

BrightBrainer feasibility study in a medical adult day program

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Abstract— Purpose: To determine the feasibility of BrightBrainer training of elderly with dementia attending a Medical Adult Day Program. **Method:** BrightBrainer brain training games were played by 10 participants who sat in front of a projector screen and interacted through a bimanual game controller. The custom games targeted several cognitive domains such as focus, problem solving, short term memory, working memory, and language comprehension. Participants had a choice of what games to play among those available, and the difficulty adjusted automatically based on individual past performance. The system underwent feasibility trials spanning 16 sessions over 8 weeks. Participants were evaluated pre-intervention, post-intervention, and at 8 week follow up using standardized neuropsychological measures. Computerized measures of movement repetitions, task performance, session duration, games played and game scores were stored on a remote server. **Results:** Group analysis showed improvement in the cognitive domain of 1.4 points on Mini Mental Status Exam (MMSE) between pre-training and follow-up. One participant who started with MCI ended with normal cognition (max scores on MMSE and Brief Interview of Mental Status - BIMS). Caregiver feedback noted participants' increased ability to follow one-step directions, to perform activities of daily living and increased desire to attend the Adult Day Program. Most participants enjoyed the computerized training.

Keywords—BrightBrainer; integrative bimanual therapy; adult day program; dementia.

I. INTRODUCTION

According to an Alzheimer's Association report [1], 5 Million Americans are suffering from the ravages of Alzheimer's disease (AD), which is a form of dementia. The economic burden for caregivers is estimated to be more than 200 Billion dollars annually in the United States and estimated to increase as 13.8 million Americans are projected to have AD by 2050 [2].

Dementia is aggravated, among other things, by social isolation, lack of physical exercise, lack of education, and poor diet. Medical Adult Day Programs (MADP) are designed to provide services to individuals with cognitive and/or functional impairments and to their caregivers. The MADPs help individuals maintain and/or improve their cognitive/physical function. In such programs participants attend about 6 hours/day, several days/week, during which

time they are offered highly structured activities designed for individuals with cognitive impairments. Typical activities are cognitive (games, mind joggers, puzzles, reminiscing, news), social (celebrations, live entertainment) and creative arts (painting, guided drawing, crafts etc.) in nature. There are currently an estimated 4,600 Adult Day Service Centers in the US [3] with over 260,000 participants and caregivers. The average age of the adult day center care recipient is 72, and two-thirds of all adult day center care recipients are women.

The BrightBrainer™ is a computerized bimanual integrative brain training system. It has been shown to induce a large number of arm repetitions when training elderly with dementia who were residents in a skilled nursing facility (nursing home) [4]. That group had a statistically significant improvement in executive function and significant reduction in depression. These earlier findings motivated the present study which investigates the use of the BrightBrainer system in an MADP setting. The study aims to determine technology acceptance by elderly of varying cognitive impairment levels and its benefit from the viewpoint of their caregivers.

II. METHODS

A. BrightBrainer System

The BrightBrainer system used in this study (Figure 1) consisted of an HP ENVY 17 laptop, a game controller, a projector, external speakers, a screen and remote server. The laptop was a gamer model with an Nvidia graphics card for high resolution graphics. The laptop received input from the game controller which was a Razer Hydra [5] with two game pendants held in each hand by the participant. The controller included a stationary base which generated a weak magnetic field used to measure many times per second the position of the participant's hands. Each pendant was sampled at 125 readings/second, a frequency sufficient to allow real-time control of the game avatars responding to hand movements. Each controller had an analog trigger which detected the amount of index flexion/extension. Wrist weights were added during the latter part of the therapy, for increased upper body exertion.

The combination of the 1280x800 pixel resolution LG WXGA DPL projector and screen created a display of sufficient size to facilitate viewing by elderly who typically have weaker eyesight. The large display had another advantage for the targeted population, namely an increase in

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their feeling of immersion in the game, facilitating increased focus on virtual reality tasks [6]. A remote HP blade server acted as a clinical data repository for the participants' game performance data stored in an Oracle MySQL database [7]. This data was used at the start of each session to adjust game levels of difficulty automatically based on past performance.

B. Custom integrative therapeutic games

BrightBrainer library of therapeutic games targeted several cognitive domains, while inducing whole arm movement repetitions. Each game, when won, provided positive feedback and "rewards" designed to improve the subject's wellbeing.

The games targeted language comprehension (*Submarine Rescue*, *Pick-and-Place*), problem solving (*Submarine Rescue*), focusing/attention (*Breakout 3D*, *Musical Drums*), short term visual and auditory memory (*Card Island*, *Xylophone*), and immediate/working memory (*Pick-and-Place*, *Avalanche*). Most games could be played in uni-manual or bimanual mode and all had multiple levels of difficulty. Their exact characteristics, including graphics scenes, scoring formulas, and difficulty adjustment have been previously described [4, 8, 9].

A BrightBrainer training session consisted of a menu of subject-selected games (Figure 2a). Each game was selected by overlapping its icon with a hand avatar and pressing the controller trigger. Before the selected game started the subjects were presented with a scene which showed intuitively the level difficulty they had previously achieved for that particular game (Figure 2b).

Each game had several difficulty levels based on game specific parameters (such as ball speed in *Breakout 3D*), whether wrist weights were used, or whether the game was played in uni-manual or bimanual mode. An artificial intelligence module increased or decreased a particular game difficulty level based on participant's prior performance on that game. If the subject completed the task of a given game twice in a row, difficulty for that game was increased the next time the participant played it. If the participant could not complete the game at a given difficulty level twice in a row, difficulty was lowered to accommodate her skill level. The



Fig. 1. Medical Adult Day Program participant training on the BrightBrainer system. © Bright Cloud International Corp. Reprinted by permission

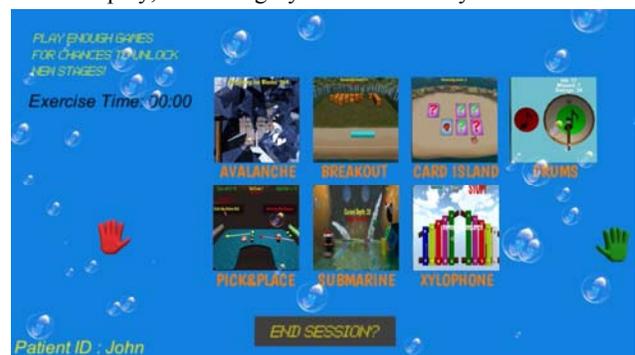
technician working with the participants was also allowed to adjust game difficulty manually by directing the subject to click a graphics button which made the following game slightly easier, or slightly harder. Once the prescribed session duration had been reached the participant's ability to play was automatically disabled so to avoid overuse-induced fatigue.

C. Virtual rehabilitation experimental protocol

Subsequent to protocol approval by Western Institutional Review Board, participants were recruited from a MADP in Central New Jersey, USA. One group of subjects was composed of elderly with dementia who attended that MADP, while the second group was formed of their caregivers. Each caregiver/Legally Authorized Representative signed two consent forms, one for the participant and one for the caregiver of that participant. Caregivers were consented so they could provide feedback on changes they would observe in their respective participant as a result of the experimental therapy.

A quiet room was set aside for the duration of the study, with an assistant to help the participants use the system. In order to monitor for overexertion/over excitement effects, the assistant was to take the participant's blood pressure and pulse before and at the end of each session.

The protocol specified that participants undergo 16 training sessions, twice/week for 8 weeks. The duration of a session was to progress from 20 minutes to a maximum of 40 minutes of actual play, increasing by 5 minutes every two weeks. The



a)



b)

Fig. 2. Graphical user interface to the games: a) session start screen; b) game level screen. © Bright Cloud International Corp. Reprinted by permission.

first 6 sessions were to be played in a less cognitively-taxing uni-manual mode, so to allow participants to get used to the system. The remaining 12 weeks of training were to be played in the more demanding bimanual mode. A new game was to be introduced every two weeks, with an array of choices increasing from 4 games in the first 2 weeks to 7 games in the last 2 weeks of training. Each game had to be played at least once per session. Depending on game preference, game performance (time taken to complete a game) and set session duration, a given game was generally to be played multiple times.

The difficulty of each game was to be increased automatically based on participant's performance, and by the addition of wrist weights in the last 4 weeks of training. The value of these weights progressed in size from 0.5 lb in week 5, to 1 lb in week 6 and for most participants 2 lb in weeks 7 and 8.

D. Participants characteristics

Fourteen participants were initially enrolled in the study, of which 10 completed it. Among those who completed the training, one participant had primary progressive aphasia and his case was described in detail elsewhere [9]. The present paper describes results on the remaining 9 participants as well as their caregivers' feedback.

The 9 participants vital statistics, education level, computer familiarity, initial depression level, cognitive impairment and initial Mini Mental Status Exam (MMSE) [10] scores are summarized in Table 1. The group was comprised of 6 females and 3 males with a mean age of 77.2 years (SD 11.04). Ethnically there were two African-American participants (both female), one Latino female and six Caucasians (among them 3 males).

The participants had all completed high school, with 2 having a Bachelor degree and 1 a post-graduate degree. They averaged 13.9 years of formal education (STD 3.2). Two thirds of the participants had no or little prior computer experience, with only 3 having had work-related computer experience.

One third of the participants had no depression, while the rest of the group was minimally depressed (Beck Depression Inventory II [11] scores of 1 to 4). Their cognitive impairment

level varied, with 1 participant having a prior diagnosis of Mild Cognitive Impairment (MCI), 5 having been diagnosed with Dementia, with an additional 2 in the Alzheimer's stage of the disease. This was reflected in their initial MMSE scores which ranged from 2 to 26 (M/SD=14.7/7.2).

Participants were allowed to continue taking whatever medication had been prescribed to them prior to study enrollment and no additional medication was administered as a condition of study participation. Similarly, no alteration was made to participants' activities in the MADP they were enrolled in at the time of the study.

E. Data collection instruments

The study used an ABAA protocol, data being collected pre- (A), during training (B), post-trials (A) and at 8 week follow up (A). The standardized neuropsychological measures of cognition and depression were administered by an independent neuropsychologist pre-, post- and at follow up.

The instruments used in the clinical evaluations were the Beck Depression Inventory, Revised, the Mini Mental Status Examination (MMSE) and the Brief Interview for Mental Status (BIMS) [12]. Data analysis was based on raw scores the participants obtained.

A custom feedback form was mailed to the participants' caregiver mid-therapy (B), at the end of therapy (A) and at 8 week follow up (A). The form was designed based on questions provided by the Director of the Medical Adult Day Program (also a co-author). Each of the 8 questions was scored from 1 meaning Strongly Disagree (least desirable outcome) to 5 meaning Strongly Agree (most desirable one). The questions solicited feedback on the changes the caregivers observed in the participants as a result of the computer training. The envisioned changes to be scored were in: 1) Improved ability to focus on a task; 2) Improvement in verbal responses; 3) Improved ability to follow one-step directions; 4) Improved ability to participate in Activities of Daily Living (ADLs); 5) Ability to share their experience with the computer games; 6) Appears more willing/ready to attend the program (MADP); 7) Open to trying new things, interacting with others; 8) Introduced them to more technology in the Home.

Apart from the above pencil and paper modes of data collection, BrightBrainer collected game performance data (B)

Table 1. Participants' characteristics pre-intervention. © Bright Cloud International Corp. Reprinted by permission.

Participant	1	2	3	4	5	6	7	8	9
Age (years)	89	88	73	62	87	66	64	81	85
Gender	Male	Female	Female	Male	Female	Male	Female	Female	Female
Race	White	White	Black	White	White	White	White	Latino	Black
Education (years)	12	12	16	16	12	12	21	12	12
Computer familiarity	None	None	Work related	Little	None	Work related	Work related	None	None
Initial Depression BDI-II score	Minimal 2	Minimal 1	Minimal 4	Minimal 1	Normal 0	Normal 0	Minimal 4	Minimal 4	Normal 0
Initial Cognitive Impairment MMSE score (0-30)	Dementia	Dementia	Alzheimer's Disease	Early onset AD	MCI	Cognitive decline	Dementia	Mild Dementia	Dementia
Initial MMSE score (0-30)	12	17	18	21	26	2	15	14	7

transparently during each training session. These data consisted of number of times a particular game had been played (to gauge game preferences), game level of difficulty achieved, game scores, number of arm movement and index finger flexion repetitions in each session, number of arm movement and index finger flexion repetitions per minute (game play intensity), the value of wrist weights worn, time spent exercising and resting.

Metadata was computed based on game performance stored in the database. For each participant the metadata analysis determined, among other variables, a composite game level for a particular session. The session composite game level was obtained by averaging the levels of individual games played in that session. Specifically each game, if played multiple times in a session at different levels, had its levels averaged. Summing of the individual game level of each type of game played in that session and dividing by the number of different games played produced the session composite game level. Similarly, the composite score was obtained by averaging the scores of individual games played by a participant in a given session.

In addition to the above measures, blood pressure and pulse were taken at the start and end of each session. The instrument used was an electrical Omron 7 series Upper Arm Blood Pressure Monitor. These measures were logged on a paper form.

F. Statistical methods

Comparisons of continuous variables pre-to-post and pre-to-follow up were done by paired t-tests. Results were transformed so that the larger the mean difference the more positive the finding. P-values less than 0.05 were considered statistically significant and values between 0.05 and 0.10 were deemed to be “trend-level”. No multiple-testing adjustment was done, and results expressed as 95% confidence intervals to document the precision of all statistical estimates.

Though low power makes a negative statement less reliable, any positive statistically significant findings implies robust findings which are not obscured by the (small) sample size. All statistical analyses were conducted using SAS 9.4 (SAS Institute, Inc., Cary, NC) [13].

III. OUTCOMES

A. Participants’ emotive and cognitive outcomes

Table 2 presents the group averages of the neuropsychological measures taken pre-training (T1), post-(T2) and at 8 week follow up (T3).

The group cognitive function as measured by the MMSE was severely impaired pre-intervention with an average score of 14.7 points. The group maintained this score post-training,

although the variability in individual levels had increased (SD 8.1 vs. 7.2 at baseline). Indeed, three participants had substantial gains in their clinical scores. Participant 5 was the least cognitively impaired of the group, having been diagnosed with MCI prior to the study. Her MMSE score at T1 was the highest at 26/30 and her BIMS score pre-training was 14/15. Post-training Participant 5 BIMS score was perfect (15 points) something she maintained at follow up. Her MMSE score progressed to a 29 (indicative of normal cognition) post-training (T2) and progressed further to a perfect 30 points at follow up (T3).

Participants 1 and 2 started significantly impaired, with BIMS scores of 3 and 4, respectively. Their MMSE scores were initially 12 and 17 indicative of dementia. Post-training their BIMS scores became 7 and 6, thus a gain of 133% and 50%, respectively. This was consistent with post-intervention gains in their MMSE scores which became 16 and 21, respectively (a gain of 33% and 24%). These gains were largely maintained at follow-up with MMSE scores of 15 and 20, respectively. Five of the 8 participants measured at follow up, had MMSE scores larger than those they had pre-training.

In the emotive domain participants started with no, or minimal depression at T1, something that was maintained at both T2 and T3.

B. Participants game performance

Each participant played an average of 150 BrightBrainer games over the 8 weeks of training, totaling about 8 hours of play. Each participant had a choice of what games they played in a given week from among those available that week. As a result the cognitive domains of problem solving (part of executive functions), focusing/attention, short-term memory, working memory and language comprehension received different amounts of training time. The amount of time (minutes of play) each participant devoted to each of these cognitive domains is illustrated in Figure 3.

Figure 4a shows the composite session game level achieved by each participant. The shape of the graph was influenced by a reset in game levels in session 7 when play mode was switched from the uni-manual to the more difficult bimanual mode. Furthermore, each subject played an increasing number of games, from 4 games available in sessions 1 to 4, to 5 games in sessions 5-8, 6 games in sessions 9-12 and finally 7 games in sessions 13-16.

Participants, with some encouragement from the researcher present in the room, were able to play all games. However their performance level depended on game and participant, such that each individual progressed differently. When performance was averaged for the group (Figure 4b), there is a clear improvement in game play over the duration of therapy.

Table 2. Participants cognitive outcomes based on standardized clinical measures. © Bright Cloud International Corp. Reprinted by permission.

Variable	T1	T2	T2-T1	95% CI T2-T1	p	T3	T3-T1	95% CI T3-T1	p
BIMS (0-15)	4.9(4.0)	5.6(4.2)	0.7 (1.9)	- 0.8, 2.2	0.33	5.4(4.2)	0.3 (1.0)	-0.6, 1.1	0.51
MMSE (0-30)	14.7(7.2)	14.7(8.1)	0 (3.2)	-2.4, 2.4	1.00	16.1(7.5)	1.4 (2.5)	-0.7, 3.5	0.16
BDI-II	1.8(1.8)	1.9(1.1)	0.1 (2.0)	-1.5, 1.7	0.87	1.3(1.3)	-0.5 (2.1)	-2.0, 1.5	0.74

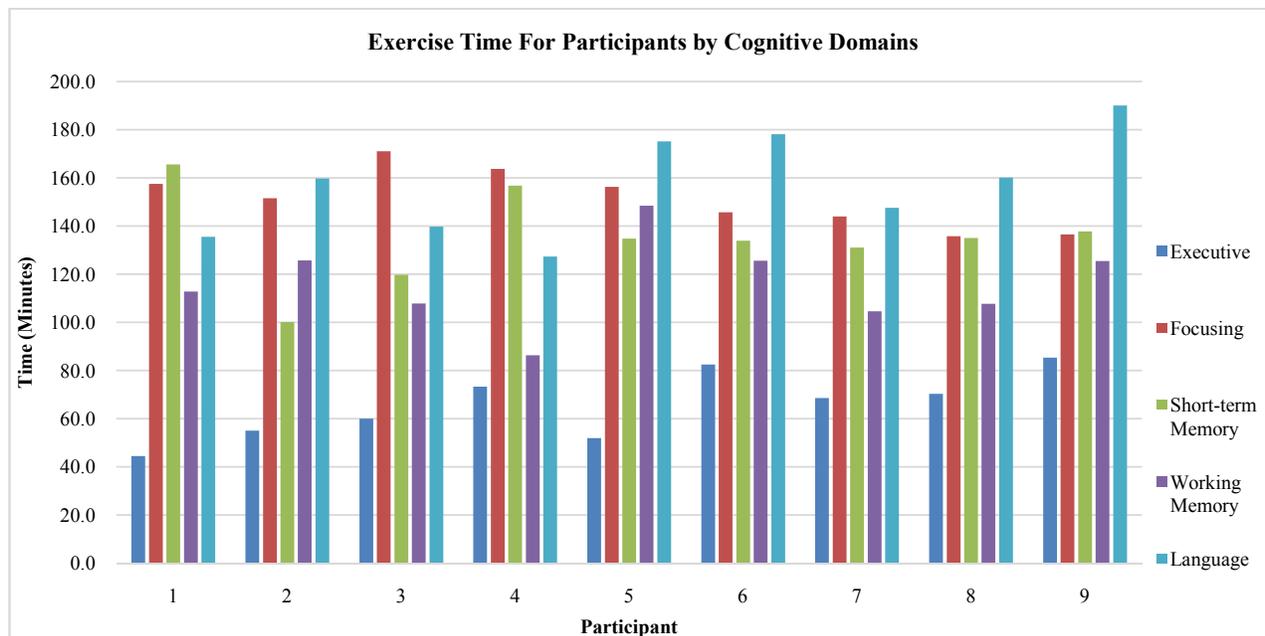


Fig. 3. Participants' cognitive domain-specific training times. © Bright Cloud International Corp. Reprinted by permission.

As expected, the group performed less uniformly with the increase in session difficulty, as exemplified by the increase in the SD intervals over sessions 1-6 (uni-manual play) and sessions 7-16 (bimanual play). This lack of uniformity manifested itself also at follow-up (session 17).

C. Observational evidence of participants' progress

The researcher present in the room noted that there was clear game improvement in the majority of the participants for all of the games. However, a lot of them struggled with "extreme" changes in game settings (such as *Breakout 3D* switching from predominantly horizontal to predominantly vertical movement of the paddle avatars, or *Drums* game going from 2 to 4 drums). For some participants, switching from uni-manual to bimanual mode was also very hard and Participants 6, 8, 9 never fully adjusted to this change. Participants were observed to generally perform better on simpler games such as *Pick and Place* and *Drums*, whereas *Submarine Rescue* and *Card Island* were harder for them. For some participants depth perception, as required in the *Submarine Rescue* game was an issue.

Participant 1 was undergoing speech therapy while at the same time participating in the BrightBrainer study. The speech pathologist noted a dramatic improvement in his speech, as shared with the authors. It is not clear how much of the participant's language gains were due to the Speech Therapist's work and how much was due to the games he played on BrightBrainer.

D. Motor training intensity and vital signs

The real-time games played by the participants and the duration of training sessions lead to a group average of close to 1,000 arm task-oriented active movement repetitions in

each of the last sessions (Figure 5a). At the end of training the index finger was flexed close to 300 times per session.

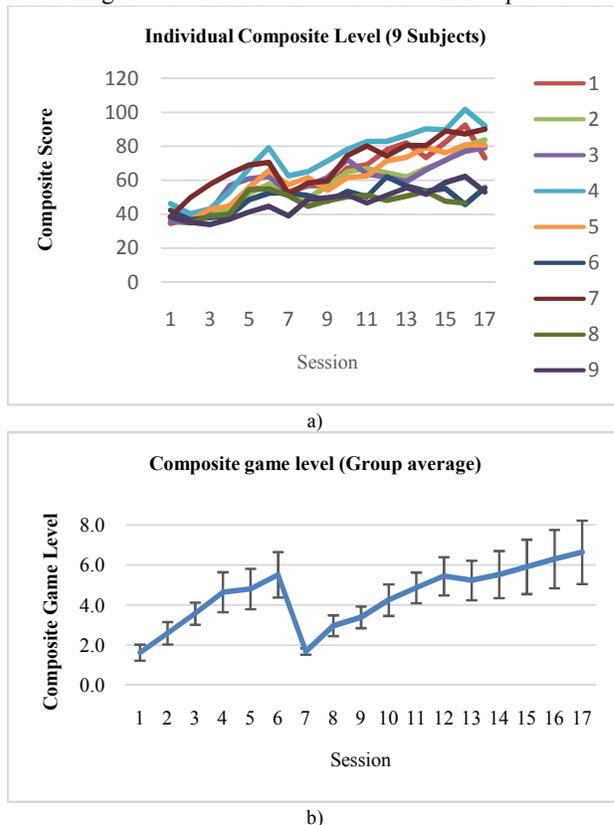


Fig. 4. Participants' composite game level vs. training session: a) individual levels; b) group average level. © Bright Cloud International Corp. Reprinted by permission.

Remarkably subjects were able to achieve this intensive training level while wearing wrist weights on each arm.

The intensive training in the cognitive and motor domains did not produce an increase in the group blood pressure. On the contrary, the group average systolic blood pressure started at 131.9 (SD 18.5) mmHg and was reduced to 118.9 (SD 17.6) mmHg by the end of training (Figure 5b). The Diastolic blood pressure group average went down from 79.7 (SD 15.1) mmHg pre-training to 73.2 (SD 14.4) mmHg. The group average pulse remained essentially unchanged, going from 65.4 (SD 9.5) heart beats/minute in session 1 to 64.3 (SD 8.4) in session 16.

E. Caregivers' feedback

After the first 4 weeks of training the caregivers for subjects 6, 7 and 9 provided feedback. Their responses were trending negative, with an average rating score of 2.3 (3 being neutral). The highest score was given to the statement that their participants appeared more ready/willing to attend the (MADP) program (3.3).

At the end of the training feedback was received from caregivers for participants 4, 6, 7, and 9. This time the overall score was slightly better (2.6), with the highest score for the statement "I observe that he/she has an improved ability to follow one-step directions" (3.5). The caregiver for Participant 6 noted that "My husband has been able to tie his shoes again. He had trouble doing so prior to this experience." The caregiver for Participant 9 wrote "I have noticed that in the

last 2 weeks O... has called me by my name (she has not done that in months), and she seems to be better at following one-step directions without additional prompting/follow up." The majority of caregivers agreed that they would recommend the system to others.

At follow-up caregivers for participants 5 and 8 provided feedback which had an overall higher score than post-training (3.25). The caregivers agreed that the participants they cared for had improved ability to focus on a task, and appeared more willing/ready to attend the (MADP) program.

IV. DISCUSSION

The present study is the first one to investigate BrightBrainer feasibility in a MADP setting. The training was in parallel with, and in addition to activities organized by the MADP in the room next door. Thus participants had a choice whether to continue with the BrightBrainer training or not. Twelve of the 14 participants enrolled chose to do so and they liked the system. Subsequently 2 participants had to stop training because of medical reasons unrelated to this study.

The enjoyment with computer training by the participant group with an average age of 77 years bodes well for future adoption of computerized maintenance (and in the case of MCI remediation) training. The participants' progress in the intensive computer-based training is remarkable in view of the fact that more than half had no prior computer experience. This may be due to the intuitive games and natural whole arm interactions involved in BrightBrainer brain training.

Several caregivers provided feedback on the benefits they observed midway through the training, at the end of training and 8 weeks thereafter. While mid-therapy and post-training the overall score tended negative (below 3), at follow up it became slightly positive (3.25). Caregivers reported improvement in their participants' ability to follow directions, improved vocabulary or more independence in ADLs. This is in line with the substantial improvement in the participant with PPA, as reported elsewhere [9].

There are currently no universally accepted computer-based cognitive rehabilitation systems or interventions. One computer software package that has been developed for training attention deficits in adults post traumatic brain injury is "Attention Process Training-3" [14]. The software offers a large number of exercises and exercise levels, however interaction is through a mouse (thus 2D movements) or speech, and no integrative training is provided.

Studies involving computer training of subjects with dementia attending Adult Day Programs have previously been reported. A randomized pilot study targeted higher functioning dementia participants from an ADP [15]. Participants in the experimental group undertook 12 weeks of interactive multimedia training on the web (3 times/week, 20-min session). A control group had daily psycho-stimulation for 8 hours offered by the ADP, and a second control group was medicated at home. After the study the experimental group saw an increase of 2 points in their MMSE, vs. 0.5 points in

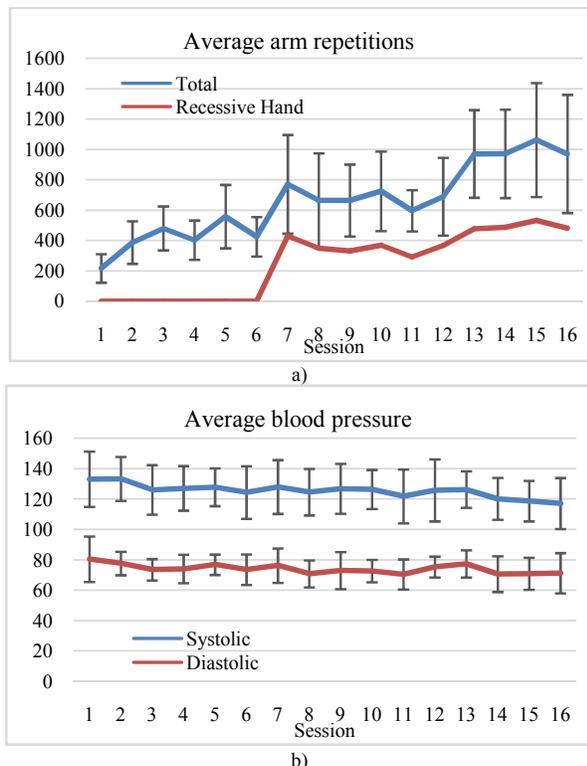


Fig. 5. Group averages vs. training session: a) arm repetitions; b) blood pressure. © Bright Cloud International Corp. Reprinted by permission.

the control group attending ADP activities. The second control group who only took medication had no cognitive gains. At 12 week follow up the experimental group maintained gains better than the group who had attended the ADP

Compared to the dementia subjects in the above ADP study, who had a group MMSE score at baseline of 20.6 points, the group that trained on BrightBrainer initially had a much lower average MMSE score of 14.7 points. The BrightBrainer group had no gains on the MMSE post-training (14.7 points), however the average score at follow-up had increased to 16.1 points (a gain of 1.4 points). The small 0.6 points gain on BIMS was maintained at follow up. Remarkably, the higher functioning participant (MCI) training on BrightBrainer had a larger gain of 3 points post-training and a 4 points gain at follow-up. She received the maximum score on *both* BIMS and MMSE at follow up, indicative of normal, unimpaired cognition. The substantial benefit for the higher functioning subject and the fact that she maintained it occurred despite the shorter training duration compared to the previously cited Adult Day Program study. This is pointing to the need to explore further the MCI population where BrightBrainer may provide more cognitive gains than for the other participants in the present study who were low-functioning (including two in the Alzheimer's phase of dementia).

Colombo and colleagues [16] describe a study of 10 elderly subjects with dementia who were long term residents in a Skilled Nursing Facility. This study is similar to the BrightBrainer study described here in the group size, the frequency of training (2 sessions/week), the administration conditions (quiet room with a researcher assisting), and the use of bimanual interaction with a graphics game of increasing difficulty. The cognitive impairment of the group of SNF residents ranged from severe to mild (MMSE scores of 11 to 24) with an average of 16.4 (SD 4.6). Researchers found that the dementia group participated well in the intervention and was interested in the game, with some participants achieving its highest difficulty level. Post-training MMSE average score increased by 1.6 points after a total of up to 4 hours of game play.

The above findings are similar to those of a previous BrightBrainer study on 10 participants who were also SNF residents [4]. Following 8 weeks of biweekly sessions the group had statistically significant improvements in executive function (as measured by the World Generation test - part of Neuropsychological Assessment Battery [17]) and in depression. Eight of 9 neuropsychological tests showed changes in the improvement direction indicating an effective rehabilitation ($p < 0.01$). BrightBrainer technology was well tolerated with mean satisfaction ratings of 4.9/5.0 across participants.

The prior BrightBrainer SNF study used standardized measures that were cognitive domain specific. The lack of more detailed cognitive standardized evaluations is a limitation in the present study. The MMSE and BDI tests were

selected based on input from the MADP where the study was conducted. In retrospect more sensitive clinical tests may have revealed additional information on the training effect.

The participants continued their tailored activities in the MADP while undergoing BrightBrainer training. This may be seen as a confounder, except that for several participants there was improvement in their cognition, not merely a slowing down of their cognitive decline.

The purpose of this study was to establish feasibility in terms of the acceptance of the various games by the participants and individual improvements. Thus another limitation of the current study is its small sample size. While initial research results are encouraging, future research should enroll a larger participant sample as well as establish a control condition to better determine change following treatment.

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