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Embedded Assessment Algorithms within Home-Based Cognitive Computer Game Exercises for Elders

Holly Jimison, *Member, IEEE* and Misha Pavel, *Member, IEEE*

Abstract—**With the recent consumer interest in computer-based activities designed to improve cognitive performance, there is a growing need for scientific assessment algorithms to validate the potential contributions of cognitive exercises. In this paper, we present a novel methodology for incorporating dynamic cognitive assessment algorithms within computer games designed to enhance cognitive performance. We describe how this approach works for variety of computer applications and describe cognitive monitoring results for one of the computer game exercises. The real-time cognitive assessments also provide a control signal for adapting the difficulty of the game exercises and providing tailored help for elders of varying abilities.**

I. INTRODUCTION

Maintaining cognitive performance is an important factor and concern of elders everywhere. Nearly 50% of all people over the age of 85 are found to have a measurable decline in cognitive function [1]. However, common clinical practice does not offer methods for detecting cognitive decline at an early stage, when therapies may be more effective. Recent research has demonstrated the importance of detecting cognitive decline in an early stage [2-4]. Some cognitive issues have immediately treatable causes, such cognitive disturbances due to medication interactions or short-term medical conditions. However, even with long-term conditions, such as dementia, there are many new therapies that researchers presume would have improved efficacy with earlier detection. In this paper we describe a framework for embedding cognitive assessment algorithms within computer games to infer cognitive changes on the part of computer users. Frequent assessments allow us to detect relevant changes in various aspects of performance that can be used to adapt the user interface in real time and also provide a mechanism of early detection of cognitive problems.

This approach offers the promise of providing a low-cost home monitoring and therapeutic intervention to maintain elders' cognitive abilities. Elders are the fastest growing demographic of new computer users in the United States. In a recent survey conducted by the Pew Internet and American Life Project [5], they found that 22% of American adults over the age of 65 use the Internet. Interestingly, elders in this group are even more likely than other Internet users to go online and check email each day [5]. In addition, nearly 35% of elders who use a computer have played a game online, comparable to 39%, the average rate of computer game play for other age groups. Given this rapid growth of computer use by users at risk for cognitive problems, as well as the current large use of computers by the advancing wave of baby boomers, we have an important opportunity to collect and interpret naturalistic computer interaction data for diagnostic purposes. In our project on monitoring and adapting computer game exercises based on embedded assessment algorithms, we have demonstrated an approach that offers potential improvements in both the detection of cognitive problems and serves as a framework for cognitive health coaching.

II. DIFFICULTIES WITH STANDARD COGNITIVE ASSESSMENTS

In standard clinical practice, cognitive screenings are usually performed only if there are patient or family concerns about cognitive dysfunction, and then repeated only infrequently (e.g., yearly). These screening tests, such as the Mini-Mental State Exam, the Kokmen Short Test of Mental Status, and the Memory Impairment Screen, can be performed in a physician's office, but are fairly course and not particularly useful for the early detection of problems [6]. More complete neuropsychological batteries can be performed to obtain more sensitive diagnostic information, but these are more expensive, time-consuming, and require a visit to a specially trained clinical psychologist. These tests normally include measures of short-term and working memory, divided attention, motor speed, planning, and general executive function. Typical cognitive tests include:

- Verbal Fluency - a test of semantic processing and recall from long term memory (participants to recall as many words as possible given a specific semantic category or one or more phonemic constraints).
- Word-List Acquisition – a test of learning and recall from short and long term memory (participants learn and recall a list of words).

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H.B. Jimison is an Associate Professor of Medical Informatics at Oregon Health & Science University and a Senior Research Scientist at Spry Learning (phone: 503-418-2277; fax: 503-494-4551; e-mail: jimisonh@ohsu.edu).

M. Pavel is a Professor in the Department of Biomedical Engineering at Oregon Health & Science University and a Senior Research Scientist at Spry Learning (email: pavel@bme.ogi.edu).

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- Word list Recognition - a test of ability to recognize words previously presented (participants are asked to detect words previously presented).
- Constructional Praxis – a test of visual and motor processing and visual memory (participants copy several line drawings from memory).
- Trail-Making Test – a test of visual search and set switching abilities (participants trace a sequence of digits or interposed digits and letters).
- Symbol Digit Modalities Test – a test of sustained attention and set switching (participants match coded numbers to a long list of symbols).
- Letter-Number Sequencing - a test of working memory and attention (participants see or hear a list of letters and digits presented in random order and then repeat numbers in numerical order and then letters in alphabetic order).
- Finger tap test – a test of motor speed that has been shown to be predictive of future cognitive decline (participants tap their index fingers as fast a possible for 10 seconds).

One of the features of cognitive impairment is the increasing variability in performance. Infrequent assessments of these standard neuropsychological tests do not offer a mechanism to pick up this variability. In addition, the standard practice of comparing an individual's performance score to population norms is plagued by effects of confounding factors such as language abilities, education level, cultural background and baseline abilities.

In our work with monitoring computer interactions to infer cognitive performance, we make use of these metrics of verbal fluency, short-term and working memory, planning abilities, and divided attention. However, we are able to make assessments every time an elder uses one of the computer game exercises. Although our computer assessments are less direct and more noisy, we have the benefit of multiple nearly continuous measures and can analyze within subject trends. This substantially reduces unwanted confounding effects due to education, language abilities, and culture. In addition, we are able to characterize variability in performance over time, which in itself is a powerful indicator of cognitive function.

III. APPROACH TO COGNITIVE GAME DESIGN

In our project on monitoring elders' computer interactions, we first performed a needs assessment to define elders' preferences for computer applications, games, and potential barriers to computer use. We used focus groups and surveys to help us define a set of features for an elder Web portal that we could use as a research environment to collect real-time interaction data. We also defined a set of enjoyable computer games that could be adapted for cognitive monitoring. To select the games for further development, we observed which features were most enjoyable and easily understood by elders and then also did a cognitive task analysis on each of the games to characterize its appropriateness for providing information on one of the cognitive dimensions described in the previous section on standard cognitive tests.

In our assessment of elders' preferences for computer games, we discovered a wide variety of definite preferences. Some users were facile with word games and enjoyed them. Others definitely preferred card games with strategy. We found that it was important to have a suite of multiple games to keep people engaged and using the computer routinely. In addition, we needed a variety of computer activities to assess various aspects of cognitive performance and develop close matches for the standard types of neuropsychological assessments.

Figure 1 shows two word games we developed to provide us with proxies of a measure of verbal fluency. The first game is a word jumble, where the users are given 7 letters of a scrambled word and then asked to create as many words as possible (3 letters and up) with more points for longer words. If the user is able to guess the longest word, he or she may go on to the next round. In the second word game, the user is asked to create words by clicking on adjacent letters in sequence. Again, there is an incentive through scoring to create longer words and try to use up the highlighted letters.

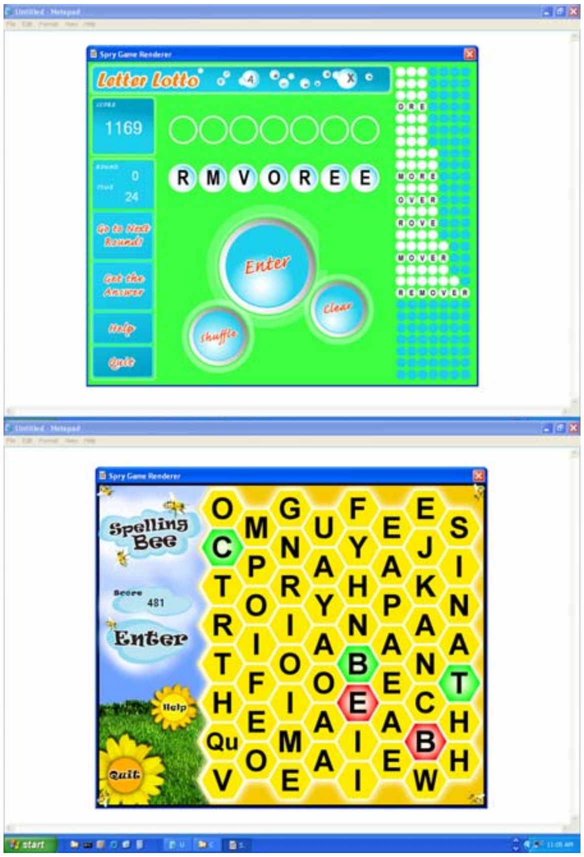

Figure 1: Two word games with embedded assessment algorithms to measure proxies for verbal fluency.

Our cognitive assessment algorithms for both of these word games takes into account word complexity (a mix of word length and frequency of use in the English language), the total number of words created, and the speed of generation of words. This measure is designed to approximate the standard verbal fluency measures, however, our measures have the potential to be more specific in that they are continuous measures, where we can look for within subject trends and be less influenced by unwanted biases dues to education and language abilities.

Figure 2 shows an example of one of our computer games to measure and train short-term and working memory. This game is based on the card game of Concentration, where a number of cards are placed face down and the user may view 2 of the cards at a time, attempting to match cards and remove matched pairs until having cleared the board. This game requires spatial memory and difficulty may be adapted by increasing the number of cards and/or by increasing the difficulty of the match. For example, card matches range from simple shape and color matches to cognitively more difficult matches, such as matching a digital clock time with the analogue picture equivalent.

Figure 2: Example of a computer game designed to measure and trains short-term and working memory.

Figure 3: Color and shape matching game that tests planning ability, memory and attention.

In most of our cognitive computer game exercises we have assessment algorithms with indirect measures of memory. The card game shown in Figure 2, provides us with our most direct measure of short term and working memory.

We have designed other computer games to specifically test and train additional dimensions of cognition. For example, Figure 3 shows a shape and color matching game that provides us with measures of planning (inferring the number of steps ahead a user would have to be able to plan in order to be successful). In this game we can also manipulate difficulty and provide added features to test memory and divided attention. Other cognitive exercise games in testing include activities that involve maintaining vigilance and attention for multiple activities, such BlackJack counts of 21 across both rows and columns, and a game version of the standard Trail Making Test, where users must simultaneously maintain a memory for ordered numbers and letters.

Most of our experience and testing of computer games for cognitive monitoring has come from our work with an implementation of the popular Solitaire game of FreeCell, as shown in Figure 4. In our earlier needs assessment, we found that this game was by far the favorite with the elders that we interviewed. Thus, it was the first computer game we adapted for use in cognitive monitoring. In our research version of FreeCell, our embedded assessment algorithms compare user performance to our computer solver. The lower graph of Figure 4 shows the game difficulty starting at 82 moves to optimal solution (upper left starting point). The lower line shows the computer solver's direct path to solution, and the upper line shows the subject's moves going toward and away from the best solution. We use the slope of the subject's performance as a measure of efficiency of play. In our early pilot work comparing FreeCell performance of cognitively healthy elders to those with diagnosed mild cognitive impairment, we were able to use the efficiency metric to distinguish the two groups.

	Ave of Subjects' Ave Efficiency	**SD of Subjects' Ave Efficiency**	**Average of Subjects' SD Efficiency**
Normals	0.58	0.12	0.38
MCI	0.27	0.72	0.55

Table 1: FreeCell efficiency cognitive metric scores for 9 cognitively health elders and 3 elders with mild cognitive impairment.

Table 1 shows the results of our early pilot tests to show the feasibility of monitoring computer interactions in the home [6]. In this study we monitored 12 elders in a local senior residential facility for a period of 3 weeks. Using conventional neuropsychometric tests described earlier, we found that 3 of the elderly subjects (mean age 80.2 +/- 8.0) had mild cognitive impairment. Using only data from their

FreeCell performance we were able to distinguish cognitively healthy subjects from those with mild cognitive impairment [6]. Interestingly, the variability of the measures over time was in itself a useful feature in classifying cognitive impairment.

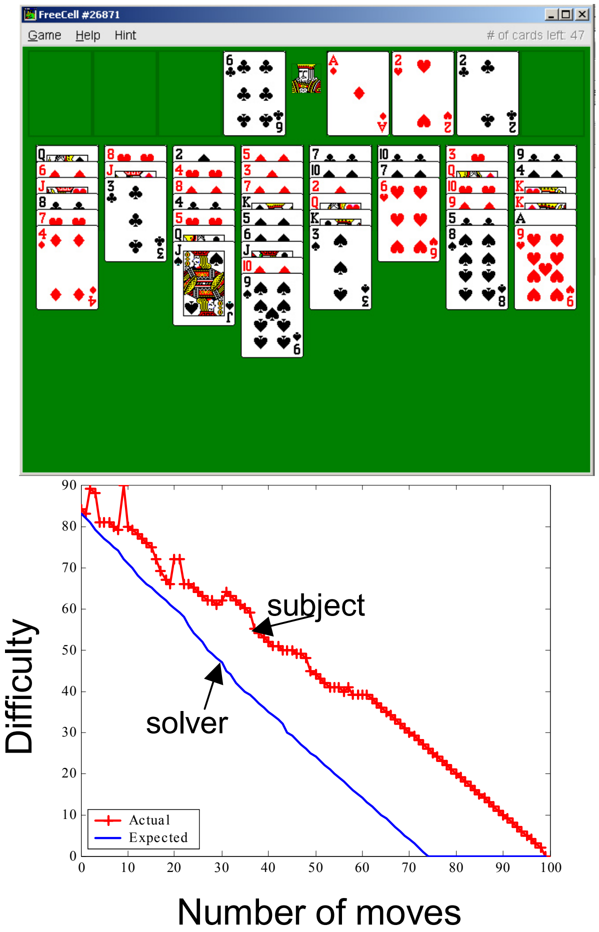

Figure 4: Sample screen of the game of FreeCell (Solitaire game requiring significant planning) and a diagram showing subject performance versus computer solver.

IV. EMBEDDED ASSESSMENT ALGORITHMS

We have designed the embedded assessment algorithms for each of the cognitive exercise computer games to measure performance in real-time so that the game difficulty and user interface features can be tailored to an individual user. We adapt the difficulty to ensure a win rate of between 50% and 80%. Our goal is to keep users engaged by having the activities be challenging but not overly frustrating. In addition, this range of win rate provides us with more sensitive cognitive monitoring data than if a user would easily win or always lose a game. We also use real-time analysis and feedback to tailor hints and help messages as part of the user interface. If we detect that a user is having memory problems or divided attention problems, we are then able to immediately adapt our user interface.

Most importantly though, our work on cognitive monitoring is designed to provide clinical alerts. With the metrics on memory, speed of processing, verbal fluency, set switching, and planning, we are able to detect significant improvements, declines and relative performance. This information can be used to guide cognitive health coaching suggestions. Based on the elder's preferences, he or she may choose to share this information with caregivers and clinicians.

V. CONCLUSIONS

With this project, we have demonstrated a method for monitoring and potentially remediating cognitive performance using easily accessible and enjoyable computer games. This approach offers substantial benefits in being able to measure within subject changes over time in a natural setting. Our ability to detect trends in cognitive performance offers the possibility of early detection, both of possible future cognitive decline that could be treated early, and of near-term effects of medication interactions or more acute illnesses. We are currently preparing to test of the effectiveness of this approach in a large prospective long-term trial in 300 elders' residences. With the embedded assessment algorithms, we will be able to test the validity of our proxy measures against standard neuropsychological assessments. This approach to in-home continuous assessment of cognitive performance has the potential to be an inexpensive method of facilitating cognitive health management for elders, helping them maintain their quality of life and independence.

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