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Monitoring Computer Interactions to Detect Early Cognitive Impairment in Elders

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***Abstract*—Maintaining cognitive performance is a key factor influencing elders' ability to live independently with a high quality of life. We have been developing unobtrusive measures to monitor cognitive performance and potentially predict decline using information from routine computer interactions in the home. Early detection of cognitive decline offers the potential for intervention at a point when it is likely to be more successful. This paper describes recommendations for the conduct of studies monitoring cognitive function based on routine computer interactions in elders' home environments.**

I. Introduction

ELDERS are the fastest growing demographic in many countries, with a concomitant escalation of health care resources being spent on conditions associated with aging. One of the key functional losses at risk with aging is a decline in cognitive abilities. Estimates vary depending on assessment protocols and populations studied, but up to 50% of all individuals over age 85 are found to have measurable decline in cognitive function [1]. These individuals are at high risk for dementia, requiring increasing levels of assisted living. Even mild cognitive declines lead to degraded quality of life. Thus a major goal of seniors and their families is to optimize their quality of life and remain not only physically, but also mentally fit.

Researchers have demonstrated the importance of identifying decline in cognitive function [2,3,4]. These changes may be observed as short-term effects, such as medication side effects or unrecognized medical illnesses. Optimally, reliable early detection of future cognitive decline may provide clinicians an opportunity to intervene at an earlier point in time where therapy could be more successful.

The goal of our work in the project described in this paper was to develop and test monitoring software that would provide trend information on metrics that are likely to be useful in predicting an elder's degree of cognitive health. These metrics include relative typing speed and accuracy, relative mouse movement efficiency, and relative performance on computer games that have been designed for cognitive monitoring. Our continuous monitoring of cognitive indicators allows us to perform trend detection of individual performance, so that we are less susceptible to unwanted variability due to educational, language, and cultural backgrounds, as compared to traditional cognitive assessment tests. In this pilot project, we deployed our monitoring software in the homes of 15 elders in the Portland, Oregon metropolitan area for a period of 6 months and tested our ability to monitor computer activities and keep elders motivated and engaged in using the computer. This test was in preparation for a larger prospective long-term study that will determine our ability to use these types of metrics to predict future cognitive decline. Based on our pilot test of the monitoring software in the homes of elders, we developed a set of recommendations for effectively managing a large number of elderly participants in a long-term study, and eventually, as a routine service available to the public at large.

II. Background and Motivation

A. Computer Usage by Elders

There has been a rapid growth in the number of elders using computers in the United States. According to a 2004 Pew Internet and American Life survey, 15% of adults 65 and older use the Internet [5]. However, adults 65 and older are participating at faster rates, and that trend is expected to continue. The survey also showed that 93% of seniors with Internet access have sent or received email, and that seniors are more inclined to go online and check email on any given day than any other group of Internet users. The second most common online activity for seniors is researching information, especially health topics. Additionally, over a third of the population of seniors online play computer games.

B. Previous Work with Elder Computer Use

In a previous study done with the Spry Learning Company and sponsored by the Intel Corporation, we conducted focus groups with older computer users to provide us with necessary background on existing computing and communications needs, as well as interface preferences. We studied 15 residents (mean age 79.5 ± 8.5) in the Calaroga Terrace retirement community in Portland, Oregon. Participants were selected because of their interest and use of computers. Participants identified e-mail, Web browsing, and computer games as the applications they used most

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often. Our focus group data indicated that monitoring incidental computer use such as game playing is not seen as invasive as people perceive these activities as beneficial for their cognitive well-being.

Following our needs assessment of elderly computer users, we then tested a research version of the FreeCell computer game that monitored play performance on a daily basis. In this pilot study on 12 participants over a 3-week period, we demonstrated the feasibility of differentiating cognitively healthy elders from those with mild cognitive impairment. This work led us to propose testing unobtrusive measures of computer interactions in a prospective study to evaluate our ability to provide early predictions of cognitive decline.

III. Methods

Our research methodology centered on testing our prototype software for monitoring computer interactions of elders in their residential environment. We included both experienced and inexperienced computer users, as well as both cognitively healthy participants and those with mild cognitive impairment (MCI). We tracked the effort and techniques used for training and maintaining engagement with using the computer.

A. Development of Monitoring Software

The monitoring program for this pilot project recorded data about a user's keyboard, mouse, and application use using functions from the Windows operating system (for the purposes of this pilot project, we standardized on the use of computers with the Windows 98 or 2000 operating systems). The system registry starts the program when the machine boots up, thereby avoiding the need for the subject to start the program. We ensured that no windows from this software would be displayed, and that it was not represented on the user's toolbar or taskbar, thus minimizing the chance of a subject accidentally terminating the process and creating gaps in the monitoring record. Whenever a subject interacted with the keyboard, the program recorded the date, time, key pressed, and the number of milliseconds (ms) since the last keystroke (inter-stroke interval). For mouse movements, it recorded the date, time, mouse location (in X, Y screen coordinates), and the number of milliseconds since the last mouse movement. This last measure is usually determined by the mouse sensitivity and the screen refresh rate of a given computer, since the program records every movement of the mouse, rather than just the endpoints of a given mouse motion. During application use, the software recorded identifying information about the application (title and class), as well as the date, time, and milliseconds since the previous application was active. Applications that were active for less than 500ms were ignored, to avoid flooding the record with the large number of applications intended only for system use; due to their exceedingly short duration, these applications are unlikely to have been part of a human-computer interaction.

In this project we developed additional software to automatically transfer the monitoring data to a secure server behind our institution's firewall. A data log program sent daily reports of attempted data transfers to the researchers on the project, with the intention of being able to intervene with the study participants if they were having trouble using the computer.

B. Subject Recruitment and Descriptive Statistics

We enrolled 15 participants, both men and women, above the age of 70 years to have their home computer use monitored for a period of 6 months. The participants were recruited from senior residential facilities in the Portland, Oregon metropolitan area and from a research participant registry at Oregon Health & Science University's Layton Aging Alzheimer's Disease Center). All subjects signed written informed consent to participate.

The protocol for the study required that on the first visit to the participant's home, the research assistant would consent the participant and then administer the following set of cognitive tests:

- Finger Tapping Speed (measuring handedness, 3 trials on both right and left hands)
- Mini Mental State Examination
- Geriatric Depression Scale
- CERAD Word List Acquisition / Delayed Recall / Intrusions / Distractors
- Digit Symbol Test
- Letter-Number-Sequencing
- Verbal Fluency Test (Category: Animals, Fruits, Vegetables)
- Boston Naming
- Clinical Dementia Rating

In addition to the cognitive tests, the research assistant assessed the participants Activities of Daily Living, Instrumental Activities of Daily Living, and administered a Computer Use and Attitudes Survey.

The 15 subjects enrolled in this study ranged in age from 71 to 96 years (mean age of 82.8 ± 6.3 years). 12 subjects (75%) were women. From the cognitive assessments, we determined that 3 of the 15 subjects had mild cognitive impairment (20%). All subjects were living independently in their own home or apartment.

Our Computer Use and Attitudes Survey consisted of questions on computer self-efficacy, computer anxiety, general technology use, and previous experience with computers. With regard to computer use, 13 (81%) reported having used a computer before, 9 (56%) already had a computer in the home, 9 (56%) had used email before and 8 (50%) had been on the Web. We also asked about their preferences for computer games. 4 (25%) of the subjects reported liking computer games, although none of the subjects were already familiar with FreeCell.

The self-efficacy questions on the computer survey were of the form "How confident are you in your ability to …"

Although some participants were initially confident in their ability to move a cursor or use email, the vast majority had little initial confidence on most computer tasks.

We also measured participants' response to questions about computer anxiety. In general, there was an even spread in responses among the participants, with most mean scores resulting in a "neutral" response. The survey responses for these questions ranged from 1 = *Strongly Disagree* to 5 = *Strongly Agree*, with 3 being *Neutral*. The following is a list of the topics covered by the computer anxiety portion of the survey, with the mean response at the end in parentheses.

1. I feel anxious whenever I am using computers. (3.0)
2. I wish that I could be as calm as others appear to be when they are using computers. (3.6)
3. I am confident in my ability to use computers. (2.5)
4. I feel tense whenever working on a computer. (2.8)
5. I worry about making mistakes on the computer.(2.6)
6. I try to avoid using computers whenever possible. (2.6)
7. I experience anxiety whenever I sit in front of a computer terminal. (2.6)
8. I enjoy working with computers. (3.3)
9. I would like to continue working with computers in the future. (4.0)
10. I feel relaxed when I am working on a computer. (2.5)
11. I wish that computers were not as important as they are. (3.0)
12. I am frightened by computers. (2.0)
13. I feel content when I am working on a computer. (2.8)
14. I feel overwhelmed whenever I am working on a computer. (2.9)
15. I feel comfortable with computers. (2.7)
16. I feel at ease with computers. (2.6)

Finally, we also collected survey data on each participant's use of technology in general. We found that more that 80% of the participants used a television and answering machine on a daily basis, but that routine use of other technology, such as microwave ovens, cell phones, VCRs and CDs were less frequent.

C. Software Installation and Computer Training

The research assistant for this project was trained to teach elders to use computers using methods established by the Spry Learning Company, a company specializing in teaching seniors to use computers. In their day-long training of the research assistant, they emphasized effective teaching strategies for working with seniors and dealing with self-confidence barriers, as well as hands-on practice preparing and teaching classes based on Spry Learning's Computer and Internet Literacy Curriculum. Our goal in this phase of the project was to develop methods for efficiently training elders to use computers and keep them engaged during the study.

The computer training took place during a second visit by the research assistant to each elder's home. Most initial training took approximately 2 hours. We monitored training time and emails used to prompt people throughout the study. Some of the particularly challenging issues in this study had to do with enrolling 3 subjects with mild cognitive impairment and not providing subjects with high speed "always on" connections to the Internet. For this study, we provided 7 of the subjects (44%) with computers and monitors (refurbished hardware from OHSU) and newly purchased modems. Much of the training difficulty and later questions centered on user interface issues surrounding the process of dial-up for modem access to the Internet. The process had substantial delays with no obvious indication of what was happening during the delay available to the subject. Our users often kept trying to "make it work" during the dial-up. An important additional drawback to using modem access with a single home phone line for this study is that the computer use poses a safety issue when the phone line is tied up for long periods of time (users often forget to log off). However, this would not be a problem if cable or DSL access were provided, as they are "always on."

The 3 participants with mild cognitive impairment were very difficult to train and keep in the study. The participants in the study were initially classified as cognitively normal, with a CDR (Clinical Dementia Rating) of 0 during the initial assessment visit. During repeated home visits over a period of several months (?) for computer training and downloading of data it became clear to the research team that 3 of the participants had MCI, with a CDR of 0.5. Future studies will need to determine the range of cognitive impairment that may be present in persons with MCI that will allow such a subject to follow a computer training program or for those MCI subjects with prior computer experience, the degree to which they can continue to function at the computer.

All of the participants in the study were given hard copy training materials to remind them of the key concepts. In general, whereas, current computer users could be brought up to speed with the requirements of the study and training on new activities, teaching new users who had never owned a computer before was challenging and usually took multiple home visits. There were not enough subjects in this pilot study to identify other specific subject characteristics that might influence the capabilities of the subjects to learn or use the computer.

This pilot project was useful in providing us with a better understanding of the training challenges involved with new computer users who live in their homes (as opposed to residential facilities with several subjects in one location). In addition, we saw a clear value for remote access (with permission) to a study participant's computer for "just-in-time" training and technical support.

IV. Keyboard and Mouse Analysis

We looked at keyboard typing speed and mouse movement indicators of motor activity. For the analysis of keyboard typing speed, our previous work had focused on using repeated samples of user login typing speed. The uniform context, presumed steady-state of learning, and multiple identical measures make this sample of typing speed as independent of unwanted variation as possible. For a moving estimate of speed we measured inter-stroke interval for a known login for each user and averaged each between key time for an estimate of speed for a single login. We then used a trimmed mean (excluding the upper and lower 25% of values) with a moving average over a window of 1 week for a dynamic estimate of typing speed. We also used the central 95% of data to measure variability of typing speed from day to day.

In our analysis of participants' mouse movements, we focused on the idea that measuring the efficiency of trajectories executed by the user may provide useful information relating to sensory-motor function. The basic data consist of point-to-point movements, where each move is represented by samples in time corresponding to the locations of the cursor on the computer screen. We developed metrics that are rotation and scale invariant, for example the ratio of the lengths of the trajectory to the distance between the starting and ending point. In addition, we measure Fourier Descriptors in terms of harmonic functions that capture the various rates of deviation from a straight line.

In general, there is a possible relation between keyboard speed (inter-stroke interval) and the variability of performance and cognitive function. We examined the means and standard deviations of keyboard inter-stroke interval hypothesizing from earlier work that the degree of variability may the best indicator of dementia onset. More longitudinal data in a larger sample of normal and declining individuals will be needed to arrive at a more definitive conclusion with regard to this relationship.

V. Recommendations

Our experiences in this pilot study have provided us with insight on how to best conduct future studies on monitoring computer interactions in the home environment. A summary of recommendations is outlined below:

- In protocols calling for computer training and ongoing interaction, careful cognitive assessment at entry and as the study progresses is necessary to determine the effect of cognitive decline.
- For computer interactions monitored in the course of everyday interactions, cable, DSL or wireless access to the Internet provides the most seamless interface to the subject.
- Provide tested user-friendly interfaces to key applications.
- Upload data nightly with variable access times. Use Remote Access software to be able to view a participant's screen remotely to provide technical support and "just-in-time" training.
- Recognize the training effort involved for the research team if new computer users must be each trained in their homes (as opposed to residential facilities with several subjects in one location).
- Create a system for a research assistant to view key data on subjects on a daily basis. Key variables to record /or display may include:
  - Subject Characteristics
    - Subject Identifier
    - Age
    - Previous computer experience
    - Type of computer, type of connection
    - Other people in household
    - Favorite people to communicate with
    - Favorite computer activities
    - Goals for future computer use
  - Current computer activities (plot daily use)
  - Weekly "diary" (health issues, vacations, etc.)
  - History of communications
  - Library of news items of interest to elders (to use on Bboards and emails)
  - A group email tool that tailors similar emails to subgroups of users
- Create a very simple Web Portal for all participants in a future study to use that includes instant messaging, an electronic bulletin board for the study, a clickable news window with frequent updates.

VI. Conclusion

We have shown that it is feasible to monitor computer interactions in the homes of elders. These observations provide guidelines for future larger in-home or residential facility-based studies. Several measures, such as computer use activity, keyboard typing speed, and variability in performance, are promising measures to include in algorithms for predicting and monitoring cognitive decline.

This monitoring information may prove to be valuable in the cognitive health management of elders, potentially providing indications for early treatment to maintain function and independence.

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