A serious-gaming alternative to pen-and-paper cognitive scoring – a pilot study

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ABSTRACT

The majority of cognitive virtual reality (VR) applications have been for therapy, not cognitive stratification/scoring. This paper describes the BrightScreener™ and its first pilot feasibility study for evaluating elderly with various degrees of cognitive impairment. BrightScreener is a portable (laptop-based) serious-gaming system which incorporates a bimanual game interface for more ecological interaction with virtual worlds. A pilot study was undertaken to determine if BrightScreener is able to differentiate levels of cognitive impairment based on game performance, as well as to evaluate the technology acceptance by the target population. 11 elderly subjects were recruited by the Clinical Coordinator at the Memory Enhancement Center of America (MECA, Eatontown, NJ) site. They had an average age of 73.6 years, and averaged 14.5 years of education. Subjects first underwent clinical scoring with the standardised Mini Mental State Exam (MMSE). During the same visit they underwent a familiarization session and then an evaluation session on the BrightScreener. At the end of their visit, each subject filled a subjective evaluation exit form. Technologists were blinded to MMSE scores. Subsequent group analysis of the Pearson correlation coefficient showed a high degree of correlation between the subjects' MMSE scores and their Composite Game Scores (0.90, $|P| < 0.01$). Despite the small sample size, results suggest that serious-gaming strategies can be used as a digital technique to stratify levels of Cognitive Impairment. This may be an alternative to conventional standardised scoring for Mild Cognitive Impairment and Dementia.

1. INTRODUCTION

According to the Alzheimer's Association (2013), more than 5 Million Americans are suffering from the ravages of this irreversible neurodegenerative disorder. Alzheimer's is a disease with unknown causes, and no effective treatment to slow its relentless progression. As a consequence 1 in 3 seniors die from complications related to dementia, becoming the 6th leading cause of death in United States.

Equally important to the large number of seniors affected, is the impact this degenerative cognitive disorder has on society. The same report cited above estimates the value of caregiver care at more than 200 Billion dollars annually. With the aging of America this situation will only worsen, having been called the "Grey Tsunami." It is estimated that 13.8 million Americans will have Alzheimer's by 2050, with an associated staggering cost of 1.2 trillion dollars (Hebert et al, 2001).

The National Institute for the Aging (part of NIH) had issued new guidelines regarding the diagnosis of cognitive disorders related to Alzheimer's (McKhann et al, 2011). These guidelines outline the progression of cognitive decline from pre-clinical phase, to Mild Cognitive Impairment (MCI), and finally dementia due to Alzheimer's Disease. The pre-clinical phase is a newly defined stage of the disease reflecting current evidence that measureable biomarker changes in the brain may occur years before symptoms affecting memory, thinking, or behaviour can be detected. In the window of 5 years or more prior to any symptoms, individuals at risk of progressing to full blown dementia should receive special monitoring and early intervention. Unfortunately, this is not typically the case in current standard of care.

In the second phase (MCI) mild changes in memory and thinking are noticeable and can be measured on mental status tests, but are not severe enough to disrupt a person's day-to-day life. Finally, with the progression to dementia due to AD, areas of thinking, memory and behaviour are moderately to severely affected.

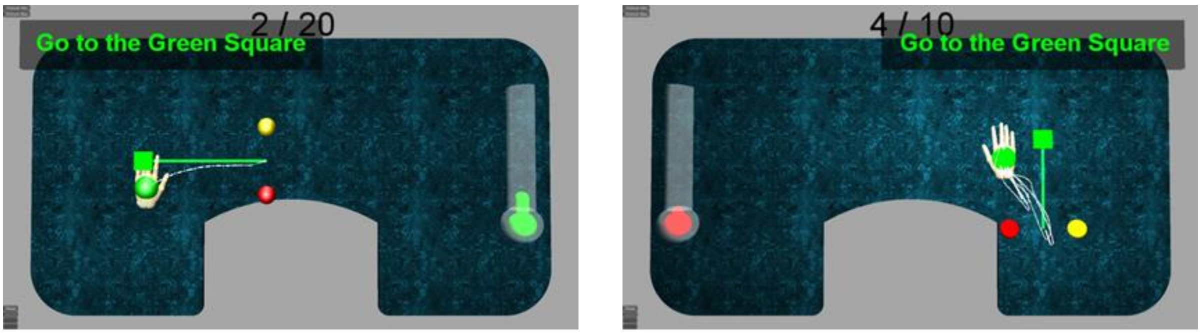
Early screening of an aging America is typically done using the Mini Mental State Exam (MMSE) (Rosenzweig, 2010) or the Clinical Dementia Rating (CDR) questionnaire (O'Bryant et al, 2010), both paper-based tests. MMSE takes 15 minutes to administer, and involves the tester and the patient. It does not however capture indirect information related to the subject's social life, independence in daily activities, hobbies, all of which could shed light on the subject's possible cognitive impairments. CDR is more involved, incorporating the input of the caregiver/spouse and takes about 50 minutes to administer. It is more precise than the MMSE, because it captures information from additional areas. Still, there is strong agreement between the two instruments for general categorization of impacted individuals as mild, moderate or severe (Perneczky, 2006). However, administering both of these cognitive tests to a large number of subjects becomes impractical with current methods due to associated cost and scarcity of qualified practitioners.

What is needed is a portable system that can be placed in primary care physician's office, and performs a quick screening for MCI with minimal human assistance (which reduces the costs and a source of variability). This would allow treatment to be applied earlier, with a higher chance of slowing down the disease progression. To further reduce care costs and increase access, such system should be a computerized platform with both cognitive testing and therapy functions, as well as the ability to present data remotely.

In an early review of cognitive evaluation technology (Wild et al, 2008) it was found that computerized cognitive testing systems offer advantages in standardization of administration and stimulus presentation, accurate measures of response latencies, automated comparison in real-time with an individual's prior performance and reduction of testing cost. However while these systems address the basic indices of psychometric properties, their variability in available computerized test batteries requires case-by-case analysis.

In 2010 Bright Cloud International (BCI) developed the *BrightArm™*, a robotic table for integrative rehabilitation of elderly stroke survivors (Rabin et al, 2012). The next year the company experimented with three dementia ward residents who had also motor involvement due to upper extremity fractures (Burdea et al, 2013*a*). Of the three subjects, two had intact working memory, and one was in an advanced stage of Alzheimer's and had lost her working memory. Figure 1 shows side-by-side the same Pick-and-Place game played by a subject with intact working memory (left) and the Alzheimer's subject (right). Her difficulty in remembering what to do, once she had picked up the ball is visualized by the winding trace of her arm movement on the BrightArm table. This led BCI to the idea that serious games have a cognitive impairment scoring function.

Section 2 describes *BrightScreener*, a laptop-based system being developed by BCI to provide integrative cognitive scoring using bimanual interaction with custom VR games. Section 3 presents results from its first pilot trial on elderly subjects with various degree of cognitive function. These results are discussed in Section 4, and compared with other studies involving computerized systems used on MCI and dementia subjects. Concluding remarks are given in Section 5.



(a) *(b)*

Figure 1. *BrightArm training of residents in a dementia ward: (a) subject with intact working memory;(b) subject with no working memory due to Alzheimer's disease (Burdea et al, 2013a). ©Bright Cloud International. Reprinted by permission.*

2. METHODS

2.1 Experimental system

Unlike the BrightArm, BrightScreener is laptop-based, and portable. As seen in Figure 2, the new system hardware incorporates a Razer Hydra bimanual game interface (Sixense, 2011), allowing the subject to interact with the custom simulations. The Hydra pendants are light, intuitive to use and track full arm movements in real time. In addition they measure the degree of index flexion-extension, which combined with the tracking feature allow the creation of dual tasking scenarios.

2.2 Games used for cognitive scoring

The BrightScreener software is comprised of several games that were ported from BrightArm and re-written in Unity 3D (Unity Technologies 2012). Unity 3D is better documented than Java 3D used in the earlier BrightArm system. Furthermore, all games were made to have uni-manual and bimanual modes, with game avatars controlled through the Hydra pendants. Four of the games were selected for the BrightScreener cognitive evaluation feature. These games were *Breakout 3D*, *Card Island*, *Tower of Hanoi 3D* and *Pick-and-Place*.

Breakout 3D (Figure 3*a*) asked subjects to bounce balls alternating between right and left peddle avatars, so to destroy rows of crates placed on an island. The game tested executive function through reaction time (processing speed) and task sequencing, as well as attention.

Card Island (Figure 3*b*) asked subjects to pair cards arrayed face down on the sand. Hand avatars were used to select and turn cards face up (two at-a-time) when the pendant trigger button was pressed. The placement of the game on an island integrated the sound of waves, so to further relax the subjects. The Card Island game tested short-term visual memory and attention.

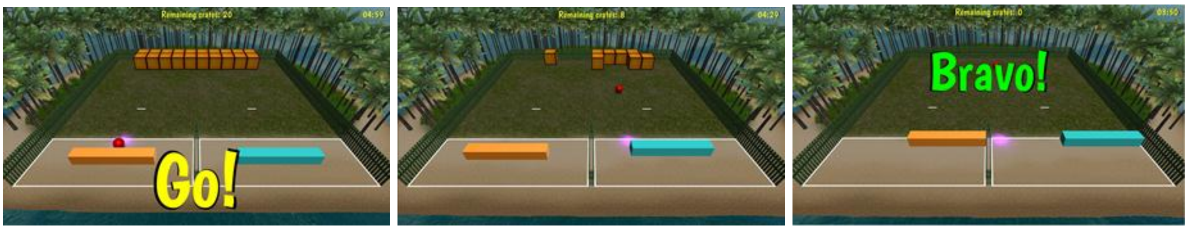
Tower of Hanoi 3D (Figure 3*c*) is BCI version of a well-known cognitive game, normally played with a mouse. The subject was asked to restack disks of varying diameters from one pole to another pole, using the third pole as way-point. The complexity of the task stemmed from the requirement that a larger disk may never be placed on top of a smaller one. A disk was picked up by overlapping it with a hand avatar and squeezing the trigger to flex the hand fingers. In bimanual mode there were two hands, one colored green and one red, and disks were similarly colored. Each hand avatar could only manipulate like-colored disks. The game tested executive function (task sequencing and problem solving).

Finally, in *Pick and Place* (Figure 3*d*) the subject had to pick up a ball, from several available, and place it on a like-colored target square. While en route to the target the movement of the hand avatar was traced. The game tested working memory and divided attention when played in bimanual mode.

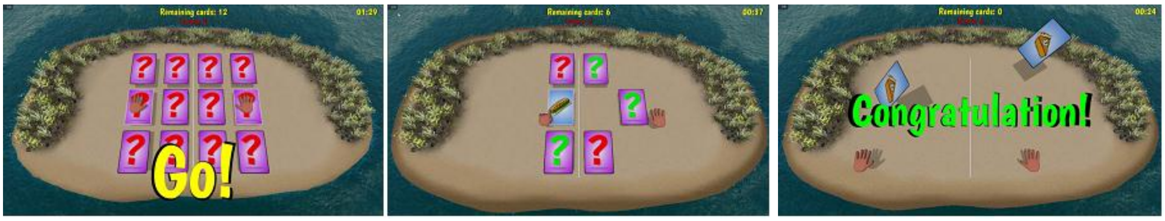
Each game had four levels of difficulty, with the most basic setting utilizing one hand controller (uni-manual mode). The remaining three levels required both hand controllers to play (bimanual mode). At successive levels, *Breakout 3D* becomes more difficult with increase in the speed of the ball and decrease in the size of the paddle avatars used to bounce it. *Card Island* became more complex by increasing the number of cards to be paired with each level. Similarly, the number of disks in *Towers of Hanoi 3D* increased with successive difficulty levels (two disks, then three, then four disks). *Pick and Place* increased difficulty with the increase in number of targets and the removal of visual cues used by subjects to match ball and target colors and complete the pick and place task.

(a) *(b)*

Figure 2. *The BrightScreener™ system: (a) game interface;(b) subject during training (Burdea et al, 2014). © Bright Cloud International. Reprinted by permission.*



(a)



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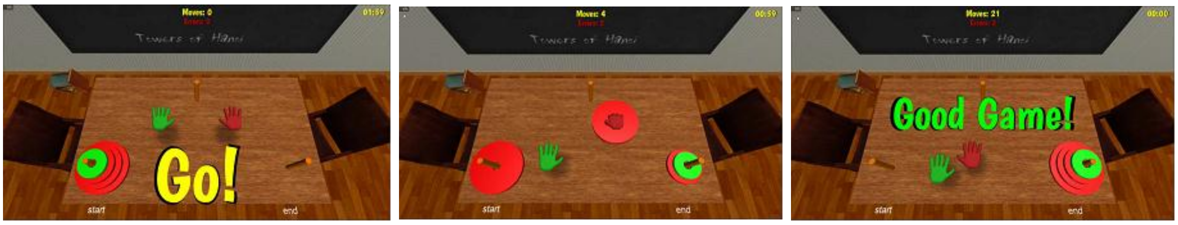

(c)

(d)

Figure 3. *BrightScreener testing games: (a) Breakout 3D;(b) Card Island; (c) Tower of Hanoi; (d) Pick-and-Place (Burdea et al, 2013b). © Bright Cloud International. Reprinted by permission.*

2.3 *Game scoring Algorithms*

The scoring algorithms for *Breakout 3D*, *Card Island*, and *Pick and Place* have been detailed previously (Burdea et al, 2014). The scoring equation for each game incorporates both difficulty and performance metrics. For example, there is a 25% bonus in difficulty for playing bimanually over the uni-manual version of the same game. Play time is typically used to rate game performance. The score formula for *Tower of Hanoi 3D* is:

$$Score = \frac{\left(If\ bimanual\ 1.25;\ else\ 1.0\right)*\left(Minimum\ \#\ of\ Moves\right)*100}{Log\left(Time\ in\ Seconds\right)*\left(Actual\ \#\ of\ Moves + \#\ of\ Dropped\ Disks\right)} \quad (1)$$

In the numerator, level of difficulty is quantified by whether the game is played in bimanual mode (25% bonus) and minimum number of moves needed to complete the game. Restacking 2 disks required a minimum of 3 moves, 7 moves were necessary to restack 3 disks and 15 moves for 4 disks. In the denominator, game performance is quantified by the logarithm of play time and the actual number of moves taken to complete the game combined with the number of disks dropped en route to the poles. Longer length of game play (measured by time and number of steps) corresponds to lower performance and hence has a lower game score.

2.3 *Study design*

The sequence of steps used in this study consisted of (1) subject consenting, (2) a tutorial session on the BrightScreener, followed by (3) standardised cognitive testing, then (4) the game-based testing session and (5) an exit questionnaire. Each subject completed the study in the span of a few hours (depending on their cognitive functioning level). The study was approved by the Western Institutional Review Board and took place during two days at the Memory Enhancement Center of America – MECA (Eatontown, NJ) in February 2014.

2.3.1 Participants characteristics. Eleven subjects were recruited by the study Clinical Coordinator, from the pool of potential participants at MECA. Of these five were women and six men. Subjects 1-5 were tested the first Saturday and Subjects 6 –11 were tested a week later. The group had an average age of 73.6 years, with a range from 61 to 90 years old and a standard deviation of 8.6 years. The mean education level was 14.5 years in school, with a standard deviation of 4.2 years.

2.3.2 Tutorial and testing session composition. Since subjects were new to BrightScreener, it was necessary to have a tutorial session before the actual cognitive evaluation session. During the tutorial session subjects played the four games previously described, and each game was played at progressively harder levels of difficulty. The subjects cycled through all four games at the most basic level of difficulty before progressing to the next level of each game type, and so on. The tutorial session lasted about 35 minutes per subject.

For testing, the subjects completed the four levels of difficulty of a given game before proceeding to the next game, and so on. The evaluation session lasted about 30 minutes per subjects.

Table 1. *Subjects' characteristics (gender, age, education level).*
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Subject	Sex	Age	Years in school
1	M	64	16
2	M	73	19
3	M	82	22
4	F	90	14
5	M	73	18
6	F	77	12
7	M	78	14
8	F	70	14
9	F	61	12
10	F	64	13
11	M	78	6
Average age	73.6 (8.6)	Average School years	14.5 (4.2)

2.3.3 Data Collection Instruments. Subject's data was collected during the study using MMSE, game scores, and an exit interview. Mini Mental State Exam was used to evaluate the subject's cognitive function. The MNSE was administered by the Clinical Coordinator in a quiet room and the BCI researchers were blinded to the scores.

Subsequent to the MMSE testing, subjects were given the BrightScreener evaluation session and game scores stored transparently for each subject. Finally, the subjects filled a subjective evaluation exit form in the Clinical Coordinator room. The form had 8 questions scored on a Likert scale from 1 (least desirable outcome) to 5 (most desirable one). The questions were: "Were instructions easy to understand?," "Were the games easy to play?," "Were the game handles difficult to use?," "How easy was playing with one hand?," "How easy was playing with both hands?," "Were you tired after playing the games?," "Did you have headaches after playing the games?," and "Did you like the system overall?"

3. OUTCOMES

3.1 MMSE scores

Table 2 lists the MMSE scores of the 11 study subjects. These scores ranged from a low of 9 to a high of 29 (out of a maximum of 30). The average MMSE score was 23.9 with a standard deviation of 5.4. Based on their MMSE scores, participants were ranked by degree of cognitive impairment from 1 (the least) to 11 (the most). Subjects with identical scores (1 and 6, 2 and 8) were given the same rank (1 or 7, respectively).

The MMSE scores may be used to determine the degree of cognitive impairment (Folstein, 2001). Three of the subjects were classified as having normal cognitive function, seven of the subjects were diagnosed with Mild Cognitive Impairment (MCI) and one with Severe Cognitive Impairment (Alzheimer's). For control, at least one participant that was expected to have a normal diagnosis was included in each day of the study. However, the identities of these individuals were not known by technologists conducting the game training and testing sessions.

3.2 Testing session game score-based ranking

Table 3 summarizes the game scores and corresponding ranking during the testing session. For each of the 4 games played the score assigned was the average score for four difficulty levels of each game. Participant 4 consistently scored the lowest across games, however the participant with the highest score varied between games. In order to realize an overall ranking, each participant's scores were averaged into a Composite Score. Subject 4 had the lowest composite score (5.9) and Subject 5 the highest composite score (61.3).

Subsequently the 11 subjects were ranked from 1 to 11 using the composite game scores. The scores were also categorized into four basic bands following degree of cognitive impairment: normal, mild, moderate, and severe. The thresholds quantizing composite scores to the cognitive impairment levels were calibrated based on the fact that the Clinical Coordinator indicated prior to study that two undisclosed participants were expected to have a normal cognitive state. As seen in Table 3, eight of the participants were categorized as MCI, none of the participants were classified as having moderate cognitive impairment and one participant was categorized has having severe cognitive impairment. This is consistent with the distribution of the MMSE, although individual classifications do vary (i.e. participants 2 and 6).

Table 2. *Subjects' MMSE scores and cognitive impairment levels.*
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Subject	MMSE Score	MMSE Rank	Cognitive impairment level
1	29	1	Normal
2	24	7	Mild
3	25	5	Mild
4	9	11	Severe
5	27	3	Normal
6	29	1	Normal
7	26	4	Mild
8	24	7	Mild
9	23	9	Mild
10	25	5	Mild
11	22	10	Mild

3.3 MMSE score correlation to serious games score

Table 4 shows the Spearman correlation (Laerd, 2013) between individual game scores and the MMSE test scores. The correlation values ranged from a low of 0.6 for *Breakout 3D* to a high of 0.85 for *Tower of Hanoi 3D*, with probability $|P| < 0.05$. As seen, the correlation for *Breakout 3D* was less than for the other games due to the fact that Subject 11 performed particularly well for this game. When Subject 11 was removed from the correlation computation, the *Breakout 3D* correlation increased to 0.75. This correlation value is now in line with *Card Island* and *Pick and Place* correlation values.

The Composite Score correlated to MMSE outcomes better than individual game scores. The correlation value was 0.90 with a confidence $|P| < 0.01$. This is reflective of the nature of the individual games, each targeting a different group of cognitive domains. The rationale for using the Composite Score is a broader spectrum of domains may be captured in a single value, similar to the methodology of the MMSE instrument.

The Spearman correlation was subsequently computed between the ranking of subjects using MMSE scores and the ranking of those same subjects based on game scores. The ranking using the composite score had a correlation value of 0.6 and $|P|<0.05$. The Spearman value was higher when ranking by *Tower of Hanoi 3D* alone with a correlation of 0.69 with $|P|<0.05$. A better Spearman correlation was achieved by limiting the contribution of *Pick & Place*, correlation value of 0.71 with $|P|<0.05$.

Table 3. *Subject's game scores and corresponding ranking.*
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Subject	Breakout Score	Card Island Score	Pick & Place Score	Towers Score	**Composite Score**	Composite Rank	Cognitive impairment level
1	78.8	43.3	37.1	74.3	**58.4**	3	MCI
2	51.9	49.9	52.0	86.9	**60.2**	2	Normal
3	64.7	53.5	36.9	70.5	**56.4**	5	MCI
4	18.3	5.4	0.0	0.0	**5.9**	11	Severe
5	69.9	53.6	46.1	75.5	**61.3**	1	Normal
6	39.7	41.0	36.1	76.8	**48.4**	8	MCI
7	56.1	56.8	38.9	77.6	**57.3**	4	MCI
8	46.7	49.6	32.5	55.6	**46.1**	9	MCI
9	58.6	57.6	42.4	57.9	**54.1**	7	MCI
10	61.2	60.8	23.5	71.6	**54.3**	6	MCI
11	83.4	26.8	26.6	20.4	**39.3**	10	MCI

Table 4. *Subjects' game scores correlation to their MMSE scores.*
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	Breakout 3D	Card Island	Pick & Place	Tower of Hanoi	Composite Score
Correlation	0.60	0.75	0.78	0.85	**0.90**
P	0.045	0.006	0.0037	0.00048	**0.00008**

Spearman rank correlation tends to amplify noise in the ordering. This is seen through the fact that the overall correlation value of 0.6 is much lower than the 0.9 found by correlation between composite game scores and MMSE scores. If BrightScreener were to be used as a cognitive function scoring tool, it may be sufficient to categorize subjects into 4 general categories (normal, Mild, Moderate and Severe cognitive impairments), as opposed to get exact ordering within particular categories. To this end, the cognitive impairment levels for games scores was correlated with the diagnostic from MMSE test. Here, a much higher correlation value of 0.8 was measured, with a $|P| < 0.01$.

3.4 Subjective evaluation outcomes

The subjects were asked to fill out a subjective questionnaire after completing the game-base testing. Although anecdotal evidence suggested that the subjects rarely played video games, the subjective evaluation response was consistently positive. For example, subjects gave an average rating of 4.8 to the question "Were the instructions easy to understand?"

The challenge of playing bimanually was measured through the question: "How easy was playing with both hands?" This received the lowest rating of all questions, namely a 4.1 out 5. Finally, the subjects were asked "Did you like the system overall." Each of the 11 participants gave the system a perfect rating of 5. All the other questions received a rating of 4.3 to 4.8.

4. DISCUSSION

The aims of this pilot study were: 1) to determine if the BrightScreener system was able to differentiate levels of cognitive impairment based on game performance, and 2) to evaluate the technology acceptance by the target population. Virtual reality use in emotive therapy has been tried successfully for a number of years, beginning in the 90s (Rothbaum et al, 1999). Within the cognitive domain many studies have used virtual supermarkets to train executive function (Lee et al, 2003), or as a more ecological method for MCI diagnosis (Werner et al, 2009). Researchers tested a group of 30 MCI patients and 30 healthy elderly adults. They observed significant differences in the performance of the two groups in the virtual supermarket simulation. A key differentiation with the prior systems is that BrightScreener uses serious-games as a scoring method for cognitive impairment. The results were shown to be consistent with determination of a popular pencil and paper screening method (MMSE).

BrightScreener interactions were mediated by a bimanual game controller, and the technology was well accepted by the subjects. Another usability study involving an off-the-shelf game interface used the Wii controller with dementia patients (Boulay et al, 2011). Similar to the present study, researchers found that subjects were able to use the Wii and liked the technology very much.

It is important to note that, while the BrightScreener game scores and composite scores correlated well with the subjects' MMSE scores, there is room for improvement. Specifically, the areas of language processing and problem solving, while present in the MMSE tests, were missing to a large extent from the BrightScreener games. It is possible that with more games covering these areas, the overall correlation could improve further.

The number and composition of the subject group also played a role in the feasibility study outcome. The level of cognitive function of the 11 subjects was such that Moderately Impaired subjects were missing from the sample. Furthermore, the sample was small, with implications on the statistical power of the study findings. Further studies are needed to determine if the same correlations exist for a larger sample, and/or for different patient populations.

5. CONCLUSIONS

This paper presented the BrightScreener portable digital system. A pilot study evaluated its ability to score Cognitive Impairment of adults based on game performance. To the author's knowledge this is the first study of a bimanual game library for use in cognitive evaluation. Bright Cloud International believes that the full potential of BrightScreener will be realized when acting as a dual platform for cognitive scoring and for rehabilitation. With greater adoption of BrightScreener in clinical practice, longitudinal studies may be possible, with subjects unaware that they are periodically evaluated, possibly at a distance. For dementia populations, the hope is that focussing on a pleasant and non-threatening activity that engages thinking may prove to be successful in delaying the onset of Alzheimer's Disease.

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