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Integrative Motor, Emotive and Cognitive Therapy for Elderly Patients Chronic Post-Stroke

A Feasibility Study of the BrightArm™ Rehabilitation System

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Abstract—**The BrightArm rehabilitation system is designed for integrative motor, emotive and cognitive training of low- and higher-functioning individuals. This paper presents the BrightArm's first feasibility study on 5 elderly skilled nursing facility residents chronic post-stroke. Results show improvements in motor impairments, upper extremity function, independence in activities of daily living, as well as better focusing and short-term visual memory following therapy. There was uniformly good acceptance of the technology by the participants which gave it an overall rating of 4.1 out of 5.**

Keywords- stroke; virtual reality; dual-task; depression; upper extremity; motor retraining; memory; executive function; focusing; shoulder strength, BrightArm.

I. Introduction

The Center for Disease Control has reported that in 2009 the US direct and indirect costs associated with stroke totaled a substantial 70 billion [1]. In many cases, patients post-stroke present with both motor deficits and emotive/cognitive impairments. Acute cognitive impairments (the first month after stroke) have a prevalence of about half of those suffering their first stroke [2]. The more prevalent types of cognitive impairments are those affecting executive function and visual perception/construction. While many recover from mild cognitive impairment within 6 months after stroke [3], the risk of dementia increases post-stroke for those with pre-stroke cognitive decline (such as the elderly) [4].

The inter-relation between cognitive impairments and physical/occupational therapy outcomes is an area that merits attention. Physical therapy outcomes post-stroke benefit from feedback provided to the patients in the form of knowledge of performance (KP) and knowledge of results (KR). Feedback in motor re-learning is in fact considered the second most important element after the necessary amount of practice [5]. Patients' cognitive impairments (diminished attention, impaired visual memory, diminished executive function) impact the understanding and processing of KP and thus influence physical rehabilitation outcomes. Specifically, in an upper extremity (UE) reaching task, KP was less understood by clients with cognitive deficits [6].

Virtual rehabilitation [7] provides an opportunity to improve rehabilitation outcomes due to its rich KP and KR, engaging and highly motivating tasks, and adaptability to each patient. Several computerized systems for UE motor rehabilitation using virtual reality are commercially available. The Armeo Spring (Hocoma AG, Switzerland) is a passive exoskeleton structure worn by the patient for gravity support during arm reach. Grasp strength and arm movement are used to play rehabilitation video-games [8]. The IREX system (GestureTek, Canada) uses chroma key techniques and a vision camera to project the image of the patient directly into a (mostly two-dimensional) game scene. Patient enjoyment is high, however no haptic (touch and force) feedback is provided [9]. Furthermore, IREX lacks limb gravity support, making it more appropriate for higher functioning patients. The Nintendo Wii game console is being used by many hospitals and clinics for motor re-learning post-stroke [10, 11]. While use of the Wii addresses the need for low-cost equipment, its reliance on off-the shelf games may lead to demoralization of low-functioning patients. The Wii is not appropriate for individuals challenged by arm gravity loading or with severe finger spasticity, resulting in difficulty holding the Wiimote or pressing its buttons [12]. Moreover, overuse-induced tendonitis (called "Wiiitis") has been reported [13].

Rehabilitation post-stroke is labor-intensive and costly. These costs may be artificially increased by current clinical practice, due to separate motor, emotive and cognitive interventions. Burdea [14] predicted that these therapy paths will merge into a single, integrative approach for populations that need it (such as elderly patients post-stroke), provided by a virtual therapist. This integration should result in health care costs and patient time savings.

Bright Cloud International Corp (BCI) is a spinoff of Rutgers University. Funded by an SBIR grant from the National Institutes of Health, the company has been developing the *BrightArm*™, a system designed to provide easily comprehended, flexible, adaptable, mood-boosting integrative UE motor, emotive and cognitive virtual rehabilitation. The BrightArm is a follow on to the Rutgers Arm II [15], which has been successful in improving UE motor function in patients chronic post-stroke [16]. This paper

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presents the first clinical feasibility study of the BrightArm on a group of elderly participants who were chronic post-stroke and residents on a skilled nursing facility (SNF).

II. Methods

The inclusion criteria for the feasibility study were stroke that occurred at least 1 year prior, age (>60), good mental awareness (to be able to comprehend the consent form and the simulation exercises demands) and residency in a SNF (nursing home). Exclusion criteria were total lack of active movement in the affected UE, blindness, severe cognitive delay, or dementia. Participants were recruited from among the residents of the Roosevelt Care Center (RCC), a large SNF in Edison, New Jersey, USA. All participants received medical clearance from their attending physicians and subsequently signed a consent form approved by the Western Institutional Review Board (a regulatory body that oversees BCI research on human subjects). The BrightArm was subsequently installed at the RCC in a dedicated room with a dedicated Internet connection to BCI headquarters. Prototype usability was first tested with 4 elderly but healthy volunteers. Subsequent evaluation and training of 6 participants chronic post-stroke took place in Fall 2010. Of these, 1 stopped participation due to illness unrelated to the study and 5 completed the experimental therapy.

A. Participants characteristics

Table I gives the vital statistics, motor impairment, emotive (depression level) and cognitive state as well as co-morbidity characteristics of the participants. The 5 participants (1 female and 4 male) ranged in age from 62 to 81 years old. Their stroke had occurred between 19 and 119 months prior to the intervention, and in all but one participant, affected their left side. They were initially very low functioning, with an UE score for the Fugl-Meyer Assessment (FMA) [17] of 4 points to 28 points (out of a maximum of 66 points). This corresponds to severe UE motor impairment in Participants 1, 2 4, and 5, and marked impairment in Participant 3. All participants presented with some degree of spasticity. Depression levels varied among participants, 3 being minimally depressed, 1 presenting with moderate depression, and 1 with no depression. Initially, 4 participants endorsed severe impairments in attention, memory, or both, and 1 participant had less severe cognitive impairments. All participants had multiple co-morbidities, 2 having a history of epilepsy, and 1 of severe anxiety. All used wheelchairs to travel within the SNF.

B. Data collection instruments

The protocol used was ABAA, with data collected at pre- (A), post- (A), and 6-week follow-up (A) evaluation sessions and transparently during each training session (B). Data presented here is for ABA component of the protocol, with follow-up data (A) to be presented elsewhere. There were 18 training sessions, over 6 weeks, 3 sessions/week. During each training session data were collected by the rehabilitation games (see BrightArm description section). At the end of every other week of training participants rated their experience on a subjective evaluation paper questionnaire. The form had 9 statements: "The system was easy to use," "The games were interesting," "I had no muscle pain or discomfort," "The instructions given to me were useful," "I was not bored while exercising," "The length of exercising in a day was appropriate," "There were few technical problems," "I would encourage another patient to use it," and "I liked the system overall." Each statement received a score ranging from 1 (least desirable outcome) to 5 (most desirable one). Pre- and post-evaluation sessions primarily involved collection of UE motor impairment and functional measures by a senior occupational

TABLE I PARTICIPANTS CHARACTERISTICS AND MEDICAL HISTORY PRE-INTERVENTION.

Participant	**1**	**2**	**3**	**4**	**5**
Age (years)	65	69	62	81	67
Gender	Female	Male	Male	Male	Male
Race	White	White	White	Black	White
Time since stroke (months)	119	21	73	73	19
Affected side	Left	Left	Right	Left	Left
Motor impairment level	Severe	Severe	Marked	Severe	Severe
Initial Fugl-Meyer Assessment UE score	5	4	28	10	11
Spasticity	Elbow, fingers	Elbow, fingers	Fingers	Elbow, fingers	Elbow, fingers
Depression level	Moderate	Minimal	Minimal	Minimal	Normal
Cognitive state	Severely impaired visual and verbal attention Severely impaired visual memory	Severely impaired visual memory	Severely impaired verbal memory	Severely impaired visual and verbal attention Severely impaired visual and verbal memory	Moderately impaired verbal attention Mildly impaired visual attention
Co-morbidities	Hypertension, Lag amputation, Anemia, Aneurism heart, Tobacco use	Epilepsy, Ischemic Heart, Hypothiroidism, Asthma, Chronic airway obstruction, Chronic pain	Aphasia, Convulsion, Hypertension, Epilepsy	Malignant kidney, Nocturia, Hypertension, Abnormal gait, Cataracts	Anxiety, Macular degeneration, Hypertension
Ambulation	Wheelchair	Wheelchair	Wheelchair	Wheelchair	Wheelchair
Language	Non-English	English	English	Non-English	English

therapist (OT), and of clinical emotive and cognitive impairments tests (performed by a neuropsychologist). Both clinicians were blinded as to the therapy methodology and scope. The neuropsychologist subsequently became a co-author of this paper (JH).

For the UE motor impairment evaluation, the measures used were the affected shoulder strength (measured with calibrated weights placed at the wrist), grasp strength (measured with a mechanical Jamar dynamometer) and finger pinch strength (measured with a mechanical pinch gauge). The motor retraining functional measures were the Jebsen test of hand function [18], the UE subset of the FMA test, and changes in activities of daily living (ADLs) self-reported on a standardized questionnaire [19]. The ADL questionnaire was modified by removing tasks thus SNF residents do not perform (driving, preparing food, vacuuming, tying laces). To improve ADL self-report accuracy, post-training questionnaires were filled by nurses or certified nurse aides.

The standardized measure used in the emotive evaluations was the Beck Depression Inventory [20]. The tests used for cognition were Neuropsychological Assessment Battery [21] (NAB) Attention Module digits forward and backward (used for verbal attention), NAB Attention Module dots (visual attention), the Hopkins Verbal Learning Test (HVLT-R), Revised [22] (verbal memory) and the Brief Visuo-spatial Memory Test, Revised (BVMT-R) [23] (visual memory). Alternate test forms were used whenever possible to minimize test-taking practice effect.

C. *The BrightArm rehabilitation system*

The BrightArm system (Fig. 1*a*) [24] consists of a wheelchair-accessible motorized training table, a computerized forearm support, two overhead digital cameras, a large high-definition TV, a multicore PC workstation, custom rehabilitation games and a remote clinical server. Participants in their wheelchair are accommodated by BrightArm ability to lift or lower itself, depending on the patient's height. Unlike the precursor Rutgers Arm II, the BrightArm trains either arm without need for table rotation vs. the display. An electrical tilting mechanism (absent in the Rutgers Arm II) allows the therapist to set the surface angle to resist (pitch up) or assist (pitch down) the trained arm movement. The momentary pitch angle and table height values are measured by analog potentiometers and transmitted wirelessly to the PC. Patients put their arm on a low-friction forearm support and grasp a deformable rubber pear. Its air pressure is processed by the arm support electronics and transmitted to the PC wirelessly. The dimensions and attachment mechanism of the forearm support allows use of rehabilitation wrist weights such as those used in conventional therapy. Tracking of the arm position and orientation on the table surface is done by a combination of 2 IR diodes on the forearm support, the overhead digital cameras with IR filter, and IR diodes at the table periphery used for initial calibration.

At the start of every session the participants perform a baseline for affected arm reach and hand grasp strength. The

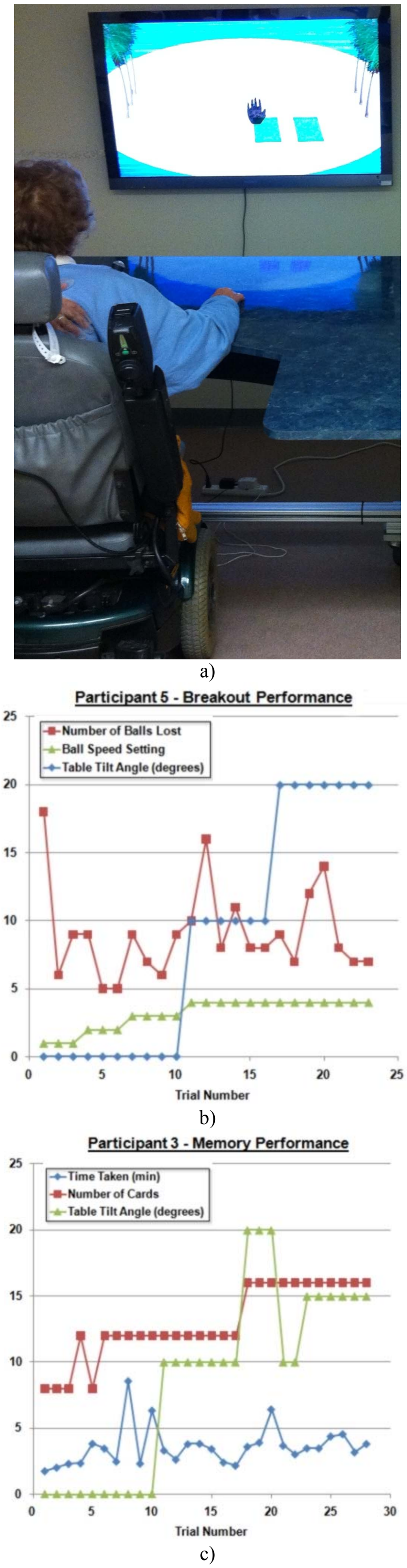

Figure 1. BrightArm system: a) Participant 1 training; b) Participant 5 *Breakout 3D* balls lost vs. table tilt and ball speed; c) Participant 3 *Card Island* completion time vs. number of cards to match and table tilt.

baseline is patient, arm, table-tilt and wrist weight dependent, parameters which are stored in the database for each session. The arm reach is visualized as an area of the BrightArm table avatar that changes color when transited by the patient. For grasp strength, the avatar is a virtual thermometer-like gauge which shows the momentary and maximum grasp strength. Arm reach and grasp strength data are used to adapt the custom games to each participant, each session. In game settings that require dual-tasking (reach and grasp) momentary grasp thresholds are set at 25% of the measured grasp strength that day, and sustained grasp condition at 10%. These values are intended to prevent arm pain and discomfort observed in Rutgers Arm trials with participants chronic post-stroke [15].

In its current configuration the BrightArm therapy sessions consist of five custom games namely *Pick-and-place*, *Breakout 3D*, *Treasure Hunt*, *Card Island* and *Towers of Hanoi 3D*. Each game has settings for "no grasp," "momentary grasp" and "sustained grasp" conditions, and several difficulty levels.

- *Pick-and-place* is a game designed to improve motor control, shoulder/grasp strength, by asking the patient to pick up a ball with a hand avatar and follow a prescribed path to a target, while the actual arm movement is traced in real time. Dual-tasking is implemented by requiring that grasp strength be maintained en route to the target, lest the ball avatar falls and has to be picked up again. Difficulty level is further increased by making the target area progressively smaller. Depending on where the target and ball are initially located the game trains primarily shoulder flexion/extension or abduction/adduction.

- *Breakout 3D* is designed for executive anticipation, focusing, arm speed and shoulder/grasp strength. It is BCI version of the well-known arcade game, except this time the paddle avatar used to bounce virtual balls is controlled by the patient and the brick wall to be destroyed is placed distal when training primarily shoulder adduction/abduction and lateral when training shoulder flexion/extension. In the dual-task condition the patient is asked to grasp just before bounce, lest the ball passes through the paddle avatar and is lost. Further difficulty levels are set by increasing the speed of the ball and decreasing the size of the paddle.

- *Treasure hunt* trains arm endurance and shoulder/grasp strengthening. The patient controls a shovel avatar and has to dig out a number of treasure chests buried in the sand on a desert island. Dual task condition requires the patient to grasp the shovel lest it will not move, while difficulty is increased by periodic sand storms that cover some of the already found treasures.

- *Card Island* trains short term visual memory and focusing. It shows the same island, this time with an array of cards arranged face down. The patient has to find all the pairs of cards, two trials at a time. Dual-tasking is set by the condition that the patient grasps when the hand avatar overlaps the chosen card to turn it face up. Game difficulty is determined by the number of cards (8 easy, 12 medium, 16 hard). BrightArm technology customizes each card deck for each participant, so to facilitate memory training.

- *Tower of Hanoi 3D* is BCI version of the classic logic game that is normally played with a computer mouse on a web browser. The game trains executive function and asks patients to stack disks of different diameters on one of 3 poles. The disks are initially on one pole, stacked in increasing size from top to bottom and the player has to re-stack the disks on another pole in the same order of sizes. The third pole is used as a way point. The BCI version of the game presents a 3-D scene showing 3-D disks, 3-D poles and a hand avatar controlled by the participant's arm movement and grasping. The poles are placed inside the participant's arm reach area, and participants have to overlap a disk with the hand avatar, and then grasp to pick it up and subsequently place it precisely on a desired pole. The continuous grasp condition, when selected, requires that participants maintain gasp strength above a threshold, else the disk falls en route and has to be picked up again. Game difficulty depends on the number of disks (2-easy, 3-medium, 4-hard), more disks corresponding with a larger sequence of moves needed to restack the disks and to larger cognitive load. Thus *Tower of Hanoi 3D* trains not only logic and executive function but also motor control, shoulder/grasp strengthening and dual-tasking.

Each of the 5 games includes performance feedback rewards (fireworks and applause) for positive reinforcement and designed to improve the participant's morale.

D. *Experimental Protocol*

The 18 therapy sessions progressed in duration from 20 minutes of actual play per session (week 1), to 30 minutes (week 2), to 40 minutes (week 3) and 50 minutes (weeks 4 through 6). In addition to training duration, training intensity was increased by progressively tilting the table from 0° (horizontal) in weeks 1-3, to 10° (week 4) and 20° (weeks 5 and 6). Each session consisted of a sequence of *Pick-and-Place*, *Breakout 3D*, followed by *Treasure Hunt, Card Island* and *Tower of Hanoi 3D,* and the sequence repeated as needed to achieve the prescribed session duration. Each exercise difficulty was progressed from easier games with no required grasping (weeks 1) to most difficult ones requiring sustained grasping (week 6), when the addition of wrist weights was also attempted. A senior OT assisted the participants when needed in the first 4 weeks, and a certified therapist assistant assisted in weeks 5 and 6. At the start of each session the participants' spastic elbow and fingers were stretched by the therapists prior to virtual rehabilitation. In addition to actual game play participants were asked to perform actual activities under supervision in the last 2 weeks of training. These included squeezing a rubber ball, using silverware in simulated feeding, picking up objects, and writing in the case of Participant 3 (who was highest functioning).

III. OUTCOMES

A. Participants' upper extremity motor impairment

Four of the 5 participants showed significant improvement in shoulder strength (Table II). While none could lift wrist weights pre-, post therapy they were able to lift between 1 and 2.5 lb. Grasp strength on the Jamar mechanical dynamometer improved in 4 participants. Of these, Participants 1, 2 and 4 had been unable to grasp pre- while Participant 3 had a substantial increase (9 lb) in grasp strength following the intervention. Pinch strength did not improve, except for Participant 3 who became stronger in all 3 pinch configurations. As seen in Table III, there was improvement in participants' active range of movement as well. Shoulder extension and abduction improved in all participants with increases ranging from 5° to 30° and 15° to 30°, respectively. Except for the lowest functioning Participant 2, all the others also showed increased active range of shoulder flexion, ranging from 15 to 25 extra degrees. All but 1 participant increased their active elbow flexion (by up to 25°, and 3 saw increases in their elbow extension, with the largest gain of 15° for Participant 5. This participant also had a substantial increase of 30° in his active range of elbow pronation.

B. Participants' UE function and activities of daily living

Participants 1, 2, 4 and 5, who had high spasticity, were unable to perform any of the 7 timed tasks composing the Jebsen test of hand function (writing, simulated page turning, lifting small common objects, simulated feeding, stacking checkers, lifting large light objects, and lifting large heavy objects). Participant 3, who was less impaired, was able to complete three tasks, his overall time dropping from 1167 seconds pre-, to 953 seconds post (an 18% improvement in his hand function).

Participants 1, 2, 4 and 5 started with severe motor impairments and extremely low scores on the FMA test (5, 4, 10, and 11, respectively) as seen in Table IV. Post therapy Participants 1 and 5 progressed into the Marked motor impairment range, with FMA score increases of 11 and 12 points, respectively. There was essentially no change in FMA UE score for the other 3 participants.

Improved shoulder strength and increased affected arm use resulted in more independence in ADLs in 4 of the 5 participants. On a modified standardized list (12 activities), pre-intervention Participants 1, 2, 4, and 5 were unable to perform 11 tasks, while Participant 3 was unable to perform 6 tasks. Post-therapy the number of tasks they were unable to perform dropped to 3 for Participant 1, to 2 for Participant 3, 10 for Participant 4 and 6 for Participant 5. Remarkably, Participant 1 now had no difficulty performing 5 ADL tasks, and Participant 3 was independent in 7 such activities.

C. Participants' emotive and cognitive outcomes

Pre-training the participants had varying levels of depression scores, ranging from 26 (or moderate depression) for Participant 1 to 0 (normal) for Participant 5. As seen in Table V, the participants' mood generally improved post-, notably Participant 1 depression level dropped to "mild", and Participants 3, and 4 showing reduced scores within the

TABLE II CHANGES IN SHOULDER AND GRASP STRENGTH IN FIVE NURSING HOME RESIDENTS CHRONIC POST-STROKE AFTER 6 WEEKS OF TRAINING.

Participant	**1**		**2**		**3**		**4**		**5**	
Session	Pre-	Post-	Pre-	Post-	Pre-	Post-	Pre-	Post-	Pre-	Post-
Shoulder strength anterior	0	2.5	0	0	0	1.5	0	1.5	0	1.5
Shoulder strength lateral	0	2.5	0	0	0	1	0	1.5	0	1.5
Grasp strength	0	2.33	0	1.66	2.7	11.3	0	1	0	0
Pulp-to-Pulp strength	0	0	0	0	0	5	0	0	0	0
Key Pinch strength	0	0	0	0	11	13.7	0	3	0	0
3 finger tip strength	0	0	0	0	0	2	0	0	0	0

NOTE: Shoulder strength measured with wrist weights (lb); grasp strength measured with mechanical Jamar dynamometer (lbf); pinch strength measured with a mechanical pinch gauge (lbf)

TABLE III CHANGES IN UPPER EXTREMITY ACTIVE RANGE OF MOVEMENT IN FIVE NURSING HOME RESIDENTS CHRONIC POST-STROKE AFTER 6 WEEKS OF TRAINING.

Participant	**1**		**2**		**3**		**4**		**5**	
Session	Pre-	Post-	Pre-	Post-	Pre-	Post-	Pre-	Post-	Pre-	Post-
Shoulder flexion (increase)	0-20	0-45 (25)	0	0 (0)	0-35	0-50 (15)	0-30	0-50 (20)	0-50	0-65 (15)
Shoulder extension (increase)	0-40	0-45 (5)	0	0-30 (30)	0-40	0-50 (10)	0-20	0-35 (15)	0-30	0-35 (5)
Shoulder abduction (increase)	0-40	0-60 (20)	0-15	0-30 (15)	0-30	0-40 (10)	0-30	0-50 (20)	0-20	0-50 (30)
Shoulder internal rotation (increase)	0-20	0-25 (5)	0	0-30 (30)	0-40	0-50 (10)	0-70	0-70 (0)	0-30	0-30 (0)
Elbow flexion (increase)	95-120	95-125 (5)	70-85	50-85 (20)	70-110	70-110 (0)	92-110	87-120 (15)	70-85	55-85 (15)
Elbow extension (increase)	95	90 (5)	0	0 (0)	70	70 (0)	92	87 (5)	70	55 (15)
Elbow pronation (increase)	0-90	0-90 (0)	0	0 (0)	0-50	0-55 (0)	0-30	0-50 (20)	0-20	0-50 (30)
Elbow supination (increase)	0-5	0-5 (0)	0	0 (0)	0-10	0-15 (5)	0-10	0-10 (0)	0	0-10 (10)

NOTE: joint angles measured with a mechanical goniometer (degrees).

TABLE IV CHANGES IN UPPER EXTREMITY FUNCTION AND INDEPENDENCE IN ACTIVITIES OF DAILY LIVING IN FIVE NURSING HOME RESIDENTS CHRONIC POST-STROKE AFTER 6 WEEKS OF TRAINING.

Participant	**1**		**2**		**3**		**4**		**5**	
Session	Pre-	Post-	Pre-	Post-	Pre-	Post-	Pre-	Post-	Pre-	Post-
Fugl-Meyer Upper Extremity Test Score (66 is max)										
UE score (increase)	5	16 (11)	4	2 (-2)	28	28 (0)	10	11 (1)	11	23 (12)
Activities of Daily Living (out of 12 standardized tasks)										
Unable to perform	11	3	11	11	6	2	11	10	11	6
Some difficulty	0	4	0	0	6	3	1	1	1	5
No difficulty	1	5	1	1	0	7	0	1	0	1

"minimal" range. Participant 5 emotive state had worsened to "minimal" with a score of 5. In the attention/focusing aspect of cognition there was across-the-board improvement among the participants. Participant 1 started severely impaired in verbal attention and in visual attention, but improved to mildly impaired and low average, respectively. Participant 3 progressed from "moderately impaired" to "mildly impaired" and from "low average" to "average" in these domains. Participants 4 and 5 had similar improvements. In the visual memory domain there were improvements in 3 participants, Participant 2 went from severely impaired to "low average", Participant 3 from "low average" to "average", and Participant 5 progressed from "average" to "superior" range.

D. Computer baseline and game data

Supported arm reach baseline areas at session start showed significant increases in all participants. As seen in Fig. 2, participants started with small and uneven arm reach, as measured in camera tracking units. By the end of therapy their arm reach had not only significantly increased, but became closer to the curved reach of a healthy person. Comparing pre- and post- arm reach, are increases ranged between 224% for Participant 1 and 1418% for Participant 9.

Computer game data provides an indirect way to gauge participants' mental state, as seen in Fig. 1*b,c*. Participant 5 motor, focusing and executive functions seemed to have improved, as he maintained the number of balls lost in the Breakout 3D game, despite a 400% increase in ball speed and an increase in table tilt from 0° to 20°. Similarly, Participant 3 had a doubling of time taken to match the cards in *Card Island* memory game, for twice as many cards, and at 15° table tilt.

E. Participants' subjective evaluation of the BrightArm

Participants liked the system and gave it an overall score of 4.1 out of 5. The lowest score (3.2) was given to "There were few technical Problems," to be expected as this was a new system. Participants gave, however, almost maximum rating (4.7) on "I liked the system overall" statement.

IV. DISCUSSION

A. Training Results

1) Motor and function

Participants benefited greatly in their motor impairments and function from training on the BrightArm system. Pre-training they had been unable to lift weights at their wrist, but four participants were able to do so post-training. Four participants could not exert force in grasping pre-training, but three of them could do so post-. As seen in Table II, grasp strength readings post-therapy ranged from 1 lbf for

TABLE V EMOTIVE AND COGNITIVE OUTCOMES IN FIVE NURSING HOME RESIDENTS CHRONIC POST-STROKE AFTER 6 WEEKS OF TRAINING.

Participant	**1**		**2**		**3**		**4**		**5**	
Session	Pre-	Post-	Pre-	Post-	Pre-	Post-	Pre-	Post-	Pre-	Post-
Emotive Outcomes										
Depression Index	26	18	1	1	6	5	11	2	0	5
Depression level	Moderate	Mild	Minimal	Minimal	Minimal	Minimal	Minimal	Minimal	Normal	Minimal
Cognitive Outcomes (Attention/Focusing)										
Verbal Attention (digits forward)	Severely Impaired T=25	Mildly impaired T=35	High-average T=58	Average T=56	Moderately impaired T=30	Mildly impaired T=36	Moderately impaired T=30	Severely impaired T=28	Moderately impaired T=30	Average T=46
Verbal Attention (digits backward)	Mildly impaired T=32	Mildly impaired T=31	Average T=46	Average T=55	Low average T=39	Average T=44	Severely impaired T=25	Mildly impaired T=31	Average T=46	High average T=60
Visual Attention (Dots)	Severely Impaired T=27	Low average T=39	Average T=50	Average T=53	Low average T=41	Average T=44	Severely impaired T=24	Average T=40	Mildly impaired T=34	Average T=44
Cognitive Outcomes (Memory)										
Verbal Memory HVLT-R Trials 1-3	Mildly impaired T=35	Severely impaired T=26	Average T=46	Average T=50	Severely impaired T=27	Moderately impaired T=30	Severely impaired T=24	Severely Impaired T=27	Low average T=37	Mildly impaired T=36
Visual Memory BVMT-R Trials 1-3	Severely impaired T=22	Severely impaired T=23	Severely impaired T=23	Low average T=37	Low average T=42	Average T=55	Severely impaired T<20	Severely impaired T<20	Average T=47	Superior T=67

Participant 1, to 11.3 lbf for Participant 3. Since the repeatability of Jamar dynamometers has been reported to be 2.6 to 3.1 lb [25] only Participant 3 had a statistical significant increase in his grasp strength. These results are in line with our earlier studies on the Rutgers Arm II [16], where two of the four subjects crhonic post-stroke could not grasp or pinch pre-training but could do so post-six weeks of training. Another study of gravity supported UE training was conducted in with the Armeo Spring [26]. The study aimed at improving parethic arm strength and function in ten subjects with multiple sclerosis. After eight weeks of training (three half-hour sessions/week playing games) results showed improved arm function, but no significant increases in muscle strength.

Shoulder active range increased between 15° and 25° in flexion and between 10° and 30° in abduction. The intratester reliability of shoulder goniometry was cited at 0.87 to 0.99 with an accuracy of about 3° [27]. Thus the range increases in this study are not due to goniometry uncertainty. The average increase in supported arm reach was 634%, vs. an average increase of 263% obtained after the same amount of therapy for four chronic stroke subjects training on the Rutgers Arm II [16]. This much larger increase may be due to the lower arm function (per Fugl-Meyer test) for the SNF residents pre-training, vs. the subjects who trained at Rutgers. Participant 1, who started with a FMA score of only 5 improved to a score of 16 post-training on the BrightArm, while Participant 5 went from a FMA score of 11 to 23. While test-retest FMA score differences of ±2 points could occur by chance [28], the two participants in this study improved 11 and 12 points, respsctively. These FMA increases are in line with the significant arm reach increases graphed in Fig. 2, and cannot be attributed to chance. They are about twice what has been previously reported for other UE virtual rehabilitation studies of patients chronic post-stroke [29, 30]. Interestingly, the first case study chronic post-stroke on the Rutgers Arm, training 4 weeks on the table kept flat, had a FMA 7 point increase (from 22 to 29) post-intervention [31]. His supported arm reach area increased 39% after 4 weeks of training, and was 90% larger than pre-training after an additionnal week of training. It is possible that these smaller gains were due to the shorter therapy, and to the fact that he started at a higher functional level than either Participant 1 or 5 in this study.

2) Emotive and cognitive

Pre-training the depressive state of the five participants varied from none for Participant 5, to "minimally depressed" for Participants 2, 3 and 4, and to "moderately depressed" for Participant 1. Participants 1 and 4 benefitted most from the experimental therapy, with reduction in BDI II scores from 26 to 18, and from 11 to 2, respectively. These results are in line with a lerger study, in which 19 geriatric participants played Wii games for half hour, three times/week for 12 weeks. [32]. Results showed a 50% or larger reduction in depresson in one-third of the participants.

Simple auditory attention, focusing and visual attention improved substantially in four participants post-intervention. It is possible that imrovement in abbility to focus is due to the fast graphics (as in the *Breakout 3D* game) which ellicited more activity in the visual cortex. Other studies of attention, this time involving young healthy video game players, showed significantly better attentional resources compared to young healthy non-players [33]. Three participants improved in visual memory, in line with a study of 72 undergraduate students which also showed that playing video games results in improved visual memory [34]. Results on verbal memory improvements were mixed, which may be due to the fact that the *Card Island* memory game trained visual rather than verbal memory. This points to the need for new games to train verbal memory, and of incorporating verbal memory elements in other games presented here.

3) Participants acceptance of the technology

Participants complied with the protocol, attended all training and evaluation sessions and practiced the required amount of time without complaining. Their overall rating

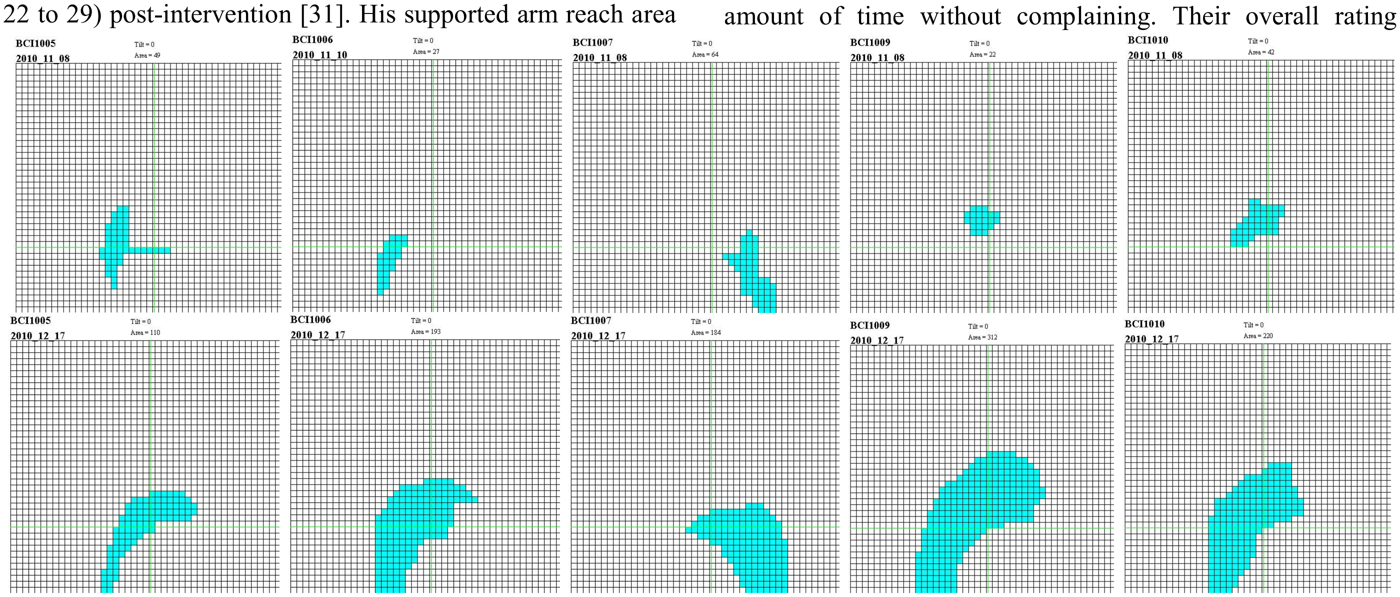

FIGURE 2. SUPPORTED ARM REACH BASELINE IN FIVE NURSING HOME RESIDENTS CHRONIC POST-STROKE: A) BEFORE TRAINING (TOP); B) AFTER TRAINING (BOTTOM). © BRIGHT CLOUD INTERNATIONAL CORP. REPRINTED BY PERMISSION.

score of 4.1 out of 5 indicates acceptance of the BrightArm system, in line with numerous other UE virtual rehabilitation studies [35-37] showing patients' acceptance of virtual rehabilitation.

The nurses and CNA's who worked with the 5 participants reported in all cases a marked improvement in the residents overall level of function, spirit and motivation. Nurses and CNA's felt that the participants were excited about the trials. They demonstrated consistently improved daily living skills and presented with carry-over from session to session. Nursing staff and CNA's interviewed felt that the 5 participants were excited about participation in program and were disappointed when the trials were completed.

V. Conclusions

This represents the first feasibility study of the BrightArm rehabilitation system. Despite the severe motor and cognitive impairments with which the participant presented pre-training, they were all able to use and enjoy the system. Clinical evaluations showed improvements in motor impairment in all participants and remarkable improvement in FMA scores in 2 participants. In the cognitive domain there was uniform improved attention, and varying improvements in memory. It is necessary to continue the BrightArm clinical evaluation with more subjects, and eventually controlled studies.

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A Nair OT performed the motor evaluations. M Jagtap OT, P Joshi OT, and Y Lockhart COTA trained the participants.

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