effect of aging. They also can be caused by other factors, such as a neurological disease. For example, Parkinson's disease and Cerebral Palsy[1] (CP) are two well-known neuropathic disorders characterized by various motor system deficiencies. There is a large body of literature studying the performance of users with disabilities which examines the validity of the Fitts' law model for people with motor impairments. Below is a summary of some of those studies.

Rao *et al.* [25] showed that individuals with Cerebral Palsy with upper limb disability have difficulty operating standard computer input devices such as the mouse and keyboard. They evaluated the performance of unimpaired individuals and those with CP while using joysticks to interact with the computer. The participants performed targeting tasks on differently sized targets at different distances. The results showed that the Fitts' law model could predict the movement time of both groups (*i.e.*, able-bodied participants and people with disabilities) properly. Performance of individuals with CP has also been investigated by Gump *et al.* [11] in a study where the participant was asked to carry out selection tasks with different indices of difficulties ranging from 2.19 to 6.00 bits. Results

[1] - Cerebral palsy is a condition that results in motor abnormalities as a direct consequence of injury to the developing brain.

showed that the movement time of CP participants could be predicted with Fitts' law model properly.

However, there were number of studies in which researchers claim that Fitts' law is not an accurate model to predict the participant's movement time for targeting tasks [4]. For example, Keates *et al.* [19] [21] compared the performance of users with motor-impairments (such as people with Cerebral Palsy or Muscular Atrophy) to able-bodied users while doing selection tasks with a mouse and keyboard. They found that there was a significant difference between the movement time of able-bodied users and users with a motor-impairment. Disabled participants were about 50% slower than able-bodied participants. A particular reason for that delay could not be identified by the authors, but they believed this delay was related to the extra effort required to control the physical submovements during the task. Keates and Trewin [20] also conducted another target selection experiment using the mouse and compared the performance of young, able-bodied users with older participants and users with motor-impairment. The results of their study indicated that older adults paused more often, and consequently it took them longer to carry out the tasks. Moreover, elderly adults also accomplished a lower peak velocity in comparison to the young adult group. Due to the high number of pauses occurring at the end of the movement, and also the high number of pauses with target re-entries, Keates and Trewin suggested that pauses were associated with movement around/through the target. Based on their results, they found that the performance of individuals with Parkinson's is somewhere between the old and young participants' performance. Both seniors and the Parkinson's users showed a small peak in the number of pauses in the first part of their movement and this occurred before the peak velocity. They also observed that, in comparison to the other groups, Parkinson's users had multiple pauses in the second half of the movement and longer pauses just before clicking the target. They suggested this pattern could be linked to the effects of the disease. Their results also confirmed that the performance of both groups of older adults and users with motor impairment differ from what was predicted by the Fitts' model and concluded that new models are required when considering older users or users with physical impairments.

In response to such a need, other studies have been conducted to explore an alternative model for Fitts' theory for people with motor disabilities. For example, Biswas and Robinson [5] developed a statistical model to predict movement time and possible interaction patterns of disabled participants performing targeting tasks by means of keyboard switches and a scanning mechanism which are normally used by people with disabilities for interacting with computer devices. They performed a detailed analysis of different phases of movement for several targeting tasks performed by motor-impaired participants and developed a statistical model to predict the movement time for targeting tasks. They claim their model predicted the movement times significantly close to the actual movement times.

This related work suggests that investigating the effect of age and motor-impairment on touch-based interactions on a handheld device is not only valuable, but also crucial to explore how well the Fitts' law formula can model their movement behavior. To accomplish this goal, I chose to measure and analyze submovement characteristics.

There is long list of studies in which different kinds of submovement measures have been introduced and used in this context. For example, Hwang *et al.* [15] examined the mouse movement of motion-impaired users with CP using submovement metrics. These measures include the number of submovements, the maximum cursor velocity in those submovements, and the period and frequency of pauses between each submovement. Similar to the performance of individuals with Parkinson's, Hwang *et al.* learned that some of the participants with CP paused more often and for a longer period than able-bodied participants. Furthermore, while performing similar tasks, they carried out five times more submovements to complete the same tasks as the able-bodied participants. Hwang *et al.* also showed a correlation between error and the maximum velocity of each submovement, which did not exist for the able-bodied users [16]. They also indicated that users—particularly those with more severe impairments—often exhibit increased cursor movement near the target which was also consistent with Keates and Trewin's finding. However, the maximum velocity of cursor displacement was different from person to person. In addition, results from Hwang *et al.*'s study suggested that the difficulties in carrying out a "point and click" task lie primarily in the "clicking" part for motor impaired users.

The metrics that were introduced in these prior experiments by Hwang *et al.* provided a powerful framework for analyzing the movement pattern of individuals with Parkinson's and investigate the effect of some of the common symptoms (*e.g.*, *Akinesia*, *Bardykinesia*, and hand tremors) on users' movement patterns and the way they interact with handheld devices.

2.4.3 Assistive technologies for elderly users and users with motor disabilities

To provide greater accessibility to computers for people with motor disabilities, researchers have invented a variety of technologies to help users overcome interaction barriers. For example, Wobbrock and Myers devised a new text entry method, EdgeWrite, for handheld devices [33]. It provides physical edges and corners to help users move smoothly along those edges while entering a text. They conducted a user study and compared the usability of EdgeWrite with a Graffiti text entry system, and found that people without motor problems could enter text with the same speed using EdgeWrite and Graffiti, but were 18% more accurate with EdgeWrite. Results for four participants with motor impairment (one with Parkinson's, two with Cerebral Palsy and one with Muscle Dystrophy[2]) revealed that they all could use EdgeWrite to enter text with an even higher accuracy than using Graffiti.

In a more recent study, Wobbrock and Gajos [32] introduced a "goal crossing" target selection technique. In "goal crossing", users pass over a target line for acquiring a target instead of hitting a particular area attributed to that target on the screen. They conducted a study with 8 participants with a variety of motor impairments (including Parkinson's and Cerebral Palsy) and 8 able-bodied participants to compare their performance on task selection and "goal crossing" using a mouse. Their results showed that the users' performance could be modeled with the Fitts' law theory. In addition to that, throughput

[2] Muscular Dystrophy is a nervous system disorder that results in loss of gross motor control while the individual still retains fine motor control, making it difficult to use a mouse and keyboard but not as challenging to carry out a stylus-based interaction with, for example, a handheld computer.

for motor impaired users was higher when using the “goal crossing” paradigm. However, based on the results, errors for “goal crossing” were higher in comparison to conventional target acquisition techniques. Because participants with motor impairments had a preference for the “goal crossing” interaction paradigm, the authors hypothesize that crossing-based interfaces will become more common as an alternative interaction technique for users with motor impairments.

Many researchers have studied and created solutions for eliminating the common types of errors that occur due to deterioration of motor skills. For example, Trewin and Keates [29] showed that slipping while clicking and accidental clicks are the source of errors for older adults and individuals with motor impairments when using a mouse. They devised an assistive software called “Steady Clicks” which suppresses these errors by freezing the cursor during mouse clicks or prohibiting multiple button presses. An evaluation with eleven users with different types of motor impairments (including Parkinson’s and Cerebral Palsy), showed that by using “Steady Clicks” participants were able to hit targets with fewer attempts. Overall task performance times were significantly improved for the five participants when using “Steady Clicks.”

Moffatt and McGrenere developed another target selection technique called “Steadied-bubbles” [23], which is a combination of “Steady Clicks” [29] and “Bubble cursor”[3] [10]. They ran a user study on 24 participants from two different age groups (younger: 19-29

[3] -Bubble cursor is a target selection technique which helps acquisition of a target by dynamically enlarging cursor activation area based on its proximity to the surrounding targets in a way that only one target is selectable at any time [10]

and older: 65-86) and found that "Steadied-bubbles" reduced slipping (unintentionally moving out the target when releasing the contact point) in pen-based target selection. They also showed that their method reduced the performance gap between ages, with the older group no longer performing significantly different from the younger group.

Although none of these studies investigates touch-based interaction on a mobile device, their findings provide good insight about how age or disease-related motor skill deficiencies can be addressed in touch-based interactions. For example, pointing errors caused by hand tremors (a common symptom of Parkinson's disease) might be eliminated by devising a tool similar to "Steadied-bubbles" or "EdgeWrite" for a touch-based interaction.

2.4.4 Performance assessment models for elderly users and users with motor impairments

In order to provide greater accessibility for motor-impaired users, Hurst and Mankoff [14] built intelligent statistical models of pointing performance to assess and detect automatically specific movement characteristics of users with different types of physical abilities by means of measuring movement and submovement metrics. To build such a model, they used laboratory data of three related research studies and the constructed model was capable to predict category of user with high accuracy (above 90%). Based on the results of predictions produced by the statistical models, the system can adapt itself in a way which improves users' interactions with the device.

The main goal of this project is to provide a deeper insight on the performance of users with different kinds of motor abilities, including users with Parkinson's disease. Touch screen devices have become a commodity in our life. However, current user interface designs on a touch screen are not necessarily accessible to users with motor impairments. Through the study of the movement behavior of individuals with Parkinson's on tasks such as targeting and scrolling, researchers and developers will be better equipped to design more accessible user interfaces for touch-based interaction.

3. LABORATORY EXPERIMENT

I conducted a laboratory experiment to examine the user performance of target selection and scrolling tasks by young adults, old adults, and individuals with Parkinson's disease. In this section, I explain my experiment on mobile touch-screen device.

3.1 Tasks and Stimuli

3.1.1 Selection Tasks

At the beginning of each selection task, the system shows two objects on the screen as shown in Figure 1. The participants were asked to touch the start button (the red oval) first to initiate the task. The size of the start button was set to 9.6 x 19.2 mm so that participants could comfortably select it with the index finger. The start button disappeared after the participants touched it, and the target (the black rectangle in Figure 1) would become selectable. The participants were then asked to touch the target. The selection was made when the contact point entered the target. The application played a beep sound when the participants successfully selected the target. The application recorded the time between when the participants entered the start button and when the participants entered the target.

3.1.2 Scrolling Tasks

I designed my experiment to use scrolling tasks instead of using a standard steering task [1] because I was interested in the user performance of a type of steering task often performed in realistic scenarios for mobile device usage. Due to the limited screen space, scrolling is a common interaction in many applications (*e.g.*, the contact list or Web browser).

The application used in this task is shown in Figure 2. The participants were asked to scroll down the screen by dragging the scroll bar widget. Once the scroll widget reached the bottom, it went back to the top of the bar, and the participants would repeat the scrolling. The system notified the participants the end of the experiment after the participants scrolled down from the top to the bottom 15 times. The application recorded the following performance measures:

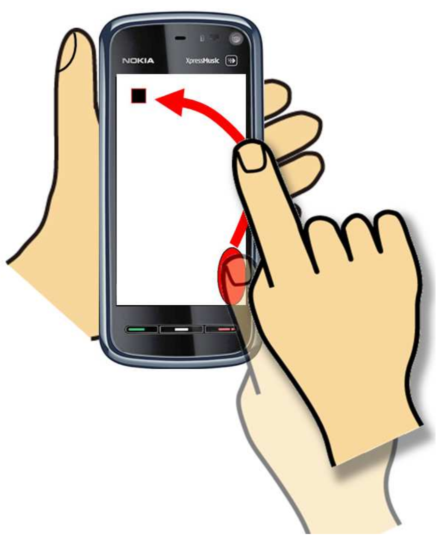


Figure 1. The selection task. The participants were asked to touch the start button (the red oval) first and then touch the target (the black rectangle).

- *Divergence*: This metric was calculated as (the total length of the actual scrolling trajectory) / (the length of the ideal scrolling trajectory). A high number value here indicates a large amount of divergence from the ideal path.
- *Velocity*: This was calculated by (the total length of the actual scrolling trajectory) / (the scrolling time).

Throughout the experiment, the length and width of the scroll bar was set to 76.8 and 8.4 mm, respectively. The participants were asked to perform two blocks of this study. Thus, each participant performed 30 trials.

Figure 2. The scrolling task. The participants were asked to scroll down 15 times in each block.

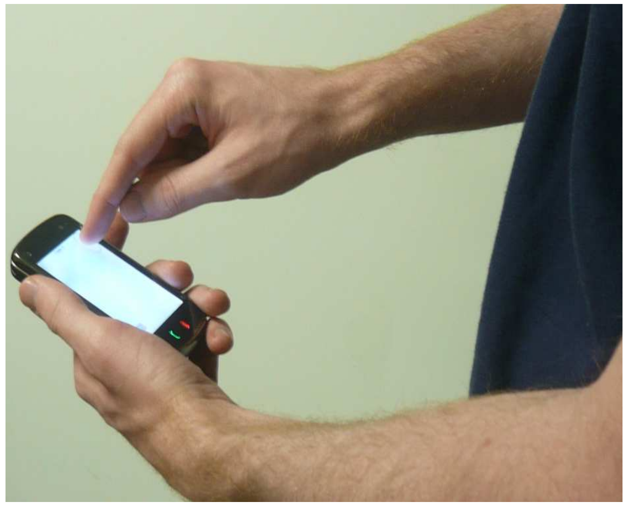


Figure 3. The experimental setup. The participants were asked to hold the device with their non-dominant hand and use the index finger of their dominant hand to interact with the device.

3.2 Procedure

After the experimenter provided a general explanation about this study, the participants were asked to perform three tasks of line drawing (one straight line and two spirals) with a piece of paper and a pen (Figure 4). This is a common way for physicians and clinicians to diagnose whether an individual has motor impairments (including impairments caused by Parkinson disease). Participants with Parkinson's disease were also asked to describe their symptoms.

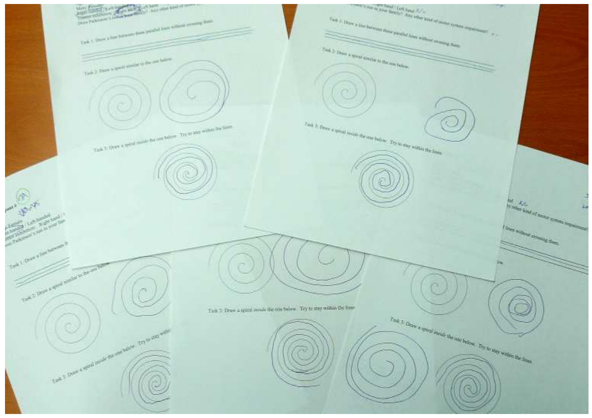


Figure 4. The lines and spirals drawn by the participants before the experiment. The drawings were used to ensure that all *YA* and *OA* participants did not have any noticeable motor disabilities.

Before starting each of the experiments, the participants were asked to practice with the applications. The participants could continue to practice until they felt comfortable with the device and tasks. After this practice, the participants were asked to complete the set of the tasks described above. They were allowed to have a short break if they felt necessary. The entire experiment took approximately 15 minutes.

I explicitly designed the experiments to be as short as possible. One reason for this is that even the simple tasks I designed might be physically demanding for a person with Parkinson's disease. I recognize that the relatively small size of the experiments can affect the results (I will discuss this more deeply later). However, I also believe that my experiments would provide enough insights about what aspects of the performance of users with Parkinson's disease should be further examined.

3.3 Apparatus

The experiment was conducted on a Nokia N97 mobile phone which has a 360 x 640 pixel display (43.5 x 77.0 mm). The effective resolution of the screen is 8.3 pixel/mm. All the applications were implemented in Python for Symbian S60.

3.4 Participant

I recruited 24 participants for this study across three user groups of differing age and motor capabilities:

- *Young Adults (YA)*: 7 participants (5 male and 2 female) in age ranging from 25 to 47. All were right-handed.
- *Older Adults (OA)*: 9 participants (4 male and 5 female) in age ranging from 63 to 80. All were right-handed.
- *Adults with Parkinson's Disease (PD)*: 8 participants (4 male and 4 female) in age ranging from 59 to 67. One participant was left-handed.

Demographic details about the participants are shown in Table 1. None of my participants had a significant visual impairment that could potentially affect their performance of the tasks. The line drawings provided by the participants were examined by a professional physician to ensure that none of the participants from *YA* and *OA* had any noticeable motor impairment.

Because one of the main goals of this research was to investigate the feasibility of creating an early detection tool for discovering signs of Parkinson's disease at its early stage, investigating the performance of individuals who are already diagnosed with Parkinson's and provided with different types of treatment such as surgery or medications may seem unreasonable. The initial plan for recruiting participants with Parkinson's was to invite patients from a neighboring hospital which specializes in the diagnosis, treatment and care of movement disorders to participate in my experiment. Specifically we were interested in recruiting individuals who have been diagnosed with the disease recently but still have not received any sort of treatment. However, due to complexity in accessing those type of patients, which caused a long interruption in this research process and was going to prolonged data collecting phase to an unacceptable period, I decided to investigate the movement behavior of people who are already diagnosed with Parkinson's and who are under treatment by means of either medication or surgery (members of Parkinson's Society Canada). The logic behind this was: medications or any other types of treatment which participants are receiving likely have suppressed the symptoms of the disease and thus their condition is somewhat similar to that of a person who is at the onset of the disease. Therefore, I believe studying the movement behavior of these groups of individuals with impairment can be helpful in providing me with a valuable insight about the feasibility of creating such an early detection tool.

Table 1. Demographic information of the participants.

Participant	Age	Gender	Years since diagnosed as PD	Cell phone usage	Symptoms
YA1	22	F	N/A	everyday	N/A
YA2	23	M	N/A	everyday	N/A
YA3	25	M	N/A	everyday	N/A
YA4	29	M	N/A	everyday	N/A
YA5	32	F	N/A	everyday	N/A
YA6	37	F	N/A	everyday	N/A
YA7	47	M	N/A	everyday	N/A
OA1	74	M	N/A	everyday	N/A
OA2	73	M	N/A	everyday	N/A
OA3	72	M	N/A	everyday	N/A
OA4	68	M	N/A	everyday	N/A
OA5	63	F	N/A	everyday	N/A
OA6	67	F	N/A	couple of times a week	N/A
OA7	74	F	N/A	couple of times a week	N/A
OA8	80	F	N/A	did not use	N/A
OA9	69	F	N/A	couple of times a week	N/A
PD1	66	F	14	rarely	Dyskinesia, hand tremor (non-dominant hand)
PD2	64	M	14	couple of times a week	Dyskinesia, hand tremor (dominant hand)
PD3	59	M	3	couple of times a week	Bradykinesia, occasional hand tremor (not specified)
PD4	61	M	10	everyday	Occasional hand tremor (dominant hand)
PD5	60	F	30	once a week	Dyskinesia, occasional hand tremor (non-dominant hand)
PD6	59	F	10	once a week	Hand tremor (dominant hand)
PD7	63	F	12	everyday	Loss of normal associated movements
PD8	67	M	17	did not use	Bradykinesia, stiffness in skeletal muscles

4. RESULTS

In this section, I present the results of my experiment. I discuss how the analyzed data relates back to the research questions that I described at the beginning of the paper.

4.1 Results of Selection Tasks

Figure 5 shows the mean selection time in different *ID*s across the three user groups. The results of the three user groups fitted to Fitts' law quite well (R^2=0.91 for *YA*, R^2=0.92 for *OA*, and R^2=0.97 for *PD*). The results also reveal a noticeable difference in the slope between *PD* and the other groups. However, an analysis of variance (ANOVA) test to examine the difference in the slopes of three regression lines did not find any difference ($F_{2,114}$=1.09, n.s.). I will discuss this more deeply later.

The mean selection time across all *ID*s were 350 msec (SD=97), 334 msec (SD=111), and 392 msec (SD=167), for *YA*, *OA*, and *PD*, respectively. A two-way between-subject ANOVA against *ID* and *UserGroup* revealed a significant effect of *ID* on the selection time ($F_{4,95}$=7.40, p<0.001), but not *UserGroup* ($F_{2,95}$=2.34, n.s.). However, by looking at the selection time in each block, I found a marginal significant effect of *UserGroup* on the selection time ($F_{2,95}$=2.56, p<0.1). The post-hoc pairwise comparison with the Bonferroni correction showed that a marginal difference exists between *PD* and the other user groups (p<0.1).

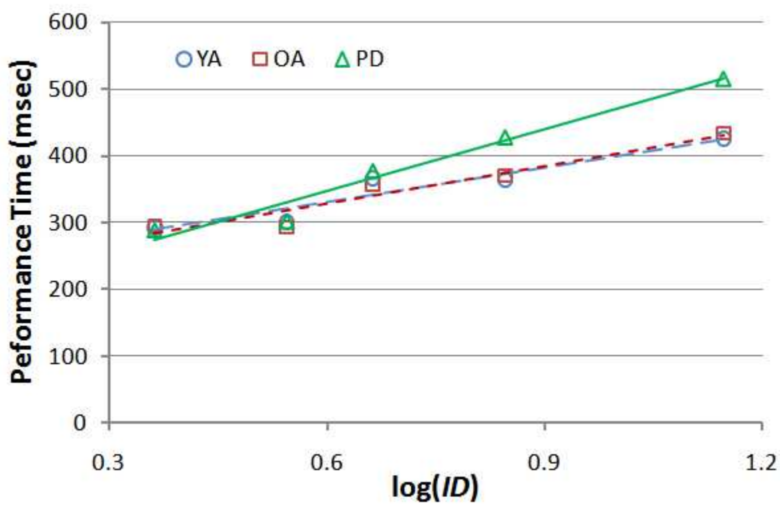


Figure 5. The mean selection time across the three user groups.

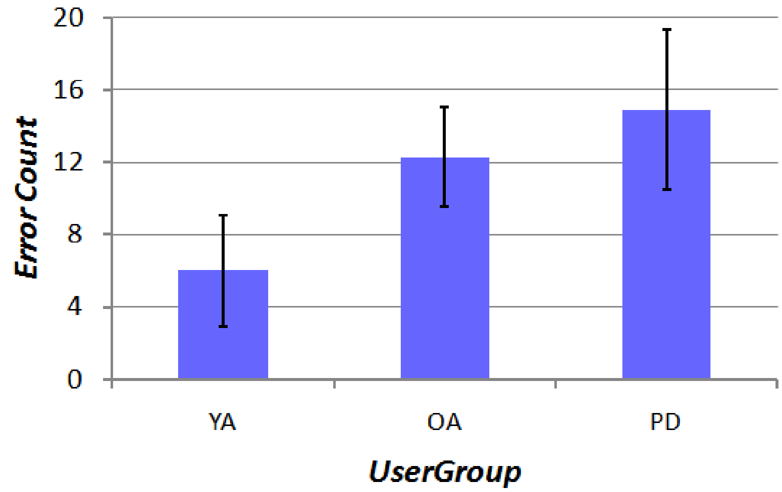


Figure 6. The mean error counts across the three use groups. The error bars represent the 95% confidence intervals.

I also measured the number of errors (the cases in which the participants failed to touch the target) for each participant. Figure 6 shows the mean error counts. My ANOVA test revealed a significant effect on the number of errors ($F_{2,17}$=7.06, p<0.01). A pairwise comparison with the Bonferroni correction showed a significant difference between *PD* (Mean=15.0, SD=5.5) and *YA* (Mean=6.0, SD=4.1; p<0.01), and a marginal significant difference between *OA* (Mean=12.3, SD=3.5) and *YA* (p<0.1).

4.2 Results of Scrolling Tasks

Figure 7 shows the mean *Divergence* I observed in the scrolling tasks. A one-way

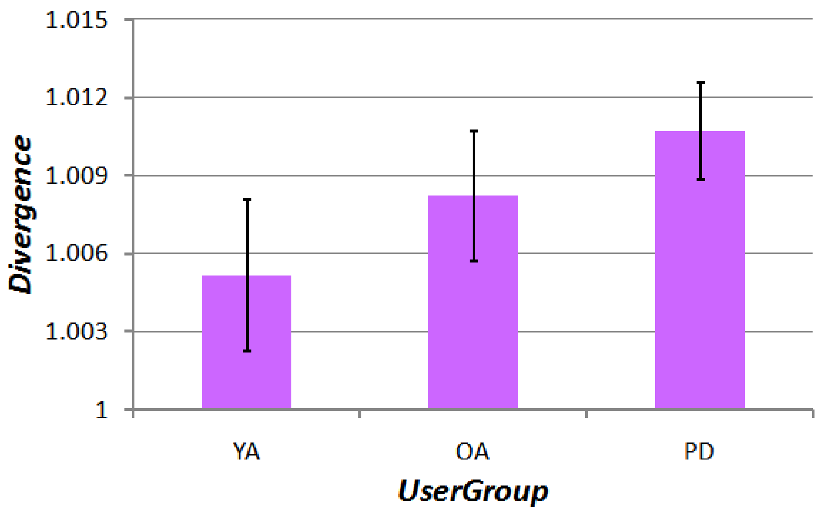


Figure 7. The mean *Divergence* across *UserGroup* in the second block of the scrolling tasks. The error bars represent the 95% confidence intervals.

between-subject ANOVA across *UserGroup* did not find a significant effect on the mean *Divergence* ($F_{2,18}$=1.37, n.s.). However, an ANOVA test found a significant effect by

UserGroup on *Divergence* in the second block ($F_{2,18}$=4.18, $p<0.05$). A post-hoc Tukey pairwise comparison revealed a significant difference between *PD* (Mean=1.010, SD=0.003) and *YA* (Mean=1.005, SD=0.004; $p<0.05$), but not between *PD* and *OA*

(Mean=1.008, SD=0.003; n.s.). Figure 8 shows three examples of the trajectories of scrolling I observed.

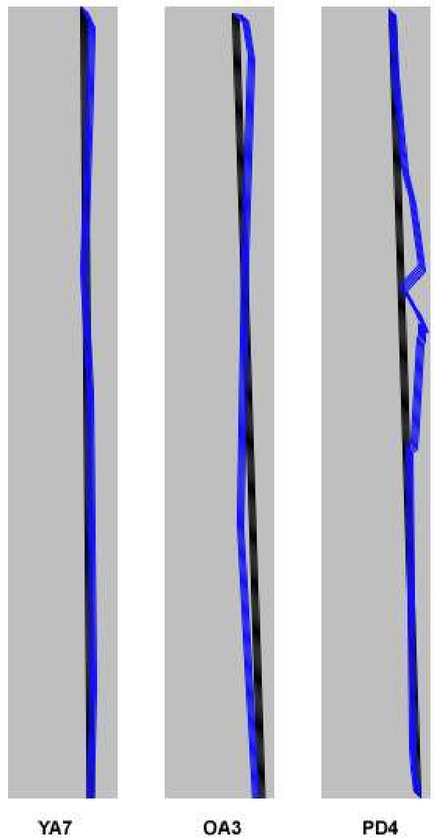


Figure 8. Three examples of scrolling trajectories drawn from the data for YA7, OA3 and PD4. The black lines represent the ideal lines calculated from the starting point and end point of the scrolling. The blue lines represent the actual trajectories by the participants.

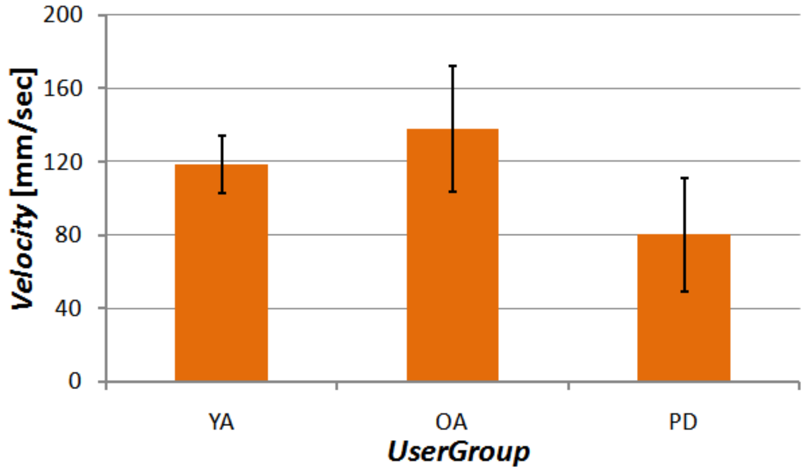


Figure 9. *Velocity* across *UserGroup* in scrolling tasks. The error bars represent the 95% confidence intervals.

Based on the distance each participant travelled in each trial, I also calculated *Velocity* (mm/sec) in scrolling. Figure 9 shows the mean *Velocity*. A one-way ANOVA test across *UserGroup* showed a significant effect on *Velocity* ($F_{2,18}$=3.56, $p<0.05$). A post-hoc Tukey pairwise comparison revealed a significant difference between *PD* (Mean=80, SD=45) and *YA* (Mean=118, SD=23; $p<0.05$). However, I did not find a significant difference between *PD* and *OA* (Mean=137, SD=50; n.s.).

5. DISCUSSION

The results from the selection task imply that the performance model for users with Parkinson's disease might be different from that of users without Parkinson's disease. Specifically, there was a marginal significant difference in the selection time between individuals with Parkinson's and the other user groups. In my experiment, the performance time fitted to Fitts' law very well. Other studies reported some cases in which Fitts' law did not predict the performance of users with motor impairments well. This indicates that further investigation is necessary to understand the cases in which Fitts' law can predict performance of users with motor impairments.

The scrolling experiment revealed that several characteristics of scrolling that are significantly different between young adults and adults with Parkinson's disease. This implies that a system may be able to detect some of the symptoms which manifest with the onset of Parkinson's disease if the system knows whether the user is young. Parkinson's disease is more common in older adults, but can happen in young adults. My results from the scrolling task could be used for designing a system to detect the onset of Parkinson's disease in young adults through the daily use of their mobile devices.

5.1 Research Implications

The results of this study are derived using a small number of participants (7 or 8 participants for each group). When a sample size is small, a null hypothesis significance test may have Type II errors (*i.e.*, a test cannot find a significant difference even though there exists). To address this problem, I need to measure the effect size of the factors [6, 7] as well. An effect size is an objective measure of the magnitude of the observed effect [8]. An effect size shows the likelihood of Type II errors in hypothesis tests, and compliments inferential statistics such as p-values.

The effect size of *UserGroup* for my ANOVA test on selection time lies in between the small size and the medium size (η^2=0.034). In ANOVA, if η^2 is over 0.14, it is generally considered that a factor has a large effect size, and it indicates that it is less likely to have Type II errors. Similarly, my ANOVA test to examine the difference in the slopes of three regression lines had a small effect size (η^2=0.014). Thus, my selection experiment might need more participants to correctly analyze the differences in the three user groups. However, despite my small sample size, I observed different trends in selection time between *PD* and the other user groups as shown in Figure 5. This is an encouraging result for further investigation on the user performance of users with Parkinson's diseases.

On the other hand, the effect sizes of *UserGroup* for my ANOVA and ANCOVA test on scrolling tasks were large ($\eta^2 > 0.1$). Thus, I could observe significant differences, particularly between *PD* and *YA*.

5.2 Design Implications

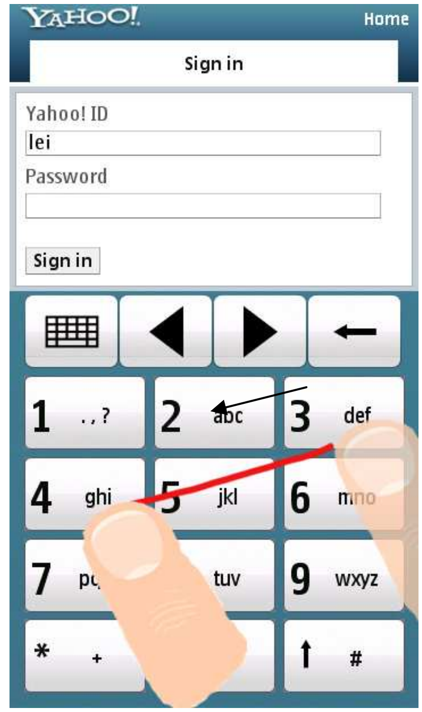
The results of this study imply there is an opportunity to incorporate frequent assessment tools for Parkinson's disease into common mobile touch-screen devices. The assessment system can monitor how users' performance varies over time by regular measuring movement features (*e.g.*, such as movement time, velocity and divergence). For example, each time the user types a word on the software QWERTY keyboard, the phone can track how fast the user selects one key after another. As I discussed, there is a marginal difference in target selection speed between older adults and users with Parkinson's disease. Thus, if the user is an older adult and the phone determines that the user's target selection performance moves closer to the performance of users with Parkinson's disease, then the phone can suggest that the user consults with a motor system specialist.

Consider another example in which user enters his username into the device on daily basis for checking his email. By recording the target selection times, after a while a data set can be created to estimate future target selection times while entering the same string of characters into the phone. By means of these recorded values, when user's performance starts to deviate from his typical range, system can notify the user that he might has a motor system problem (Figure 10).

The system also could exploit a user's scrolling for detecting Parkinson's disease, particularly in young adults. For example, when a young adult scrolls a webpage, map or a contact list, the system measures different characteristics of the scrolling (*e.g.*, divergence) and if those characteristics are close to those of individuals with Parkinson's disease, the device can suggest that the user seeks a medical examination^(Figure 11).

The current interface design for mobile touch-screen devices is not necessarily accessible to users with disabilities. The insights about user performance on touch-based selection and scrolling tasks of older adults and individuals with Parkinson's can be used to improve the usability of mobile devices for these user groups. For instance, it is generally difficult to select a small target on a touch screen with finger touch due to the occlusion [30]. From my experiment, individuals with Parkinson's disease have slower selection speed than users without motor disabilities, particularly when the logarithmic of *ID* becomes over 1.2. This problem might be more significant for people with motor disabilities. In such cases, I can expect to see a 100 msec difference in performance. This indicates that user interfaces on mobile touch-screen devices should avoid small targets or provide assistance for their selection.

(a)



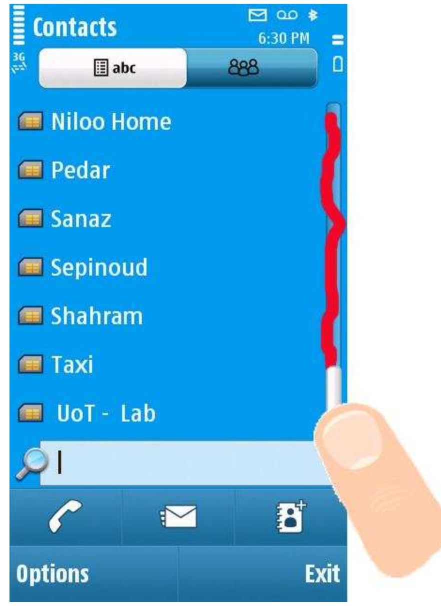
(b)

(c)

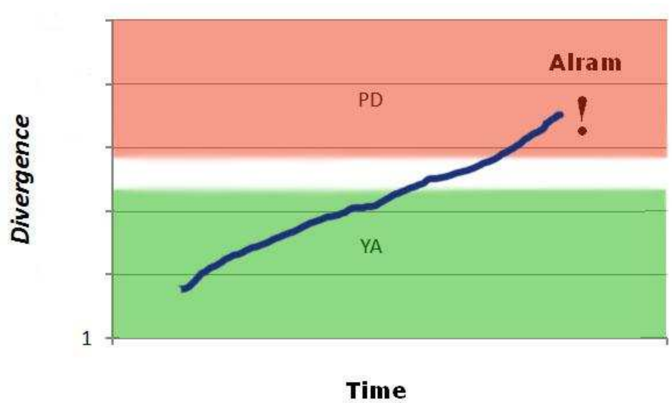
Figure 10. Example of measuring users' movement times in a targeting type of interaction. (a) When user enters his username, device will measure the times for each character selection on the screen. (b) After entering the first letter device starts to measure movement time for each of target selection made by user.

(c) The total time correspond to username entering would be recorded each time and compared with the prior username entering times done by user.

(a)



(b)



(c)

Figure 11. Example of performance assessment in a scrolling type of interaction. (a)While the user scrolls down to find his desired contact number, device measures how straight his finger moves on the screen. (b) Device measures divergence of the finger movement. The more finger deviates from the shortest line connecting the starting point to the ending point of the movement, the *Divergence* measure would have a higher value and then closer to that of individuals with Parkinson's average. (c) Device measures the *Divergence* of users' movement frequently over time and when it starts to get higher than the expected value correspond to a healthy subject at that age, then the device can notify user of his motor condition and a potential health problem.

6. CONCLUSION AND FUTURE WORK

Early detection of Parkinson's, which is one of the most common neurological disorders, can delay the onset of the disease and therefore is highly desirable. However, early detection requires frequent evaluation of an individual's motor performance, which normally occurs only after individuals are already exhibiting signs and symptoms of the disease and after being referred to a specialist. However, by the time patients are diagnosed with the disease, there is already an irreversible deterioration in the brain's neural pathway, which makes commencement of treatment at that stage less effective. For that reason, I investigated the feasibility of designing a system to detect Parkinson's disease by analysis of common user interactions on a handheld touch-screen device.

I examined the effects of age and Parkinson's disease on users' performance of target selection and scrolling tasks. I conducted two different experiments on 24 participants with different ages and motor abilities. Participants were categorized into three groups of young adults, older adults, and adults with Parkinson's. In the first experiment, I studied the movement behavior of users while carrying out a set of targeting tasks, and in the second experiment, I assessed the participants' performance in a set of straight scrolling tasks.

Based on gathered empirical data, I learned that there were differences in the performances of three groups of users. Individuals with Parkinson's had higher error rates in target selection tasks, and had longer task completion time. In the scrolling experiments, participants with Parkinson's had the highest divergence in their movement, which I believe was a result of hand tremors caused by the disease. The younger adults had the lowest divergence and the older adults were between those two groups with respect to that measure. Individuals with Parkinson's also had a lower average velocity in comparison to able-boded participants while scrolling on the screen.

In general, the results indicate that interactions commonly performed on mobile touch-screen devices potentially could be used to detect some of the symptoms caused by Parkinson's disease. The personal nature and regular use of a mobile device makes it an ideal platform for collecting data to be used as part of a repeated assessment of motor problems resulting from aging and Parkinson's. I believe this study should be seen as preliminary research for more detailed follow-up studies that will explore the movement behaviors of users with different motor functionalities at a deeper quantitative and also qualitative level. However, my analysis collected from 24 individuals with and without Parkinson's showed promising results for using touch-based target selection and scrolling tasks to possibly identifying the presence of Parkinson's in users.

I believe that future work could be on building statistical models which are able to automatically assess movement behavior while the user is performing common types of interactions. The ultimate goal is to incorporate the assessment of the user's motor performance into applications on mobile-touch screen devices (*e.g.,* entering text, browsing a webpage, using a contact list) and create a mechanism for diagnosing Parkinson's disease in its early stage.

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8. APPENDICES

8.1 Appendix A: Consent Form

Title of Research Project:

Early Detection of Parkinson's by means of touch screen cell phones

Background & Purpose of Research:

The proposed research project involves the design and evaluation of a mobile application for early detection of atypical hand tremor of individuals with Parkinson's disease. The goal of the work is to examine the ways people use today's mobile phones on a daily basis to determine if they might be showing early signs that they're developing tremors. This can be done by computing a range of acceptable "normal" movement times while operating mobile phone, such that when the user begins to deviate from this range, then it might be the case that they have

Eligibility:

To participate in this study, you must be older than 18.

Procedures:

Each participant will first be given an explanation of this study by the investigators. After signing on the consent form (see Appendix A) and answering questions of questionnaire, the mobile phone device (a Nokia N97) will be given to the participant to use for the duration of the study. The investigators will explain how to the assigned interface works and give the participant time to become familiar with the interface. The participant will then be asked to carry out a series of tasks which would approximately take 10 minutes. Each single task contains of placing the index finger on a specific start position on the touchscreen of the mobile phone and then hit another specified position on that screen, defined as target. The movement time for each task would be recorded to be analyzed and be used to approve or disapprove the research questions

Voluntary Participation & Early Withdrawal:

Your participation in this study is entirely voluntary, and you are free to cease participation at any time, for any reason. At your request, I will delete any of your data and it will not be used in my analysis or any subsequent reports or presentations.

Risks/Benefits:

There are no anticipated risks associated with participation in this study, beyond those associated with everyday cell phone usage.

Privacy & Confidentiality:

This study does not require the name of a participant or any other information to identify the participant except for the consent form. Instead, the name will be converted to a code number when the researchers store the data. Thus, the data gained from this user study is inherently anonymous.

Compensation:

I am very grateful for your participation in this study and I would compensate your time and assistance with $20.

Rights of Subjects:

You waive no legal rights by participating in this trial.

Contact Person:

If you have any questions or concerns about this study, please contact the researcher via e-mail: Leila.Rezai@rwth-aachen.de

Leila S. Rezai

Visitor researcher at University of Toronto, Computer Science Department

______________________	______________________	________
Participant's Printed Name	Participant's Signature	Date
______________________	______________________	
Experimenter Name:	Participant Number	

8.2 Appendix B: Pre-questionnaire Form

Participant

Age:

Male/ Female

Right-handed / Left-handed

Years since diagnosed as a Parkinson's patient:

Symptoms:

Tremor exhibition: Right hand / Left hand

Does Parkinson's run in your family? What about any other kind of motor system impairment?

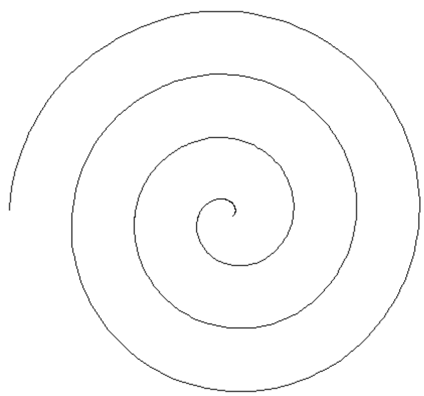
How often do you use cell phone?

Task 1:

Draw a line between these parallel lines without crossing them.

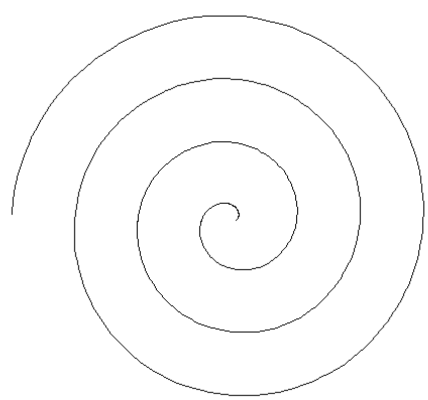
Task 2:

Draw a spiral similar to the one below.



Task 3:

Draw a spiral *inside* the one below. Try to stay within the lines.



8.3 Appendix C: Sample Data

Table 1 - Part of the Log File of the Targeting Experiment - Participant YA3

Trial Number	X	Y	Index of Difficulty	Movement Time (sec)	Traveled Distance
0	165	338	2.3333	0.140625	253.2133
1	50	70	14	0.3125	521.4326
2	70	562	4.6666	0.25	551.1769
3	54	563	14	0.265625	543.1556
4	190	325	2.3333	0.125	255.1627
5	34	97	7	0.34375	530.0651
6	199	323	7	0.25	274.2353
7	173	307	7	0.25	260.1922
8	49	549	7	0.265625	542.2785
9	184	305	3.5	0.171875	276.9856
10	210	327	3.5	0.1875	288.3609
.	.	.	.	.	.
.	.	.	.	.	.
.	.	.	.	.	.

Table 2 - Part of the Log File of the Targeting Experiment - Participant OA7

Trial Number	X	Y	Index of Difficulty	Movement Time (sec)	Traveled Distance
0	171	292	2.3333	0.28125	270.6326
1	51	49	14	0.453125	554.6927
2	64	528	4.6666	0.46875	537.5686
3	48	563	14	1.9375	581.2487
4	185	285	2.3333	2.390625	270.4089
5	59	65	7	0.390625	523.5361
6	175	305	7	0.5625	304.5669
7	199	310	7	0.484375	242.2003
8	52	541	7	0.53125	567.1552
9	215	292	3.5	0.40625	240.3934
10	185	281	3.5	0.5	255.8007
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Table 2 - Part of the Log File of the Targeting Experiment - Participant PD6

Trial Number	X	Y	Index of Difficulty	Movement Time (sec)	Traveled Distance
0	191	320	2.3333	0.28125	227.6532451
1	42	54	14	1.40625	544.6999174
2	42	538	4.6666	0.453125	538.1839834
3	44	587	14	1.328125	564.6175697
4	182	303	2.3333	0.34375	279.2131802
5	54	79	7	0.515625	536.8361016
6	167	307	7	1.1875	293.5183129
7	171	322	7	2.125	246.4467488
8	62	549	7	0.5	518.058877
9	213	326	3.5	0.359375	205.3411795
10	185	282	3.5	0.515625	253.5586717
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Table 4 - Data from the Scrolling Experiment Logfile - Participant YA 7

Trial Number	Finger Position X	Finger Position Y	Time
1	325	33	694053.4
1	329	33	694053.4
1	329	47	694053.4
1	331	80	694053.5
1	335	122	694053.5
1	340	187	694053.6
1	339	271	694053.7
1	334	385	694053.8
1	332	492	694053.9
1	326	572	694054
1	326	602	694054.2
2	323	39	694057.4
2	321	61	694057.5
2	320	105	694057.6
2	318	161	694057.6
2	314	212	694057.7
2	323	247	694057.8
2	326	347	694057.9
2	330	486	694058
2	331	590	694058.2
2	333	610	694058.3
3	324	42	694059.3
3	328	63	694059.3
3	329	96	694059.3
3	328	180	694059.4
3	330	245	694059.5
3	330	327	694059.5
3	331	404	694059.6
3	332	461	694059.7
3	333	471	694059.8
3	331	463	694060
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Table 5 - Data from Scrolling Experiment Logfile - Participant OA 6

Trial Number	Finger Position X	Finger Position Y	Time
1	324	49	9692.969
1	326	58	9693.016
1	327	95	9693.047
1	328	165	9693.109
1	331	242	9693.172
1	332	348	9693.25
1	332	468	9693.344
1	334	574	9693.438
1	336	601	9693.547
2	317	29	9696.344
2	323	29	9696.375
2	323	49	9696.422
2	323	98	9696.484
2	328	161	9696.547
2	326	245	9696.625
2	331	365	9696.719
2	332	474	9696.813
2	333	558	9696.938
2	339	603	9697.047
3	315	42	9699.438
3	311	57	9699.469
3	310	82	9699.516
3	317	149	9699.563
3	323	237	9699.641
3	332	353	9699.719
3	338	424	9699.797
3	337	457	9699.906
3	324	49	9692.969
3	326	58	9693.016
3	327	95	9693.047
3	328	165	9693.109
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Table 6 - Data from the Scrolling Experiment Logfile - Participant PD 6

Trial Number	Finger Position X	Finger Position Y	Time
1	323	27	46427.23
1	330	25	46427.27
1	326	39	46427.31
1	328	66	46427.36
1	330	90	46427.42
1	334	122	46427.5
1	332	174	46427.59
1	333	270	46427.69
1	336	376	46427.81
1	337	468	46427.92
1	337	549	46428.06
1	338	604	46428.2
2	319	26	46429.47
2	334	88	46429.64
2	337	182	46429.81
2	330	316	46430.02
2	320	443	46430.2
2	323	527	46430.42
2	326	591	46430.64
2	328	612	46430.88
3	326	29	46431.89
3	325	35	46431.92
3	322	52	46431.97
3	317	81	46432.03
3	319	117	46432.09
3	312	187	46432.17
3	317	255	46432.25
3	318	336	46432.36
3	317	395	46432.47
3	309	398	46432.59
3	297	393	46432.72
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