

# Longitudinal study of integrative virtual rehabilitation use in skilled nursing facility maintenance programs for residents with chronic stroke

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## ABSTRACT

The objective of this 45-week longitudinal controlled study was to examine the effects of integrative virtual rehabilitation with BrightArm Duo System for the maintenance of skilled nursing facility programs for elderly residents with chronic stroke. The experimental group trained intensely for 8 weeks followed by 3 booster periods at 8-week intervals. The sessions were supervised by an occupational therapist. The control (n=3) and experimental (n=7) groups both received standard-of-care maintenance. The improvement for the experimental group was significantly better than the controls in standardized assessments of UE range of motion ( $p=0.04$ ), strength, and function ( $p=0.035$ ), and for cognition and emotion ( $p=0.0006$ ).

## 1. INTRODUCTION

STROKE is the leading cause of disability in the US, with 795,000 Americans having a stroke each year (CDC, 2014). Although the mortality rate from stroke continues to decline (CDC, 2013), less than 15% of adults post-stroke recover complete upper extremity (UE) motor function (Hendricks, van Limbeek, Geurts, & Zwarts, 2002). Thus, millions of Americans in the chronic post-stroke phase (Rosamond et al., 2007) face a life of disability. Stroke affects quality of life, often causing depression (Sarah, 2009). The quality of life is even more diminished for the 15% of stroke survivors who become long-term resident of skilled nursing facilities (SNFs) (Jørgensen et al., 1995). Due to the aging of America, the societal costs associated with stroke are expected to grow to a staggering \$240 billion *annually* by 2030 (Ovbiagele et al, 2013).

Health maintenance programs provided by Skilled Nursing Facilities (SNFs) are aimed at preserving arm function, flexibility, balance, and slowing down beyond age-related cognitive decline. However studies have not shown significant benefit to depression and self-esteem from participation in a SNF health maintenance program (Sung, 2007). Furthermore, such programs are not rehabilitation interventions, per se. They lack the number of task-oriented repetitions needed, strength training, as well as the appropriate length of training. This is especially problematic for long-term residents post-stroke who present with unique needs.

In the current managed care model, post-stroke therapy typically ends 6 to 9 months from a cerebrovascular accident. However, neuroscience has shown that UE function may continue to improve years post-stroke, as long as activities are task-oriented, repeated, and well attended (Jørgensen et al., 1995; Lamola et al, 2014). Given the limited nature of traditional therapy alternate options need to be explored that can deliver ongoing therapeutic benefit efficiently across a large number of participants through to the chronic post-stroke phase. Long-term residents of SNFs who survived a stroke present with a combination of motor, cognitive and emotive disabilities. They could benefit from therapy which addresses all these domains in an integrative way. This is unlike the current therapy model of separate, disjointed therapies by different clinicians: physical therapist, occupational

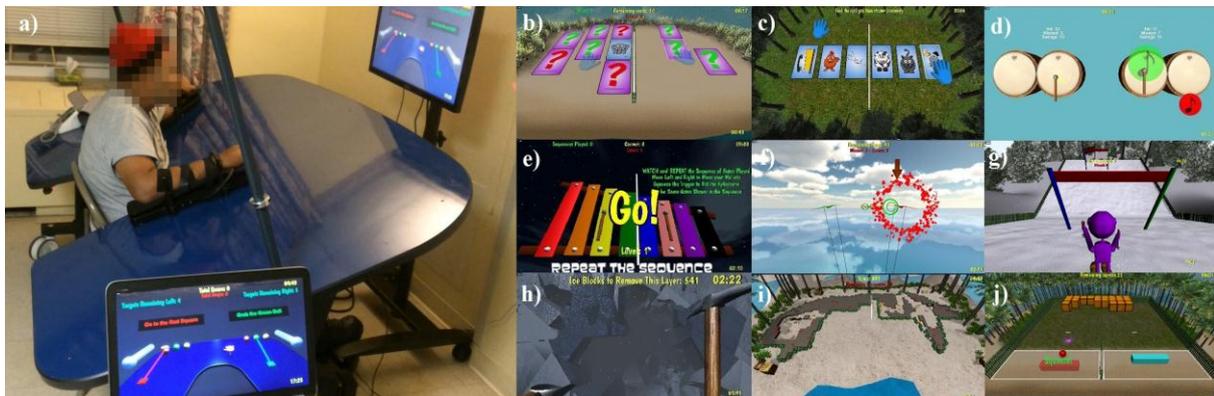
therapists (OT), neuropsychologists, psychiatrists, speech language pathologists and others. By contrast, integrative rehabilitation addresses the motor, cognitive and emotive deficits in a single-point-of-care approach. Integrative virtual rehabilitation presented in this study, uses custom therapeutic games in which the participant is asked to solve cognitive problems (such as making decisions on object sequences or remembering the location of image pairs) through physical exertion (arm movement and grasping). The emotive domain is addressed by making the custom games always winnable and by lavishly congratulating for success. More importantly, as the difficulty level is adjusted in real-time, frustration is minimized and some success is enjoyed from every session.

In order to improve the current standard of care and meet the needs of SNF residents in the chronic phase post-stroke, Bright Cloud International Corp developed the BrightArm (Rabin et al., 2012) and subsequently the BrightArm Duo (Burdea et al., 2015; House et al., 2015, 2016). A longitudinal controlled study was started in the summer of 2014 to evaluate the BrightArm Duo use for maintenance therapy of elderly SNF residents who were in the chronic post-stroke phase of their condition. The results of the completed longitudinal study with comparisons between experimental and control groups are the focus of this paper.

## 2. METHODS

### 2.1 The BrightArm Duo rehabilitation system

As seen in Figure 1a), the BrightArm Duo Rehabilitation System is a robotic rehabilitation table with two computerized forearm supports and a therapist laptop that renders custom therapeutic games to an output display. The monitor was appropriately sized to provide a level of immersion without causing motion sickness in elderly population. The subject interacted with the virtual reality (VR) game environment through active arm movement and power grasp, both being tracked in real time. The serious game library was developed in Unity 3D (Unity, 2016) and provides upper extremity training either uni-manually or bimanually. Each session, the system automatically adapted to the subject's forearm supported reach and grasp strength. Game difficulty, session duration, gravity loading on the upper extremity, were all graduated over the length of the training (House et al., 2015). The games mediated training for motor (shoulder, elbow, grasp), emotive (depression) and cognitive (executive function, focusing, short-term and delayed memory, working memory and task sequencing) training.



**Figure 1.** a) BrightArm system with subject training bimanually on Pick & Place game. Additional games: b) Card Island; c) Remember that Card ; d) Musical Drums; e) Xylophone; f) Kites; g) Arm Slalom; h) Avalanche; i) Treasure Hunt; and j) Breakout 3D. © Bright Cloud International Corp. Reprinted with permission.

Figure 1 also shows screen images of the ten games used in the study. In the game a) *Pick & Place*, the subject trained working memory by grasping a ball and moving it to a fixed target of matching color, using in-out or left-right arm movements. The matching card games b) *Card Island* and c) *Remember that Card* trained short-term and delayed visual and auditory memory, grasp strength, shoulder abduction/adduction, and shoulder flexion/extension. For d) *Musical Drums*, the subject trained focusing by controlling drum stick avatars to strike a series of notes that drifted across (up to four) drums. The e) *Xylophone* game trained short-term auditory and visual memory by having the subject repeat a sequence of musical notes using mallet avatars. The game f) *Kites* also trained focusing and motor control as the subject guided a pair of guides through a series of rings moving toward the front of the screen. Playing g) *Arm Slalom* induced shoulder rotations in order to guide a skier avatar through a downhill slalom course. In the h) *Avalanche* game, the subject cleared a series of ice walls using a pick axe and a shovel avatars through grasp and arm movements. In i) *Treasure Hunt*, the subject used one or two shovel avatars to clear sand and uncover a series of buried treasures. In the game j) *Breakout 3D*, the subject

bounced a virtual ball toward an array of crates using paddle avatars. The game trained shoulder abduction/adduction or flexion/extension depending on crates orientation, as well as focusing and executive function.

## 2.2 Subject Characteristics

The study inclusion criteria were age 60 or older; a diagnosis of stroke that occurred at least 12 months prior to participation; English speakers; cognitive skills to actively participate; cognitive impairments in at least one of the domains of attention/concentration, speed of processing, memory, and/or executive functioning; clear motor involvement with the upper extremity (Fugl-Meyer Assessment score of 5 to 45); some ability to actively move the upper extremity (~15° of total active range or better for shoulder and elbow flexion/extension). Patients were not enrolled until 4 months after casting procedures or Botox injections. Potential subjects were excluded from the study if they had severe visual neglect or were legally blind; or they presented with severe hearing loss; with receptive aphasia; with uncontrolled hypertension (>190/100 mmHg), with severe cognitive delay; non-English speakers; those with a history of violence. Potential subjects who were uncooperative with neuropsychological and motor/functional evaluations or could not comprehend the evaluation test instructions were excluded.

While approximately 100 potential subjects were screened at the two participating SNFs, only 13 subjects met the inclusion criteria and were enrolled. Most individuals were excluded on the basis of no arm impairment on either side, or full arm impairment (flaccid) on one side. To improve the statistical reliability of experimental results, participants were divided 2-to-1 between the experimental group and the control group, in accordance to the approved protocol. Of these 2 subjects were lost to follow up and 1 subject was dropped from the study as being uncooperative with the investigators. The characteristics of the 10 subjects who completed the study are shown in Table 1. The subjects were able to converse in English, most of them were wheelchair bound and were comparable in terms of characteristics such as age, gender, and time post stroke.

**Table 1.** Subject statistics and medical history pre-intervention for experimental (n=7) and control (n=3) groups of SNF residents chronic post-stroke. © Bright Cloud International Corp. Reprinted by permission

Variable	Experiment (n=7)	Control Group (n=3)
Average Age	69.7 (13.3) years	70.1 (16.4) years
Gender	5 Male, 2 Female	2 Male, 1 Female
Race	4 White, 2 Hispanic, 1 Afr. Am	2 Afr. Am, 1 Hispanic
Primary Language	4 English, 2 Spanish, 1 French	3 English
Formal education	11.7 (3.8) years	10.7 (1.5) years
Time since stroke	98 (42) months	100 (28) months
Affected side	4 Left, 3 Right	1 Left, 2 Right
UE Function Impairment	3 Severe, 4 Moderate	1 Severe, 2 Moderate
Depression Level	6 Minimal, 1 Moderate	3 Minimal
Ambulation	6 Wheelchair bound, 1 Independent	2 Wheelchair bound, 1 bed bound
Co-morbidities	Diabetes Mellitus (4), Heart condition (4), Hypertension (3), Anaemia (2)	Diabetes Mellitus (2), Hypertension (2)

## 2.3 VR Maintenance Program

The VR maintenance program for the experimental group (Table 2) began with 8 weeks of intensive training, twice a week. Each rehabilitation session on the BrightArm Duo was supervised by an OT and assisted by a system technician. Participants' blood pressure and pulse were measured before and after each session. The OT also made sure the arms were positioned properly on the forearm supports. The participant's initial preparation was followed by baseline measurements of supported reach and grasp strength of the arm(s) being exercised in that session. Each session the experimental group played a sequence of up to 10 games in a set order and repeated as needed to achieve the specified session duration. The duration of actual game play increased from 20 minutes to 50 minutes per session. Gravity loading on the UE was increased by gradating the BrightArm Duo table tilt angle from 0° (horizontal) to a 20° upward tilt and adding wrist weights (up to 2 lb.) on each arm. Exercise difficulty was increased by migrating from easier games with no grasping to more difficult ones requiring sustained grasping.

The maintenance program continued with three booster cycles comprised of 10 weeks rest followed by two-

week training (two sessions per week). The intent of the booster sessions was to maintain gains obtained in the initial 8-week intensive training. This is similar to the training of athletes who need to continue their training to remain in shape. The first two boosters followed a similar protocol to that used during the later sessions of initial intensive training. The final two booster weeks were a tournament, where each participant at one SNF played with another participant that was remotely located at the other SNF. The Western Institutional Review Board, an independent board overseeing research involving human subjects, reviewed and approved the protocol of this study in accordance with Federal Guidelines. The experimental training took place at Roosevelt Care Center, and at Hartwyck at Edison Estates, two SNFs located 8 miles apart in Edison, NJ, in 2014-15.

**Table 2.** *VR Maintenance program and assessments.* © Bright Cloud International Corp. Reprinted by permission

Maintenance Program	Activity	Assessments
Intensive Training	Train 8 weeks (2x/week)	A0 (Pre-training) & A1 (Post-training)
Booster 1	Rest 10 weeks, Train 2 weeks (2x/week)	A2 (Pre training) & A3 (Post-training)
Booster 2	Rest 10 weeks, Train 2 weeks (2x/week)	A4 (Pre-training) & A5 (Post-training)
Tournament	Rest 10 weeks, Train 2 weeks (2x/week)	A6 (Pre-training) & A7 (Post-training)

#### 2.4 Data Collection Instruments

The purpose of the study was to demonstrate the benefit of a VR maintenance program supplement to current maintenance programs. Consequently, both experimental and control groups received the standard of care from their SNF's, but only the experimental group received added therapy on the BrightArm Duo system. The system generated data for each experimental therapy session (sessions 1 to 28). These included supported arm reach baseline, power grasp strength baseline, the number of active movements, the number of grasp repetitions, and game performance data (score, errors, completion time). Also, the experimental group subjectively evaluated the system after each training period in Table 2 (A1, A3, A5 and A7) by answering question survey using a 5 point Likert Scale (1=strongly disagree, 2=disagree, 3=neither agree or disagree, 4=agree, 5=strongly agree).

Standardized assessments of motor function were performed a maximum of eight times in Table 2. OT evaluations were performed by a Senior OT consultant who was blinded to the training protocol. These OT evaluations involved assessment of upper extremity function using the Fugl-Meyer Assessment – Upper Extremity Section (FMA) (Duncan, Propst, & Nelson, 1983), the Chedoke Arm and Hand Inventory – 9 (CAHAI-9) (S. Barreca et al., 2004) for bimanual tasks. The subjects completed the standardize Upper Extremity Functional Index (UEFI-20) Questionnaire at the start and end of the therapy (Chesworth et al 2014). Arm and hand range of motion were measured using mechanical goniometers, shoulder strength was assessed using wrist weights, grasp strength was measured with a Jamar mechanical dynamometer and a Jamar pinch meter.

Standardized emotive and cognitive assessments were performed up to 5 times (A0, A1, A3, A5, and A7). Neuropsychological evaluations were conducted by a research assistant (blinded to the therapy protocol) under the supervision of a licensed clinical neuropsychologist (JH who is also an author of this paper). These assessments included the Beck Depression Inventory, Second Edition (BDI-II) (Beck, Steer, & Brown, 1996) the Neuropsychological Assessment Battery (NAB) Attention Module (Orientation, Digit Span and Dots) and Executive Functioning Module (Generation subtest) (White & Stern, 2003), the Hopkins Verbal Learning Test, Revised (HVLT-R) (Brandt & Benedict, 2001), the Brief Visuospatial Memory Test, Revised (BVMT-R) (Benedict, 1997), and the Trail Making Test A and B (TMT) (Reitan, 1958). Alternate test forms were used whenever possible to minimize practice effect. Raw scores were utilized in all data analysis. Linear regression and paired t-test was used to measure associations across individual variables. Binomial sign test was used to evaluate trends across multiple metrics. A p-value < 0.05 was deemed statistically significant.

### 3. RESULTS

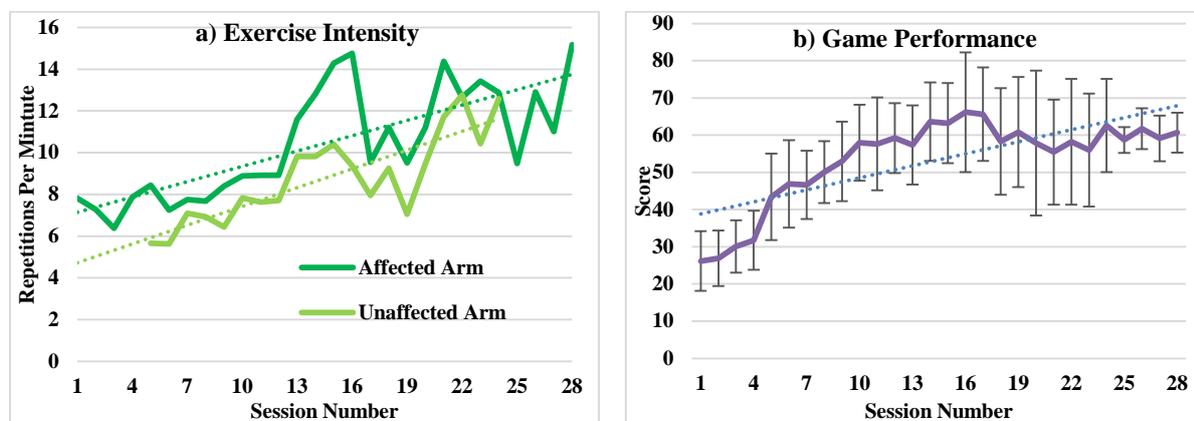
#### 3.1 Training Intensity

The experimental group played on average total of 407 games lasting an average of 986 minutes over the 45 week study. These subjects exerted an average total of 19,020 arm repetitions and an average total of 12,540 hand grasps across the 45-week study. 9,370 arm repetitions and 5,990 hand grasps occurred during the initial 8 weeks of intensive training and the remaining 9,650 arm repetitions and 6,550 hand gasps occurred during the two booster and tournament periods. The baseline areas for the affected arm supported reach was on average of 187 cm<sup>2</sup> (S.D. 186 cm<sup>2</sup>) at the beginning of the study and increased 75% to an average of 328 cm<sup>2</sup> (S.D. 217

cm<sup>2</sup>) by the end of the study (p=0.05). The baseline for the unaffected arm supported reach started at 584 cm<sup>2</sup> (S. D. 316 cm<sup>2</sup>) and increased 70% to an average of 991 cm<sup>2</sup> (S. D. 449 cm<sup>2</sup>) by the end of the study (p=0.15).

Figure 2a illustrates the total arm repetitions per minute for the affected and unaffected arms. Sessions 1 to 16 correspond to the initial training period, sessions 17 to 20 and 21 to 24 were part of booster periods 1 and 2, while sessions 25 to 28 were part of the tournament. The training clearly became more intense with subsequent sessions, increasing along a slope of 6.6 repetitions per minute for the affected arm between sessions 1 and 28 (p<0.001). The slope was 5.7 repetitions per minute for the unaffected arm (p<0.001) between sessions 5 and 24 (the unaffected arm was not used in the last 4 sessions which was part of the tournament).

Figure 2b graphs the average game score for the experimental group by session number. The game score increased from 26 in session 1 to a high score of 66 in session 16, before leveling off to 61 during the booster and tournament periods. The linear fit has an intercept of 39.0 points at session 1 and increased along a slope of 1.1 points per session (p<0.001). The standard deviation of the game score increased over the initial training and the first two booster sessions, showing uniformity in performance decreases as game difficulty increases. The last 4 sessions on the graph depict tournament sessions and have smaller standard deviation compared to the previous booster sessions. This is due to the fact that the tournament was played uni-manually with the affected arm, such that a team of two subjects played a given game. This reduced the difficulty level for each subject, thus they performed more uniformly.



**Figure 2.** a) Arm repetition intensity and b) composite game score and standard deviation by session number for the experimental group of Skilled Nursing Facility residents chronic post-stroke. © Bright Cloud International Corp. Reprinted by permission.

### 3.2 Upper extremity active range of motion

As seen in Table 3, 19 out of 25 range of motion metrics for the experimental group improved between the assessments A0 and A7. The resulting binomial sign test was statistically significant (p=0.01). In comparison to the control group, the experimental group had better improvement for 18 of 25 range of motion metrics between assessments A0 and A7. The binomial sign test rejected the null hypothesis of no difference in the improvement between experimental and control groups (p=0.04).

### 3.3 Upper extremity functional assessments

Functional standardized measures also improved at post-tournament (A7) relative to pre-training (A0). Fugl-Meyer Assessment scores for the experimental group went up an average of 4 points from 15.6 to 19.6. The t-test results were statistically significant (p=0.03). FMA for the control group declined on average 5.0 points from 27.7 and to 22.7, near the minimal detectable change of 5.2 points (Wagner et al, 2008). CAHAI-9 increased from 11.9 to 22.9 for experimental subjects and the associated t-test was statistically significant (p=0.004). The 11 points improvement is higher than the minimal clinically important difference (MCID) of 6.3 points (Barreca, 2015), and is indicative of improved ability to perform bimanual Activities of Daily Living (ADLs). CAHAI-9 for control subjects declined 4.0 points from 30.0 to 26.0. UEFI-20 declined 3.7 points for experimental (34.5 to 31.4) and declined 6.3 points for controls (37.0 to 30.7). Neither met the MCID of 8 points (Chesworth et al., 2014).

### 3.4 Upper extremity strength

As shown in Table 4, 8 of 10 UE strength measures had larger improvement for the experimental group than the control group between assessments A0 and A7, but the sign test was not statistically significant (p=0.1).

**Table 3** Shoulder, elbow and finger range of motion (degrees) for experiment vs. control group of Skilled Nursing Facilities residents chronic post-stroke, with A0 pre-training and A7 post-tournament (week 45). \* indicates sign reversed so all positive differences in table indicates improvement; Underline denotes A7-A0 better for experiment than control group. © Bright Cloud International Corp. Reprinted by permission.

Variable	Affected Arm						Unaffected Arm					
	Experimental n=7			Control n=3			Experimental n=7			Control n=3		
	A0	A7	A7-A0	A0	A7	A7-A0	A0	A7	A7-A0	A0	A7	A7-A0
<i>Shoulder Range of Motion</i>												
Flexion	42.4	42.4	0.0	64.3	60.3	<u>- 4.0</u>	141.0	131.3	- 9.7	106	119	+13.3
Extension	18.7	44.0	+25.3	20.0	38.0	<u>+18.0</u>	65.6	69.9	+ 4.3	51.3	66.0	+14.7
Abduction	68.0	74.1	+ 6.1	78.3	77.0	<u>- 1.3</u>	151.6	144.4	- 7.1	129	135	+ 6.0
Adduction	6.3	7.4	+ 1.1	5.0	3.3	<u>- 1.7</u>	34.6	36.9	+ 2.3	27.7	29.3	<u>+ 1.7</u>
Internal rot	49.3	38.3	-11.0	64.0	42.0	<u>-22.0</u>	49.3	51.7	+ 7.3	34.0	43.3	+ 9.3
External rot	12.1	9.0	-3.1	20.0	0.0	<u>-20.0</u>	59.8	73.4	+13.8	64.0	75.0	<u>+11.0</u>
<i>Elbow Range of Motion</i>												
Flexion	130	132	+ 4.9	132	138	+ 5.7	144.6	148.6	+ 4.0	144	149	<u>+ 4.7</u>
*Extension	68.7	65.6	+3.1*	25.7	45.3	<u>-19.7*</u>	3.6	3.7	- 0.1*	0.0	0.0	<u>0.0</u>
Pronation	40.0	72.3	+32.3	90.0	93.3	<u>+ 3.3</u>	82.6	94.0	+11.4	86.0	89.3	<u>+ 3.3</u>
Supination	17.9	21.9	+ 4.0	41.0	58.7	+17.7	72.0	74.9	+ 2.9	51.0	73.3	+22.3
<i>Finger Range of Motion</i>												
Thumb	7.1	17.1	+10.6	36.7	20.7	<u>-16.0</u>						
Index	25.7	33.3	+ 7.9	53.3	47.7	<u>- 5.7</u>	Within Normal Limits			Within Normal Limits		
Middle	22.9	33.6	+10.7	34.3	30.0	<u>- 4.3</u>						
Ring	28.1	31.1	+ 4.7	43.3	19.0	<u>-24.3</u>						
Pinkie	27.9	37.4	+ 8.9	48.5	25.0	<u>-23.3</u>						

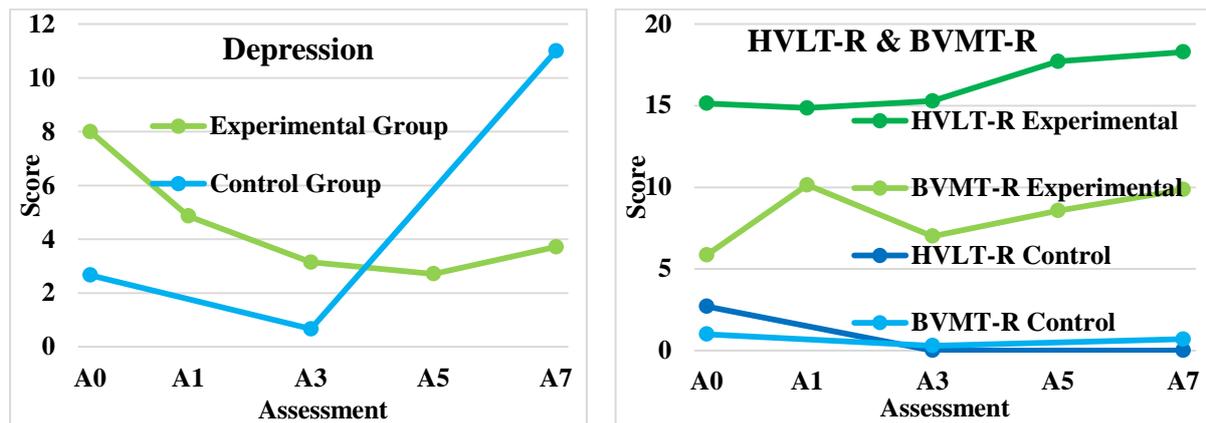
**Table 4.** Hand and arm strength (Newton) for experimental vs. control group of chronic post-stroke residents in Skilled Nursing Facilities, with A0 pre-training and A7 post-tournament (week 45). Underline denotes A7-A0 better for experimental than control group. © Bright Cloud International Corp. Reprinted by permission.

Variable	Affected Arm						Unaffected Arm					
	Experimental n=7			Control n=3			Experimental n=7			Control n=3		
	A0	A7	A7-A0	A0	A7	A7-A0	A0	A7	A7-A0	A0	A7	A7-A0
Ant. Deltoid	6.0	15.3	+ 9.2	5.2	13.3	<u>+ 8.1</u>	21.3	55.3	+ 34.9	22.2	38.6	<u>+ 16.3</u>
Lat. Deltoid	6.7	19.1	+12.4	5.9	13.3	<u>+ 7.4</u>	21.3	53.4	+ 32.1	22.2	38.6	<u>+ 16.3</u>
Hand Grip	7.6	25.4	+15.9	106	40.0	<u>- 66.1</u>	247	246	- 0.5	225	195	<u>- 30.4</u>
Tip Pinch	0.0	0.0	0.0	10.1	0.0	<u>- 10.1</u>	54.6	48.5	- 6.1	30.7	32.8	+ 4.7
Jaw Pinch	1.0	0.6	- 0.4	22.9	20.8	<u>- 2.1</u>	43.5	42.3	- 1.2	36.9	41.7	+ 2.1

### 3.5 Cognitive and emotive outcomes

Figure 3a shows that depression severity (as measured by BDI-II) for the experimental group dropped from 8.0 to 3.7 points between A0 and A7. The t-test was statistically significant ( $p=0.01$ ) and the improvement approaches the MCID of 5 points (Hiroe et al., 2005) for this measure. By comparison, depression severity for the control group became worse, and increased 8.3 points from 2.7 to 11 points when measured with the BDI-II test.

HVLT-R was used to measure verbal learning and memory. Its scores increased 3.2 points from 15.1 (A0) to 18.3 (A7) for the experimental group, but decreased from 2.7 to 0.0 points for the control group (Figure 3b). BVMT-R was used to measure visuospatial memory. Its scores increased 4.0 points from 5.9 (A0) to 9.9 (A7) for the experimental group and decreased by 0.3 points from 1.0 to 0.7 points for the control group (see Figure 3b).



**Figure 3.** a) BDI-II depression score and b) HVLT-R and BVMT-R scores for the experimental group ( $n=7$ ) and control group ( $n=3$ ) of chronic post-stroke residents in Skilled Nursing Facilities. Assessments intervals were pre- and post- initial training (A0 & A1), post-booster 1 (A3), post-booster 2 (A5) and post-tournament (A7). © Bright Cloud International Corp. Reprinted by permission.

### 3.6 Subject Attendance to Protocol and Subjective Feedback

The experimental group attendance was 97% during the initial training and 100% during booster periods 1 and 2. Attendance dropped to 93% during the tournament as one subject decided to leave the study during the final week. Experimental group participants subjectively evaluated the system after each training period using a 5 point Likert Scale. The mean response was 3.7 out of 5 after the initial training (A1), 3.5 after the first booster (A3), 3.5 after the second booster (A5) and 3.8 after the tournament (A7). The mean score overall was 3.6 out of a max of 5 points. The two ratings below 3.0 were in response to the statements: 'Playing games with affected arm was easy' (score 2.7) and 'Playing with both arms is easy' (score 2.8). The ratings were 4.0 or better for the questions: 'I would encourage others to use it' (score 4.0); 'The instructions were useful' (score 4.1); and 'I liked the system overall' (score 4.2). The highest response was 4.7 in response to the statement: 'Enjoyed playing with a partner'

## 4. DISCUSSION

The purpose of this study was to demonstrate the benefit of a VR maintenance program supplement to maintenance programs alone. Consequently, both experimental and control groups received the standard of care from their SNF's, but only the experimental group received added BrightArm Duo VR training. Neither the control group nor the experimental group received intensive upper body exercising as part of their standard of care. Thus the measured difference in gains can only be attributed to the VR component.

In making the rehabilitation process more interactive, fun and engaging for the elderly participants, BrightArm Duo technology was able to gain their acceptance as shown in the positive results of the subjective reports and high attendance rate. As reported in a recent scoping review of serious balance training games, older adults generally consider the usability and acceptance of serious games good (Nawaz et al., 2015). BrightArm Duo system is unique in its offering of VR intense training along with specially designed games and controllers to adapt the system to the individual needs of the participant.

The results of this study are in line with those of a virtual reality control study of SNF residents (Optale et al., 2010). The researchers in that study found that the experimental group showed significant cognitive improvements while controls showed progressive decline (Optale et. al., 2010) . The study duration of the cognitive VR intervention was 6 months, as compared to the 10-month maintenance study described here. The current study targeted integrative training of UE function and impairments, cognition and emotive state in elderly chronic post-stroke. It is possible that a longer duration of intervention could have resulted in more benefits for the experimental group. However the objective of the present study was primarily to initially increase and then maintain function of these elderly residents. From this perspective the authors consider the study a success. The duration of training is an aspect that is not studied for longitudinal trials chronic post-stroke and needs further investigation.

This longitudinal study was able to examine the lasting effects of VR training on motor function, cognition and emotive state. The maintenance effects were enhanced by periodic short boosters and lasted well beyond the 8-week intense training. This might indicate brain plasticity effects triggered by VR training as reported in some of the recent literature. Villiger et al., (2015) used magnetic resonance imaging before and after a 4-week VR training in people with chronic spinal cord injury and reported structural changes in the brain induced by VR training. The current study did not involve brain imaging. By closely examining the brain, future longitudinal studies can contribute to understanding the science of virtual rehabilitation.

The current study does have limitations in the small sample size, lack of caregiver data, and lack of quality of life data to support the results. Recruitment difficulties at the two SNFs were due to residents having multiple comorbidities, including many with complete lack of movement in their affected arm. The inclusion criteria which required that prospective subjects have some arm movement, coupled with the generally low function levels of the SNF residents made it difficult to achieve a larger sample size. This further supports the need for early and ongoing interventions to take advantage of increased neuroplasticity early after stroke, and then maintain gains. Future research with the BrightArm Rehabilitation System is needed to investigate the earlier stages post-stroke where larger magnitude of gains in impairment, motor function, cognitive level and reduced depression may be possible.

## 5. CONCLUSIONS

In summary, the experimental group trained on BrightArm Duo System performed on an average of 19,020 active arm repetitions and 12,540 hand grasps across the 45-week study. This resulted in statistically significant improvements in UE range of motion and strength on the affected and unaffected sides and functional improvements on ADL measures of uni-manual and bimanual function when compared to control group subjects. The decline in the control group may be attributed in part to the fact that these were elderly stroke survivors, as opposed to healthy age-matched controls. The experimental group also showed statistically significant improvements in cognition, particularly related to new memory encoding, maintenance and subsequent retrieval regardless of modality (verbal and visual). The statistically significant reduction in depression severity was notable at the end of the intensive training and was maintained through the longitudinal trial duration, compared to the control group who continued to decline.

To conclude, there are indications that integrative training with BrightArm Duo was effective in improving UE range of motion, strength, function, cognition, and in reducing depression with intense 8-week training. The effects were maintained at 45-week follow up with periodic short duration (2-week) boosters in the experimental group, while the control group continued to decline. Both groups received the standard maintenance programs of their respective SNF.

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