THESIS


ASSESSING THE IMMEDIATE IMPACT OF A MOVEMENT TRACKING-BASED

INTERVENTION FOR UNILATERAL SPATIAL NEGLECT EXPERIENCED BY STROKE

SURVIVORS

Submitted by

Roxie McFarland

Department of Occupational Therapy

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Master's Committee:

    Advisor:  Matt Malcolm

    David Greene
    Sudeep Pasrischa

ABSTRACT OF THESIS

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INTRODUCTION: A cerebrovascular accident (CVA) or stroke is the third leading cause of death and the number one cause of long-term disability for people in the United States. Approximately 30% of stroke survivors have visual-perceptual impairments that often have functional implications, including: unilateral spatial neglect (USN). USN often manifests in stroke survivors as impaired awareness of their body scheme, impaired awareness of their own body in space (proprioception), impaired awareness of their own deficits in visual-perceptual skills, and/or being unaware of their spatial environment. Previously, researchers have focused more on compensatory strategies in approaching intervention (e.g. visual scanning techniques or feedback training). Within the last 10-15 years, augmented reality (AR) and virtual reality (VR) interventions have been developed to incorporate visual scanning and feedback training to address USN. Limited research has been completed regarding AR-based training's specific impact on increasing left visual field attention for stroke survivors; however, there is an opportunity for this intervention to make a huge impact. A need exists within occupational therapy practice for an intervention that is feasible, user-friendly, and effective for increasing left visual field attention of stroke survivors that has the capability of being used within a client's home and without the direct supervision of an OT. The goal of this study was to explore and determine the beginning efficacy for a newly developed AR program for increasing the left visual field attention for survivors of R CVA. Our primary aim was to assess any change in

participants' performance of functional activities on an assessment measure, the Catherine Bergego Scale (CBS) pre-to post-intervention. Our second aim was to assess any changes in visual attention pre- to post- intervention for participants based on four paper and pencil measures: the Bell's Test, the Clock Drawing Test (CDT), Line Bisection Test (LBT), and the figure-copying test. Our third aim was to explore whether there are any significant correlations between pre-intervention measures and post-intervention measures that were used. METHODS: Eight survivors of a right cerebrovascular accident (R CVA) participated in 25-30 minutes of intervention. During pre- and post-assessment participants were scored using the CBS as it is the most reliable predictor of whether USN is affecting a person's everyday life. The CBS was modified slightly due to time constraints for sessions. CBS pre-intervention and post-intervention data were analyzed using a Related-Samples Wilcoxon Signed Rank Test ($\alpha$=.05).The four paper and pencil measures (Bell's Test, CDT, LBT, and figure copying test) were selected for assessment as they have been shown to significantly predict the presence of spatial and behavioral USN for screening purposes and offer stronger evidence of neglect when administered together rather than independently. Three paired samples, 2-tailed $t$ tests (analyzed for significance at $\alpha$=.05) were performed on data from the Bell's Test including: 1) total number of bells found by each participant pre- and post-intervention, 2) total number of connections made by each participant pre- and post-intervention, and 3) normalized connections data for each participant pre- and post-intervention The LBT was analyzed quantitatively to determine if participants qualified based on criteria for this measure as having USN pre- and post-intervention. The CDT and figure-copying test were analyzed qualitatively to assess any changes in performance pre- and post- intervention. Lastly, data from all quantitative assessment measures (Bell's Test, LBT, and CBS) were analyzed for significant correlations ($\alpha$=.05) pre-and

post-intervention using bivariate analysis. RESULTS: Participants' CBS scores pre-intervention ($\mu$=11.88±6.96) decreased post-intervention ($\mu$=9.88±5.74) indicating less USN was present during functional activities. A Related-Samples Wilcoxon Signed Rank Test was performed for pre- and post-intervention scores on the CBS which produced a statistical significance of $p$=.016 at $\alpha$=.05. All three paired samples, t tests yielded no significant correlations between pre- and post-intervention data for the Bell's Test. Some participants demonstrated qualitative improvement on the CDT (75%) and the figure-copying test (37.5%). Seven of eight participants (87.5%) qualified as having USN on the LBT pre-intervention. Of these seven participants, six (86%) demonstrated presence of USN post-intervention. No significant correlations were found after performing bivariate analyses for all quantitative assessment measures. DISCUSSION: Several randomized controlled trials and systematic reviews have presented beneficial short-term outcomes and future opportunities for increasing left visual field attention by introducing interventions involving visual scanning, virtual reality (immersive and non-immersive), and augmented reality. The quantitative data from this study provided beginning evidence that G.A.T.O.R may be effective at promoting visual-perceptual skills that are functionally relevant as reported by the Catherine Bergego Scale. Due to statistically significant findings ($p$=.016 at $\alpha$=.05) that subjects did demonstrate increased left visual field attention relevant to participation in everyday tasks post-AR intervention in comparison to participation pre-AR intervention as measured by the CBS, we accepted our first hypothesis. While most subjects did demonstrate improvement in one or more of the paper and pencil measures, findings were not statistically significant; therefore, we rejected our second hypothesis. We also rejected our third hypothesis due to a lack of statistically significant correlations found between measures. Previous research has shown that VR and AR interventions have the potential to motivate stroke survivors to

engage more frequently in at-home practice because of the option to receive immediate, unbiased feedback. G.A.T.O.R may be capable of motivating stroke survivors to engage in at-home practice and specifically challenge their visual attention. CONCLUSION: G.A.T.O.R may be useful as a supplemental intervention to address USN experienced by survivors of R CVA who are currently participating in conventional rehabilitation. Functional benefits were observed after a one-time administration of this intervention in seven of eight participants in this study as measured by the Catherine Bergego Scale. The study is limited in external validity due to small sample size ($n$=8) and requires further research to explore whether the intervention is capable of promoting long-term, functional improvements for stroke survivors with USN.

TABLE OF CONTENTS

CHAPTER 1: INTRODUCTION

A cerebrovascular accident (CVA) or stroke is the third leading cause of death and the number one cause of long-term disability for people in the United States (Khademi et al., 2012). The prevalence and recurrence of stroke is expected to increase by 25% by 2030 (Brewer et al., 2012) with approximately 800,000 people experiencing a stroke per year in the United States (Go et al., 2012). Research has shown that stroke survivors are at high risk for decreased participation in meaningful occupations or activities of daily living, decreased quality of life, and a decreased level of independence overall (Chan et al., 2013; Kernan et al., 2014; Gillespie et al., 2014). Approximately 30% of stroke survivors have visual-perceptual impairments that often have functional implications (Sand et al., 2013; Kernan et al., 2014).

The degree of visual-perceptual impairment that people experience because of a stroke fluctuates based upon the location and extent of brain damage (Brewer et al., 2012). Lesions in the parietal lobes, frontal and cingulate cortex, and the basal ganglia have all been found to cause neglect, a specific visual-perceptual impairment (Ogden, 1985). Neglect is defined as a disorder of attention (Robertson & Halligan, 1999) and known to accompany hemiparesis (or paralysis on the left side of the body) as a common outcome of a R CVA (Tsirlin et al., 2010; Wilson et al., 1987) with most cases of neglect resulting from lesions to the posterior, right parietal lobe (Ogden, 1985).

**Impact of Neglect**

While studying the location and extent of lesions using magnetic resonance imagining (MRI) provides clinicians and researchers with valuable information, it is not enough to predict the impact neglect will have on the lives of those who experience. Depending on how it

1

manifests, neglect is commonly attributed to impaired sensory skills (visual, tactile, auditory, etc.) or cognitive skills (attentional, representational, perceptual) (Antonucci et al., 1995). For purposes of this study, it will be referred to as visuo-spatial neglect or unilateral spatial neglect (USN). USN is further categorized depending on the space that is neglected, including: personal (occupied by the person's body), peripersonal (surrounding the person's body, within an arm's reach), and extrapersonal (surrounding the person's body, out of arm's reach) (Ting et al., 2011). USN has the potential to markedly impair all areas of occupational performance and participation (Robertson & Marshall, 1993; Chan et al., 2013). For example, personal neglect can affect self-hygiene tasks such as: grooming, dressing, and bathing and extra-personal neglect can affect safety with functional mobility, driving, or social participation.

**Foundation of Treatment for Neglect**

Historically, USN was not specifically targeted in rehabilitation settings as a focus of therapy until the 1960's as has been documented by peer-reviewed research (Robertson & Marshall, 1993). Due to the lack of an established theoretical framework for intervening with neglect and the numerous presentations of this neurological disorder, the best intervention approach remains an enigma. There is marked variability between which evidence-based interventions are actually used in practice by occupational therapists to address USN (Menon-Nair, Korner-Bitensky, & Ogourtsova, 2007) and the absence of clinical practice guidelines specifically for stroke survivors with USN seems to be contributing to low professional awareness of the interventions that are available (Petzold et al., 2014).

Some researchers believe that neglect occurs from a deficit in orientation bias to the right resulting from damage to the multisensory cortex; they use this theory to inform intervention approaches that focus on "inducing a leftward orientation bias" (Kerkoff & Schenk, 2012,

p.1073). These approaches often incorporate the use of modalities that manipulate sensory signals presented to a client (e.g. optokinetic stimulation, neck vibration (Schindler et al., 2002), or prism adaptation (Serino et al., 2009)). While one study was able to show that prism adaptation can have beneficial, long-term, functional outcomes for stroke survivors with USN (Shiraishi et al., 2010), most researchers assert that this approach requires further research to support its use in practice (Newport & Schenk, 2012; Arene et al., 2007; Frassinetti, Angeli, & Meneghello, 2002). Other researchers contend that neglect results from impaired self-awareness, also known as anosognosia. This often manifests in stroke survivors with this visual impairment in impaired awareness of their body scheme, awareness of their own body in space (proprioception), awareness of their own deficits in visual-perceptual skills, and/or being aware of their spatial environment. Researchers use this theory to inform intervention approaches that focus more on compensatory strategies (e.g. visual scanning techniques or feedback training).

Interventions that target USN often focus on compensation (which "utilizes remaining intact brain function"), substitution (which "adapts to the impairment by using prosthetic devices or environmental modification"), restitution (which "retrains the impaired function"), or compensation and restitution (Ting et al., 2011, p.124). Currently, there are a number of USN-specific interventions designed to supplement conventional rehabilitation practices in occupational therapy using one or more of these approaches. Many evidence-based interventions involve visual scanning training, limb activation, and sensory cueing.

Visual scanning training (VST) involves educating clients about USN and training them to use conscious, visual search strategies that include the neglected side (Ting et al., 2011). This may involve cervical rotation (head turning), visual scanning patterns from right to left, or trunk rotation (Nakatani et al., 2013, Young et al., 1983; Weinberg et al., 1977). VST is recommended

for use in clinical settings by Jutai et al. (2003), Luaute et al. (2006), and Pizzamiglio et al. (2006) who completed systematic reviews of literature focused on effective interventions for USN.

Limb activation involves the application of proprioceptive input to the affected upper extremity to draw attention to the left visual field and the left side of the body (Ting et al., 2011). This involves active or passive movement of the affected upper extremity in the contralesional space and has been shown by several studies to reduce symptoms related to visual and sensory neglect (Robertson & North, 1993; Franssinetti et al., 2001). This approach aligns well with occupational therapy's philosophy as the goal is to train individuals to incorporate their affected limb in their daily routines as much as possible. This also reflects best practice guidelines for stroke that seek to lower the risk of contractures by incorporating range of motion exercises (Robertson et al., 2002).

Sensory cueing seeks to improve attention to the neglected side using different sensory stimuli (visual, auditory, or tactile) as cues (Ting et al., 2011). This approach focuses on increasing clients' ability to respond to external feedback; therefore, encouraging more visual attention to the neglected side and training clients to develop the habit of scanning their neglected side. In theory, it relies on the ability of clients to learn and eventually cue themselves using this compensatory strategy and increasing self-awareness. This intervention is similar to limb activation, in that it easily aligns with occupational therapy's "therapeutic use of self" (Radomski & Latham, 2013). OT's are educated and encouraged to position themselves on a stroke survivor's affected side during therapy to challenge visuo-spatial attention, provide auditory feedback to facilitate recognition of the left visual field, and actively incorporate the person's affected upper/lower extremity through tactile cueing or guiding assistance. Despite the

prevalence of use in practice, Weinberg et al. (1977) is alone in documenting sensory cueing as an efficacious intervention approach.

**Contemporary and Future Treatments for Neglect**

Specialized interventions to address USN have been researched for the past 10-15 years integrating principles from VST, LA, and sensory cueing with the most up-to-date technology to determine which methods can reliably produce positive outcomes for clients who are also undergoing conventional rehabilitation (including occupational therapy). Interactive arts technologies (e.g. virtual reality or augmented reality) are examples of specialized, supplemental interventions that can be appealing and beneficial for stroke survivors (Lohse et al., 2014). Virtual reality (VR) is a computer-based program or system that aims to simulate a realistic environment (Alamri et al., 2010) and has been used in military training, entertainment industries, and medical training (Merians et al., 2006). Augmented reality (AR) uses computer-generated technology and the real-time, actual physical environment to create a blended reality (Furht, 2011). AR intends to increase a person's physical and cognitive interactions with the actual world by using real life objects (e.g. their own hand movement or coffee mug) while interacting with a simulated/virtual world (Furht, 2011). From a general rehabilitation perspective, VR and AR interventions have been presented superior to video gaming (e.g. Nintendo) due to their built-in capability of customizing computer-based programs for difficulty, duration, and complexity as this enables practitioners to challenge specific skills (e.g. left visual field attention) (Lohse et al., 2014).  For example, visual scanning exercises (similar to VST) can be implemented in VR or AR interventions to specifically target visual-perceptual skills and remediate left visual field attention (Van Wyk et al., 2014).

**Virtual Reality**

During the sub-acute stage of recovery from stroke, VR training may be more beneficial than performing real-life tasks because clients do not become as frustrated with perceptions of their current, actual level of performance and the level of performance they expect (Rahman et al., 2011). A limitation to these benefits may include the subject's use of compensatory movement strategies if they are not supervised while using VR intervention (Cameirao et al., 2012). Therefore, in order to work toward optimal outcomes for clients participating in VR-based interventions at home, OTs may need to recommend some form of social support to encourage correct biomechanical technique or visual feedback provided to the user to increase their attention to body positioning during performance. Specifically for this study, we will ensure that subjects are seated directly in front of the computer screen so their right and left visual fields are challenged equally rather allowing subjects to rotate their head and primarily engage their right visual field which is a common compensatory technique seen in R CVA survivors with USN (Cameirao et al., 2012; Tham et al., 2001).

Research has yet to fully address the effect of a VR-based intervention approach on ameliorating left visual field attention or establish the level of optimal supervision needed on an outpatient basis for adequate client support. When increasing left visual attention has been a primary outcome studied (using immersive VR-based interventions), stroke survivors have demonstrated good functional progress, particularly in the performance areas of community mobility and fall risk. Llorens (2012) presented the concept of virtual street crossing as an assessment to determine clients' abilities to attend to a busy traffic environment; however, this also demonstrated potential use as an intervention. Aravind & Lamontagne (2014) found that VR-based interventions can improve stroke survivors' detection and avoidance of static and

dynamic obstacles in real-life traffic and community ambulation situations. The study aimed to promote client safety with community mobility without actually exposing clients to dangerous situations (Aravind & Lamontagne, 2014). Lastly, Tanaka (2011) presents future research ideas for testing client fall risk in complex environments that they "see" while wearing a headset that projects a virtual environment that challenges attention, problem solving, and overall visual perceptual processing. This approach could potentially provide specific and detailed information about the impact of USN during realistic situations rather than relying on paper pencil measures or self-report of hypothetical performance to detect any impairment. Although the intervention we used for our study is AR and non-immersive like the VR-based programs mentioned above, we still prioritized assessments that examine how the AR intervention affecting participants everyday activities at home or in the community as previous research has emphasized.

**Augmented Reality**

AR-based interventions effectively integrate all the positive aspects of VR-based interventions (as previously discussed) with the added advantage of being more ecologically valid and cost effective. One study identified the specific aspects of functional movement that should be objectively measured in order to provide occupational therapists with useful feedback to monitor progress: task completion time, compactness of task, and speed of hand movement (Alamri et al., 2010). AR-based programs are capable of efficiently capturing this information, unlike VR-based programs. Fatigue and weakness were also detected in participants of the Alamri et al. (2010) study, which emphasizes the importance of planned rest breaks when recommending routines for clients who are eligible for AR-based interventions. Therefore, we incorporated two-minute rest breaks in between game segments as a part of the intervention portion of this study for participants.

Currently, only beginning evidence is available for AR-based interventions to address USN and there is a great opportunity for future research to further explore this area. Specifically, there remains a need within occupational therapy research to explore specific components and protocols for using AR-based interventions to supplement conventional rehabilitation that are consistently effective for increasing functional movement of stroke survivors' affected upper extremities and increasing left visual field attention (Lee et al., 2012; Regenbrecht et al., 2013).

AR-based interventions demonstrate a promising outlook for OTs to monitor clients' functional progress and at-home, self-directed practice from a remote location using objective data collection as well as regular phone call check-ins with clients (Van Vleet et al., 2014). If clients are able to engage in AR-based training at home, the ecological validity of this intervention will increase because clients are able to incorporate tangible objects they use in everyday life (e.g. a coffee mug) rather than those unrelated to their functional activities such as a haptic device (Khademi et al., 2012), universal gaming system controller, or computer mouse. Clients have reported personal investment and interest in engaging AR-based interventions because they more motivating than repeating tedious tasks or exercises as commonly seen in conventional rehabilitation (Van Vleet et al., 2014; Lee et al., 2012). With this motivational component, clients are likely to perform even more repetitions of functional motions while participating in AR-based intervention (Mainetti et al., 2013) and may demonstrate greater progress in shorter periods.

Limited research has been completed regarding AR-based training's specific impact on increasing left visual field attention for stroke survivors; however, there is an opportunity for this intervention to make a huge impact. Behrmann, Ebert, and Black (2004) studied the task-specific impairments people with USN experience including: serial- attention driven scanning/searching

as well as rapid detection (e.g. attending to a moving target in parallel orientation that does not require complex attentional processing). An AR-based intervention has every capability to address both of these impairments commonly seen with USN. Clients can be challenged to complete simple visual tracking of an object's path, accommodate for changes in the path, and perform complex scanning for stimuli through participation in AR rehabilitation games, which we incorporated in our study.

**The Need for Our Intervention**

While some studies have shown that cases of mild or moderate USN have the potential to resolve within 90 days (Farne et al., 2004; Nigel et al., 1993), other studies have suggested that at least 1/3 of stroke survivors will suffer a chronic form of neglect (over a year post-stroke) and will struggle with the impact this has on their participation in valued, meaningful occupations as well as their overall safety in their respective living environments (Karnath, Rennig, Johannsen, & Rorden, 2011; Rengachary, He, Shulman, & Corbetta, 2011). Stroke survivors may participate in 2-3 scheduled therapy sessions each week when they are in the sub-acute or chronic recovery phases of stroke. This frequency and short duration of scheduled therapy limits their potential to make significant functional gains due to limited practice and re-training time for visual-perceptual skills (Alamri et al., 2010). Therefore, a need exists within occupational therapy practice for an intervention that is feasible, user-friendly, and effective for increasing left visual field attention of stroke survivors that has the capability of being used within a client's home and without the direct supervision of an OT. Rehabilitation approaches for stroke survivors with or without USN are most effective when they are designed to include: repetition and concentrated practice for specific motor and perceptual skills, objective feedback that is clear and consistent when speaking to current or past performance, and activities that are meaningful and

motivational to clients that provide a "just right" challenge (Van Wyk et al., 2014). VR and AR interventions offer people the opportunity to perform timed, repetitious, computer-based activities that are both engaging and capable of giving immediate feedback about performance (Worthen-Chaudhari et al., 2013).

The goal of this study was to explore and determine the beginning efficacy for a newly developed AR program for increasing the left visual field attention for survivors of R CVA. We assessed the benefit of this program based upon specific visuo-spatial and functional outcome measures that assess visual perceptual and motor skill recovery including: the participants' performance on four paper/pencil measures that detect USN and the participants' ability to perform basic functional tasks with increased left visual field attention post-intervention. We posed the following a priori hypotheses:

*Hypothesis 1*: Subjects will demonstrate increased left visual field attention relevant to participation in everyday tasks post-AR intervention in comparison to participation pre-AR intervention as measured by the Catherine Bergego Scale (CBS)[1].

*Hypothesis 2*: Subjects will demonstrate increased left visual field attention post-AR intervention in comparison to pre-AR intervention as measured by improved performance on one or more assessments of USN including: the Bells Test[2], Clock Drawing Test (CDT)[3], Line Bisection Test (LBT)[4], and figure-copying test[5].

*Hypothesis 3*: Through analyses of correlations, we will explore the relationship between quantitative data gathered from pre-intervention and post-intervention assessment measures including: CBS, Bells Test, and LBT.

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[1] Appendix A- Catherine Bergego Scale
[2] Appendix B – The Bells Test
[3] Appendix C– The Clock Drawing Test
[4] Appendix D- The Line Bisection Test
[5] Appendix E- Figure-Copying Test

We analyzed the data obtained pre-intervention and immediately post-intervention to establish that any measurable changes were the result of the intervention and not extraneous variables. We used well-established assessments to determine the functional progress made by each participant (e.g. increased participation in daily activities) and to detect any changes in USN.

CHAPTER 2: METHODS


**Participants**

A purposive sampling method was used to recruit participants for this single group, pretest-posttest design study. Eight (8) subjects (9 male; 1 female) with a mean age of 67 (± 10.06 years) participated and gave written consent, adhering to the policies set forth by the Institutional Review Board (IRB) at Colorado State University (CSU). Each participant also consented to be video recorded or photographed intermittently throughout the intervention portion of the study for research explanation purposes only. All subjects were in the sub-acute or chronic stage of their recovery from a right CVA with a mean post-stroke time 9.42 (± 3.74 years) (please see Table 1 for demographics of participants). Potential participants were referred to the study by several occupational therapists at the Center for Neurorehabilitation Services (CNS) in Fort Collins, CO using a study flyer pre-approved by the IRB at CSU. A phone call screening[6] was completed to determine if potential participants met inclusion/exclusion criteria for the study. All participants met the following criteria : a) ≥1 month post-stroke; b) have a motor deficit affecting the upper limb; c) have a mini-mental status exam score of ≥ 24; d) able to tolerate two 30-minute therapy sessions separated by at least 15 minutes per day; and e) ≥ 18 years of age. Exclusion criteria included: a) presence of another neurological disease or injury other than stroke or TBI; b) presence of a musculoskeletal injury or disease affecting the more affected upper limb (e.g. that will be the focus of rehabilitation in the study); c) presence of a visual deficit or disease that affects the individual's ability to easily see objects on the computer screen (e.g., blindness or macular degeneration).

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[6] *Appendix F* – Phone Call Screening

Table 1. Demographic data for participants.

| Participant | Sex | Age (years) | Time since stroke (years) | Side of stroke | UE used to participate |
|---|---|---|---|---|---|
| 1 | M | 65 | 12 | R CVA | RUE (non-affected) |
| 2 | M | 69 | 2.42 | R CVA | RUE (non-affected) |
| 3 | M | 72 | .58 | R CVA | RUE (non-affected) |
| 4 | M | 66 | 2.67 | R CVA | LUE (affected) |
| 5 | F | 83 | .92 | R CVA | LUE (affected) |
| 6 | M | 45 | 1.75 | R CVA | RUE (non-affected) |
| 7 | M | 65 | 1.5 | R CVA | LUE (affected) |
| 8 | M | 70 | 1.42 | R CVA | LUE (affected) |
| Range | 1F; 7M | 45-83 | .58-12 | 8 RCVA | 4 RUE (non-affected); 4 LUE (affected) |
| Mean ($\mu$) | - | 67 | 9.42 | - | - |
| SD ($\sigma$) | | 10.06 | 3.74 | | |

All qualifying participants were enrolled in the study, and each completed the pre-test (baseline) assessment, intervention, and post-test assessment in a single two-hour session at CNS.

**Assessment (Pre- and Post-Intervention)**

Once each participant provided consent, he/she was screened using the Mini-Mental Status Examination (MMSE) and reaffirmed regarding basic information to qualify for the study. All participants exceeded the MMSE inclusion criteria score of ≥24. Next, baseline data were assessed for each participant using four paper and pencil measures that are known to detect USN: the Bells Test (Gauthier, Dehaut, & Joanette, 1989), the CDT (Tuokko, 1992), the LBT (Schenkenberg, T. et al., 1980), and the figure-copying test (Azouvi et al., 2002). The four paper

and pencil measures selected have been shown to significantly predict the presence of spatial and behavioral USN for screening purposes and offer stronger evidence of neglect when administered together rather than independently (Azouvi et al., 2002). These measures are individually described after the description of the functional measure used: the Catherine Bergego Scale (CBS).

The CBS includes a 10-item standardized checklist of tasks to observe each participant performing or ask them to disclose information regarding the functional impact of USN during daily activities if observation is not an option (Bergego et al., 1995). The CBS is the most reliable predictor of whether this impairment is affecting a person's everyday life (Azouvi et al., 2002). The CBS was modified slightly for purposes of this study as it was not possible to observe each participant perform all 10 items in a single session. Eight items on the CBS were scored based upon researcher observation of participants performing tasks (e.g. donning/doffing a jacket, searching for belongings, examining a plate of food). One item on the CBS was scored based on a simulated activity (shaving or washing their face with a washcloth. Lastly, one item was scored based upon participant report via survey method (e.g. whether or not food pocketing was problematic). Please find additional information in *Appendix A*.

The Bells Test required participants to circle/cancel all the bells they identified on a sheet containing a variety of other distractors objects (e.g. apple, candlestick, bird, etc.) (*Appendix B*). This sheet was presented and held in position at each participant's midline. Unfortunately, a copy of the original Bells Test with all 35 bells clearly printed was not accessible; therefore, only 33 bells total were included for this test. The Bells Test is known for detecting impaired visual attention of near extra-personal space (Gauthier, Dehaut, & Joanette, 1989). For the purposes of this study, the point on the sheet at which a participant started canceling bells was recorded by

the administrator of the test as well as each participant's scanning strategy/order for finding the bells, which is also common practice with this tool (Ferber & Karnath, 2001). Cancellation tests with distractors (e.g. Bells Test and Star Cancellation Test) have been reported as more sensitive to detecting USN (Gauthier, Dehaut, & Joanette, 1989) and the Bells Test, in particular, is more likely to detect omitted targets than other cancellation tests (Ferber & Karnath, 2001). Marsh & Kersel (1993) and Azouvi et al. (2002) both concluded that the Bells Test has excellent test-retest reliability.

The Clock-Drawing Test (CDT) required a participant to fill in the correct numbers of a clock when presented with a pre-drawn circle and draw arrows to designate the time: ten minutes past eleven (Tuokko, 1992) (*Appendix C*). Both visuospatial attention and praxis ability are measured by this test with USN evident when the left face of the clock is not correctly filled in (Tuokko, 1992). The CDT also has test-retest reliability consistently >.70 as a measure of USN (Tuokko, 1992; Manos & Wu, 1994). Freedman et al. (1994) found that this measure has a higher test-retest reliability ($r$=.94) when the aforementioned time is used (ten minutes past eleven). This also increases the sensitivity of the measure to detect cognitive dysfunction.

The Line-Bisection Test (LBT) required participants to designate their perception of the center of 17 lines printed horizontally on a paper (*Appendix D*). This test was also presented to the participant's midline to maintain assessment fidelity and challenge both visual fields equally. The presence of USN (in near extra-personal space) is indicated with this measure if the participant fails to recognize two or more lines completely, or if their perception of the midpoint is >.6mm from the actual midpoint on each line (Schenkenberg, Bradford, & Ajax, 1980). The LBT is a reliable measure for detecting extra-personal neglect, but not personal neglect and is best when used as part of a battery of tests (Guariglia, Matano, & Piccardi, 2014). The test-retest

reliability (*r*) of the LBT is reported consistently >.84 (Chen-Sea & Henderson, 1994; Bailey, Riddoch, & Crome, 2004) and it exhibits strong psychometric properties overall (Schenkenberg, Bradford, & Ajax, 1980).

The figure-copying test required a participant to produce a simple drawing of two trees, a house, and a fence (*Appendix E).* Presence of USN (specifically, impaired visual scanning in near extra-personal space) was determined by a participant's inability to either draw or recognize the left half of the picture presented as indicated by their omission of objects on the left side of the page (Azouvi et al., 2002). The figure-copying test has a test-retest reliability (*r*) >.7 (Azouvi et al., 2002).

**Intervention**

Approximately 1.25 hours was used for pre- and post- screening/assessments and 45 minutes was used for the intervention plus rest breaks. The intervention included 5-6 game segments for a total intervention time of 25-30 minutes. Rest breaks were given immediately after game segments for two minutes. Additional time was allotted for several participants who expressed minor physical fatigue from using their affected upper extremity. The intervention portion utilized a computer setup that included a 23" monitor, LEAP motion controller, and Games and Assistive Technologies for Rehabilitation (GATOR). GATOR was developed by Dr. Sudeep Pasricha and several undergraduate students in the Computer Engineering department at Colorado State University (CSU) whom collaborated with Dr. Matt Malcolm and several graduate students in the Occupational Therapy Department at CSU. For each participant, 5-6 games were selected for the intervention and were individually graded to provide a "just-right challenge" following best-practice guidelines for occupational therapists. These games are pictured and described in *Figures 1-6*. Grading options included: sensitivity (less movement or

more movement required by the person's upper extremity to move the on-screen cursor), difficulty of game (frequency & speed of stimuli presented on the screen), and increased presentation of stimuli on the left side of the computer screen to elicit increased visual scanning to the left visual field. Fifty percent of participants were able to use their affected (left) upper extremity to interact with the games (Table 1). The other 50% of participants were instructed to use their non-affected (right) upper extremity after being informally assessed on site to have minimal motor ability that would have prevented them from effectively interacting with the games. This decision was made based on the primary aim of the study to challenge visual-perceptual skills. Feedback was provided for all participants during gameplay (initiated by the game itself) and post-gameplay when participants' performance improved in speed, accuracy, or efficiency.
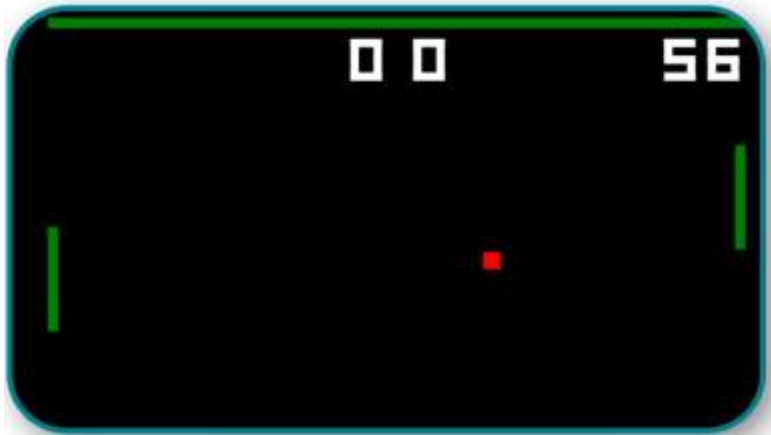
Fig. 1. Picture of GATOR: Leap Pong. Participants controlled the paddle on the left with their upper extremity by moving up and down on the table mat. The up and down movements utilized elbow flexion/extension, shoulder abduction/adduction, some shoulder flexion/extension, and scapular protraction/retraction. The on-screen paddle moved vertically, exclusively. Partiipants attempted to out-score the computer controlled paddle on the right by acquiring more points in 5-6 minutes of gameplay per game segment. Points were scored by hitting the ball past the opponent's paddle.
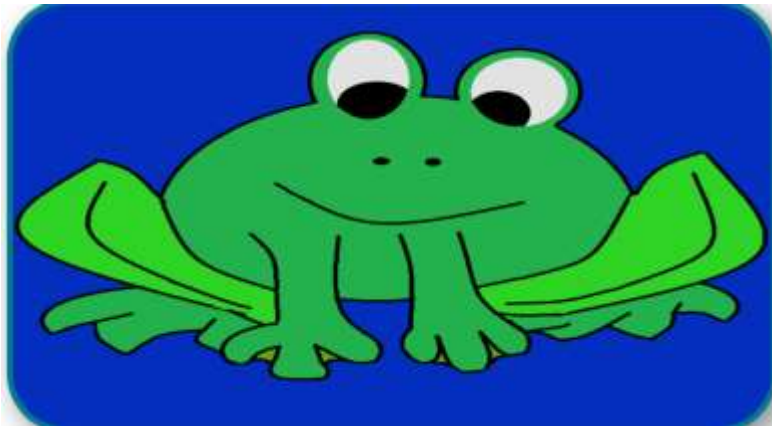


Fig. 2. Picture of GATOR: Leap Frog. Participants controlled the cursor (a frog) with their upper extremity by moving right and left on the table mat. The right and left movements utilized elbow flexion/extension, shoulder abduction/adduction, some shoulder flexion/extension, and scapular protraction/retraction. For participants who were shorter in height, this game required some horizontal abduction/adduction. The on-screen frog moved in all directions, jumping from one lily pad to the next with the goal of continuous jumping without falling off a lily pad into the pond below. Participants attempted to earn lives and points by staying on the lily pads and out of the pond for 5-6 minutes of gameplay per game segment.

Fig. 3. Picture of GATOR: Asteroids. Participants controlled the cursor (a ship) at the bottom of the screen with their upper extremity by moving right and left on the table mat. The right and left movements utilized elbow flexion/extension, shoulder abduction/adduction, some shoulder flexion/extension, and scapular protraction/retraction. For participants who were shorter in height, this game required some horizontal abduction/adduction. The on-screen ship moved horizontaly, exclusively. Partipants attempted to acquire all yellow stars presented to earn a high score while also avoiding descending rocks. Any collisions the ship has with rocks subtracts points from total points earned during the 5-6 minutes of gameplay per game segment.



Fig. 4. Picture of GATOR: Alien Invaders. Participants controlled the cursor (a ship) at the bottom of the screen with their upper extremity by moving right and left on the table mat. The right and left movements utilized elbow flexion/extension, shoulder abduction/adduction, some shoulder flexion/extension, and scapular protraction/retraction. For participants who were shorter in height, this game required some horizontal abduction/adduction. The on-screen ship moved horizontaly, exclusively. The ship automatically fired rockets at descending aliens when the participant moved the ship from right to left and left to right. Participants attempted to earn a high score while also avoiding descending bombs released by the aliens randomly. Any collisions the ship had with rockets caused points to be subtracted from the participant's total points earned during the 5-6 minutes of gameplay per game segment.
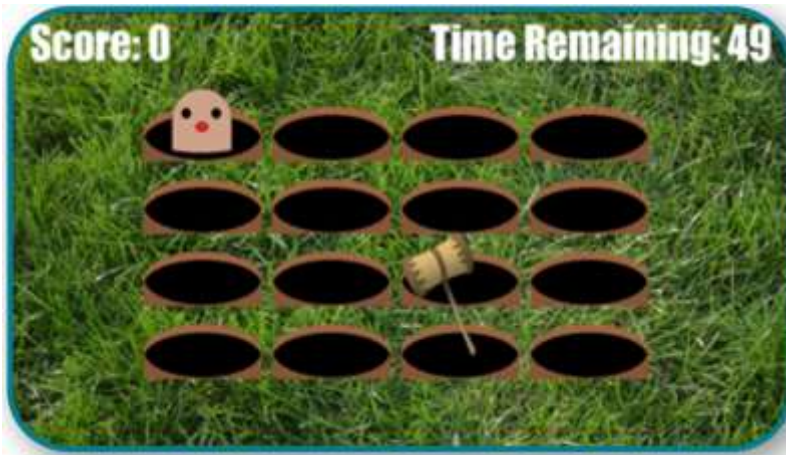
Fig. 5.Picture of GATOR: Whack-A-Mole.  Participants controlled the cursor (a mallet)  with their upper extremity by moving right, left, up, and down on the table mat. These movements utilized elbow flexion/extension, shoulder abduction/adduction, shoulder flexion/extension, and scapular protraction/retraction. For participants who were shorter in height, this game required some horizontal abduction/adduction. The on-screen mallet moved vertically, horizontally, and diagnolly respective to the movement by the participant's upper extremity. Participants attempted to move the mallet over the head of each mole that emerged from 16 possible holes pictured on the screen to earn points during the 5-6 minutes of gameplay per game segment.
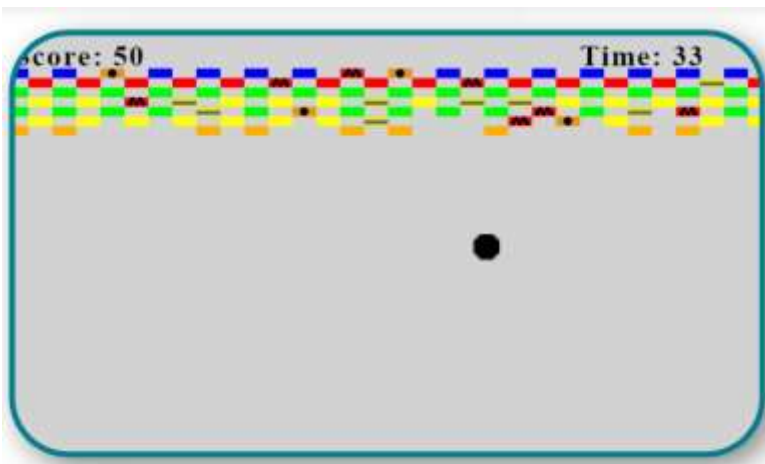


Fig. 6. Picture of GATOR: Break Out.  Participants controlled the paddle at the bottom of the screen with their upper extremity by moving right and left on the table mat. The right and left movements utilized elbow flexion/extension, shoulder abduction/adduction, some shoulder flexion/extension, and scapular protraction/retraction. For participants who were shorter in height, this game required some horizontal abduction/adduction. The on-screen paddle moved horizontaly, exclusively. Partipants attempted to use the paddle to hit the ball and direct the ball to the top of the screen to break as many blocks as possible and to block the descending ball and prevent it from entering the bottom of the screen. Participants aimed to earn a high score during the 5-6 minutes of gameplay per game segment with the speed of the ball increasing slightly throughout gameplay.

Fig. 7.Picture of GATOR: Fruit Viking.  Participants controlled the cursor (a knife)  with their upper extremity by moving in all directions on the table mat. These movements utilized elbow flexion/extension, shoulder abduction/adduction, shoulder flexion/extension, and scapular protraction/retraction. For participants who were shorter in height, this game required some horizontal abduction/adduction. The on-screen knife moved vertically, horizontally, and diagnolly respective to the movement by the participant's upper extremity. Participants attempted to slice fruit that appeared from the bottom of the screen moving in various traectories across the screen. Participants earned points for moving the knife over the fruit to effectively slice it. The speed and size of the fruit presented occurred randomly  during the 5-6 minutes of gameplay per game segment.



 Fig. 8.Picture of GATOR: Pirate's Cove.  This game was used first in all study sessions to assess the quality of movement participants' were capable of in order to adequately grade subsequent games. Participants controlled the cursor (a pirate)  with their upper extremity by moving in all directions on the table mat. These movements utilized elbow flexion/extension, shoulder abduction/adduction, shoulder flexion/extension, and scapular protraction/retraction. For participants who were shorter in height, this game required some horizontal abduction/adduction. The on-screen pirate moved in all directions respective to the movement by the participant's upper extremity. Participants attempted to move the pirate to collect large coins that appeared one at a time in random locations across the screen.Participants earned one point per coin collected and were challenged to get their highest score during the 5-6 minutes of gameplay per game segment.

Fig. 9 Picture of system setup for participants who used their affected, left upper extremity (R4, R5, R7, R8). A 23" monitor was placed at subject's midline. The Leap Motion Controller ©2015 was affixed to the pictured stand, positioned approximately 8" above the table, and directed to capture hand movement on the black table mat pictured. The black table mat was positioned at the same height for all subjects as all desks used were of the same height.



Fig. 10 Picture of system setup for participants who used their non-affected, right upper extremity (R1, R2, R3, R6). A 23" monitor was placed at subject's midline. The Leap Motion Controller ©2015 was affixed to the pictured stand, positioned approximately 8" above the table, and directed to capture hand movement on the black table mat pictured. The black table mat was positioned at the same height for all subjects as all desks used were of the same height.

Participants were oriented to on-screen feedback and provided with verbal encouragement after gameplay, but were encouraged to focus and communicate minimally during gameplay before each 5 minute game session was initiated. After completing their last game segment of the intervention, each participant was immediately re-assessed using the aforementioned paper/pencil measures and functional task measure.

**Statistical Analysis**

The Bells Test was analyzed quantitatively. First, total number of bells found by each participant pre- and post-intervention was determined. Second, the Bells Test was separated into seven columns for further analysis following the solution template originally presented by Gauthier, Dehaut, & Joanette (1989, p.10). For this study, 6/7 columns contained five bells with the farthest left column containing three bells due to the previously mentioned printer error. Each participant's starting point for circling/canceling bells was recorded for both pre/post measures as well as their corresponding number of connections. In this study, the "connections" measurement is defined as the number of column lines crossed between one found bell and the next sequential bell found. For example, if a participant found a bell within the same column as the previous bell, the number of connections= 0. If the participant located a bell in the column directly to the left or right of the column of the previously located bell, the number of connections= 1. A higher number of connections indicated a less efficient visual search strategy as more columns were crossed in the bell location sequence. As a third variable derived from the Bells Test data, connections data were normalized based on the number of bells identified: total connections for each participant were divided by the total number of bells identified by that participant. For example, the number 1.33 would indicate that the participant averaged just over 1 connection between each bell they found. Three paired samples, 2-tailed $t$ tests (analyzed for significance at $\alpha=.05$) were performed on data from the Bell's Test using *IBM SPSS Statistics 22.*

These tests included: 1) total number of bells found by each participant pre-intervention compared to total number of bells found post-intervention, 2) total number of connections made by each participant pre-intervention compared to total number of connections made by each participant post-intervention, 3) normalized connections data for each participant pre-intervention and normalized connections data for each participant post-intervention.

The LBT was also analyzed quantitatively. If a participant failed to mark a perceived midpoint on ≥2/17 lines on this measure pre- or post-intervention, he/she was said to have presence of neglect. If the midpoint placed by a participant was ≥6mm off center on ≥2/17 lines on this measure pre- or post-intervention, he/she was said to have presence of neglect. LBT pre-intervention and post-intervention data were assessed using a paired samples, 2-tailed $t$ test (analyzed for significance at $\alpha=.05$).

Both the CDT and figure-copying test were analyzed based on meeting qualitative criteria. Specifically, the CDT was analyzed for each participant's ability to include all 12 numbers on the clock-face and organize the distribution of numbers equally. The figure-copying test was analyzed for each participant's ability to include all items pictured without any omissions in the far left visual field (e.g. pine tree and/or fence). Any significant spatial deviations or omissions between pre-intervention and post-intervention were recorded.

Pre-intervention and post-intervention CBS assessments data were analyzed quantitatively for each participant's mean score of ten simulated, functional tasks. Each item was scored from 0-3 based upon their performance and calculated for a total score out of 30 possible points. Please see Table 2 for scoring criteria used with the CBS measure (Bergego, 1995). CBS pre-intervention and post-intervention data were analyzed using a Related-Samples Wilcoxon Signed Rank Test ($\alpha=.05$).

Table 2. Catherine Bergego Scale: Scoring criteria.

| CBS Score | Description |
|-----------|-------------|
| Score 0 | No neglect observed; participant explored both right and left hemi-spaces in an equal manner with no evidence of impairment. |
| Score 1 | Mild neglect observed; participant explored right hemi-space first and slowly explored or hesitated to explore the left hemi-space. |
| Score 2 | Moderate neglect observed; participant had clear left-sided omissions or collisions making performance in left hemi-space incomplete and ineffective. |
| Score 3 | Severe neglect observed; participant only explored right hemi-space and did not acknowledge left hemi-space during performance. |

Lastly, data from all quantitative assessment measures (Bell's Test, LBT, and CBS) were analyzed for significant correlations ($\alpha=.05$) pre-intervention and post-intervention using bivariate analysis.

**Catherine Bergego Scale**

Generally, participants' CBS scores pre-intervention ($\mu$=11.88±6.96) decreased post-intervention ($\mu$=9.88±5.74) indicating less USN was present during functional activities. A Related-Samples Wilcoxon Signed Rank Test was performed for pre-intervention and post-intervention scores on the CBS which produced a statistical significance of $p$=.016 at $\alpha$=.05.

Table 3. Catherine Bergego Scale: Scores of all participants.

| Participant | Total Score Pre-Intervention | Total Score Post-Intervention | Change Score |
|---|---|---|---|
| R1 | 14 | 13 | -1 |
| R2 | 22 | 16 | -6 |
| R3 | 16 | 12 | -4 |
| R4 | 9 | 8 | -1 |
| R5 | 17 | 15 | -2 |
| R6 | 12 | 12 | 0 |
| R7 | 1 | 0 | -1 |
| R8 | 4 | 3 | -1 |

Seven of eight (87.5%) participants scored lower post-intervention in ≥1 of the 10 items on the CBS indicating improvement in performance of activities with less evidence of USN involvement.

**Bells Test**

A paired samples, 2-tailed *t* test indicated that the total number of bells found by participants pre-intervention (28.25) versus total number of bells found by participants post-intervention (29.63) was not statistically significant ($p=.225$, $t=-1.330$, df=7).

A paired samples, 2-tailed *t* test was performed for the total number of connections made by participants pre-intervention (41.50) and total number of connections made by participants post-intervention (36.88) and indicated the change was not statistically significant ($p=.422$, $t=.853$, df=7).

A paired samples, 2-tailed *t* test was performed for normalized connections data for participants pre-intervention (1.396) and normalized connections data for participants post-intervention (1.303) and indicated the change was not statistically significant ($p=.689$, $t=.417$, df=7).

Results of total bells found by each participant pre-intervention and post-intervention is represented below in *Figure 9*. The total number of connections made pre-intervention and post-intervention by each participant is represented in *Figure 10*.

# Total Bells Found
## Pre-Intervention & Post-Intervention



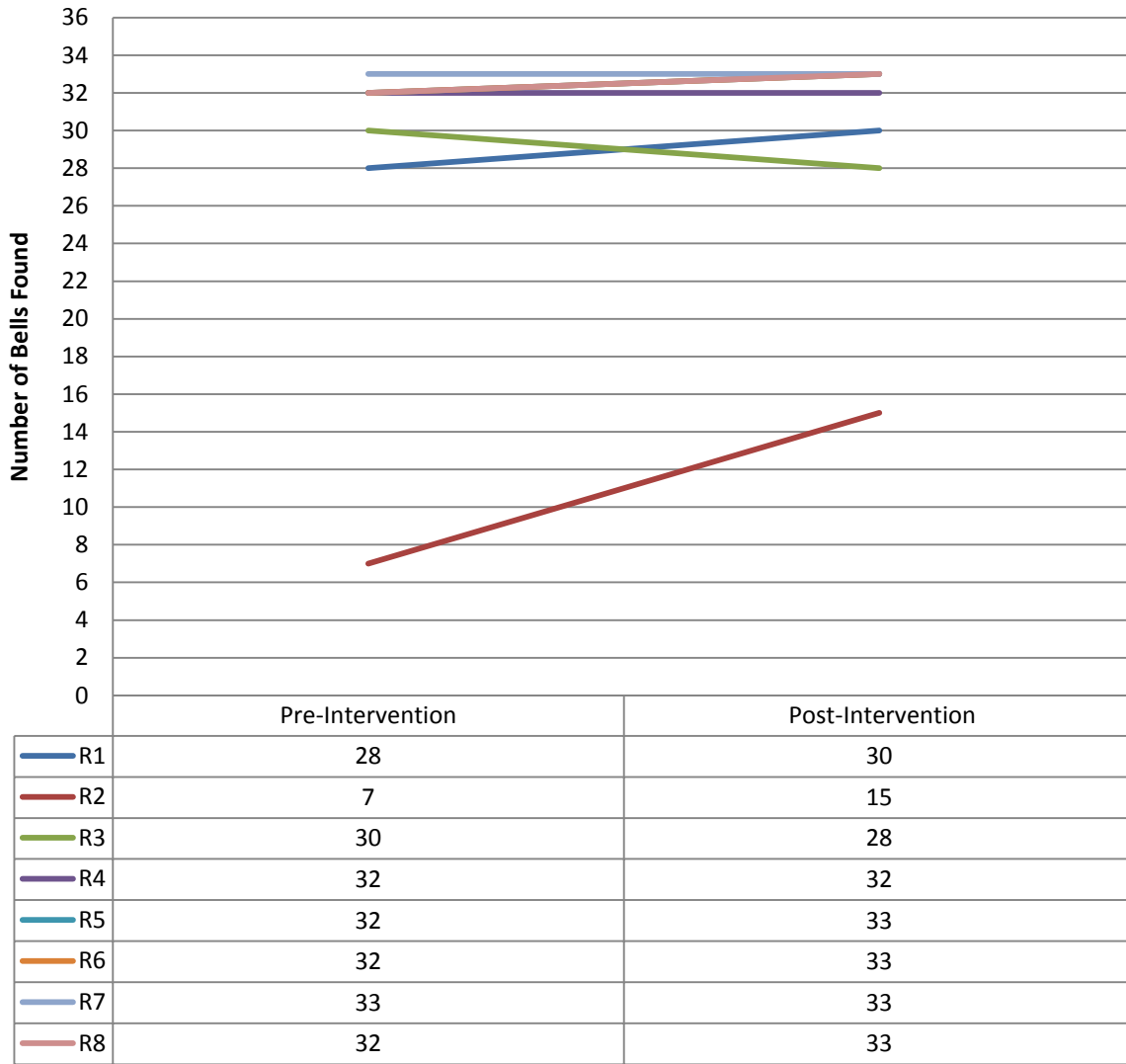| | Pre-Intervention | Post-Intervention |
|---|---|---|
| R1 | 28 | 30 |
| R2 | 7 | 15 |
| R3 | 30 | 28 |
| R4 | 32 | 32 |
| R5 | 32 | 33 |
| R6 | 32 | 33 |
| R7 | 33 | 33 |
| R8 | 32 | 33 |

Fig. 9. Total bells found by participants pre-intervention and post-intervention is represented on the line graph above. R2 found more than twice the number of bells in post-intervention than he did pre-intervention. R3 found fewer bells in post-intervention than he did pre-intervention. R4 and R7 both found the same number of bells pre- & post-intervention.

**Total Connections**
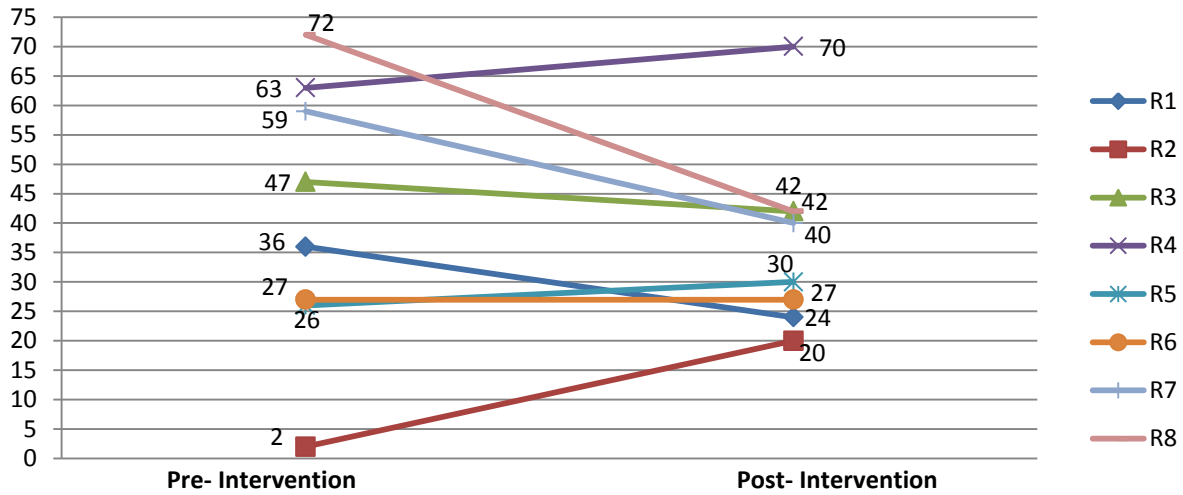**Pre-Intervention and Post-Intervention**

Fig. 10. Total number of connections made by participants pre-intervention and post-intervention is represented on the line graph above. Four of eight subjects (50%) made fewer connections in post-intervention than they did in pre-intervention. The same participants also found the same number or more bells than they did pre-intervention, indicating higher efficiency of visual search with equal or better accuracy. Only R4 & R5 made more connections post-intervention when compared with pre-intervention with finding ≤1 additional bells post-intervention indicating no improvement in efficiency of visual search.

## Clock Drawing Test

Six of eight (75%) participants demonstrated minimal improvement in the organization and distribution of numbers drawn on the clock face when analyzed qualitatively. Please see *Figure 11* for an example of this improvement.

Fig. 11. Subject R2 demonstrated improvement on the CDT assessment post-intervention when compared with pre-intervention performance. Subjects were asked to draw all the numbers represented in their correct positions on the face of a clock and set the time to ten past eleven.

**Figure Copying**

Three of eight (37.5%) of participants improved in performance on the figure-copying assessment post-intervention when compared to pre-intervention assessment. Improvement was qualitatively determined based upon a participant drawing objects (e.g. tree or fence) that were not drawn during pre-intervention assessment. For an example of this improvement, please see *Figure 12.*



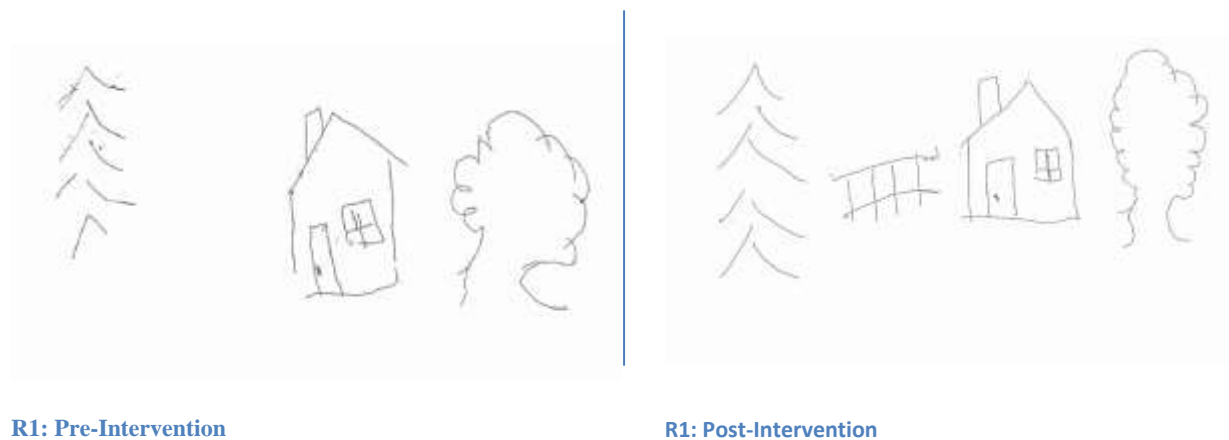R1: Pre-Intervention                    R1: Post-Intervention

Fig. 12. Subject R1 is an example of the improvement observed with 35% of participants on the figure-copying test as represented above in the drawings. Sixty-five percent of participants performed pre- and post-intervention without any observable differences on this assessment.

**Line Bisection Test**

Seven of eight (87.5%) participants qualified as having USN on the LBT during pre-intervention assessment due to their omission of ≥2 lines or drawing ≥2 midpoints >6mm from the exact center of each line. Of these seven participants, six of seven subjects (86%) qualified as having USN on the LBT post-intervention with one participant (R5) improving to meet the criteria for no presence of USN on the LBT.

Table 4. Line Bisection Test: Scores of all participants.

| Participant | USN Presence Pre-Intervention | USN Presence Post- Intervention | Change Observed |
|---|---|---|---|
| R1 | ≥2 midpoints >6mm Yes | ≥2 midpoints >6mm Yes | No |
| R2 | omitted ≥2 lines Yes | omitted ≥2 lines Yes | No |
| R3 | ≥2 midpoints >6mm Yes | ≥2 midpoints >6mm Yes | No |
| R4 | ≥2 midpoints >6mm Yes | ≥2 midpoints >6mm Yes | No |
| R5 | ≥2 midpoints >6mm Yes | No | Yes |
| R6 | No | No | No |
| R7 | ≥2 midpoints >6mm Yes | ≥2 midpoints >6mm Yes | No |
| R8 | ≥2 midpoints >6mm Yes | ≥2 midpoints >6mm Yes | No |

Table 5. Line Bisection Test: Pre-intervention vs. post-intervention mean ($\mu$) deviations from midpoint of 17 lines by each participant.

| Participant | Pre-Intervention Deviation from Midpoint ($\mu$) | Post- Intervention Deviation from Midpoint ($\mu$) | Change Observed |
|---|---|---|---|
| R1 | .768 | 1.291 | .523 |
| R2 | .537 | .8 | .263 |
| R3 | .865 | .885 | .020 |
| R4 | .568 | .435 | -.133 |
| R5 | .285 | .159 | -.126 |
| R6 | .212 | .429 | .217 |
| R7 | .432 | .485 | .055 |
| R8 | 1.012 | .576 | -.436 |

Positive changes observed (Table 5) indicate that participant deviated more from the midpoint of each line post-intervention compared to pre-intervention. Subject R6 did not qualify as having USN as he never deviated >6mm from the midpoint of each line and did not omit any lines.   A paired samples, 2-tailed $t$ test was performed for participant's pre-intervention, mean deviation from midpoint (.585) and participant's post-intervention, mean deviation from midpoint (.632) and indicated the change was not statistically significant ($p=.659$, $t=.-461$, df=7).

**Associations**

Using bivariate analysis, pre-intervention CBS scores significantly correlated with pre-intervention normalized connections data on the Bell's Test ($r=-.812$, $\alpha=.05$, $p=.014$). All other quantitative assessment measures (Bell's Test, LBT, and CBS) did not correlate at a significant level.

Table 6. Correlation Analyses: Pre- and post-intervention scores between the LBT, Bells Test, and CBS.

| Correlation Analyses for Pre-Intervention Scores | Connections Pre-Intervention Average Score | CBS Pre-Intervention Score | LBT Pre-Intervention Score |
|---|---|---|---|
| Normalized Connections Data Bell's Test, Pre-Intervention Score | 1 | -.812* | .313 |
| *- Pearson Correlation Sig. (2-tailed)* | | .014 | .451 |
| CBS Pre-Intervention Score | -.812* | 1 | -.007 |
| *- Pearson Correlation Sig. (2-tailed)* | .014 | | .986 |
| LBT Pre-Intervention Score | .313 | -.007 | 1 |
| *- Pearson Correlation Sig. (2-tailed)* | .451 | .986 | |

\*. Correlation is significant at the 0.05 level (2-tailed).

This strong, negative correlation indicates that as CBS Pre-intervention scores decreased (e.g. participants had less USN), the normalized connections data for the Bell's Test increased (e.g. participants were less efficient in finding bells in sequence).

CHAPTER 4: DISCUSSION

Research has demonstrated that stroke survivors with USN are at risk for long-term disability and benefit from specialized rehabilitation to address visual-perceptual deficits (Chan et al., 2013; Wilson et al., 1987; Kamada et al., 2011). Several randomized controlled trials and systematic reviews have presented beneficial short-term outcomes and future opportunities for increasing left visual field attention by introducing interventions involving visual scanning, virtual reality (immersive and non-immersive), and augmented reality (Alamri et al., 2010; Gillespie et al., 2015; Lee, et al., 2012; Ting et al., 2011; Van Wyk et al., 2014). However, research is scarce supporting a user-friendly intervention that has the capability of maximizing participation in at-home rehabilitation program planned by an occupational therapist and one that can promote measurable, functional gains for stroke survivors with USN.

The quantitative data from this study provided beginning evidence that G.A.T.O.R may be effective at promoting visual-perceptual skills that are functionally relevant as reported by the Catherine Bergego Scale. Previous research has demonstrated that, by targeting visual-perceptual skills with intervention, subjects can improve in performance of activities of daily living (ADL) (Van Wyk et. al., 2014) as evidenced by increased Functional Independence Measure (FIM) scores (Worthen-Chaudhari et al., 2013). Meaning, as patients become less dependent on helper assistance for activities or patients improve in performance skills (e.g. left visual field attention), their FIM scores increase. The FIM assessment is considered the gold standard assessment in occupational therapy practice because it comprehensively assesses a patient's ability to carry out daily self-care activities (e.g. dressing, bathing, toileting) (Kamada et al., 2011). The FIM is similar to the Catherine Bergego Scale, which also measures performance of ADL's, and is

commonly recognized as the best functional assessment for USN in peer-reviewed research (Azouvi et al., 2002). Improvement measured by both of these highly regarded assessments offers valuable evidence that augmented reality-based interventions can be effective at promoting functional improvement.

Due to statistically significant findings ($p$=.016 at $\alpha$=.05) that subjects *did* demonstrate increased left visual field attention relevant to participation in everyday tasks post-AR intervention in comparison to participation pre-AR intervention as measured by the Catherine Bergego Scale (CBS), we accepted our first hypothesis. Eighty seven percent of participants demonstrated functional outcome improvement in one or more tasks as measured by the CBS indicating the positive potential of G.A.T.O.R games to promote occupationally relevant, short-term gains. Our study is limited in external validity due to the small study sample ($n$=8) and further research is required to assess whether G.A.T.O.R is capable of helping stroke survivors make occupationally relevant, long-term gains.

Most subjects did demonstrate improvement in one or more of the paper and pencil measures post-intervention when compared to pre-intervention. On the Bell's Test, there was a pre- to post- change in the desired direction, but it did not reach significance. Fifty percent of participants' posttest scores suggested increased efficiency in visual scanning as indicated by their location of more bells and decreased number of connections. These slightly improved scores after such a short period of intervention are promising. Previous research has shown that efficiency with visual scanning is relevant to performance of daily activities and commonly reinforced as a compensatory strategy for stroke survivors with neglect in conventional occupational therapy (Ting et al., 2011). Most subjects also improved in spatial organization for the Clock Drawing Test with several subjects improving in the figure-copying test by

36

recognizing and drawing objects they omitted during pre-intervention assessment. The only subject who did not improve on one or more paper and pencil measures had no presence of USN indicated by LBT. He also scored the same pre-intervention and post-intervention on the CBS, CDT, and connections made in Bells test from pre-intervention to post-intervention. The only improvement the subject made was to locate one more bell on the post-intervention Bell's Test. Rather than this subject failing to improve, this may indicate that he was not as appropriate for the study with negligible/minimal USN affecting his daily life, prior to participating in the study. Overall, while the lack of statistically significant findings with the paper and pencil assessment measures used in this study led us to reject our second hypothesis; the improvement observed in multiple subjects' visual-perceptual skills (along with functional improvement observed) after only 25-30 minutes of intervention illustrates the great potential of G.A.T.O.R.

G.A.T.O.R has the added potential to act as a supplemental intervention to conventional rehabilitation or occupational therapy that is capable of motivating stroke survivors to engage in at-home practice and specifically challenge their visual attention. Our participants benefited from a unique feature of G.A.T.O.R to provide them with objective data following each game segment played that included: velocity of upper extremity movement, distance covered, and comparison of current scores to past scores so they were able to monitor their own progress. Previous research has shown that VR and AR interventions have the potential to motivate stroke survivors to engage more frequently in at-home practice because of the option to receive immediate, unbiased feedback (Worthen-Chaudari et al., 2013; Hanif, Niaz, & Khan, 2011; Subramanian et al., 2013).

While the feedback option cannot replace the clinical judgment or direction of a therapist, it does offer a realistic and feasible solution to encouraging at-home practice (Turolla et al.,

2013). Outpatient OT's are often limited in their ability to supervise at-home programs as they are typically not reimbursed for this time or have the time to do so during a productive work day. Ideally, clients could use G.A.T.O.R in their place of residence, in addition to ongoing participation in outpatient occupational therapy. OT's could remotely access individual client's profiles online through G.A.T.O.R that can objectively track performance over time and can report whether or not clients are performing at-home practice. G.A.T.O.R allows OT's the option to design and grade home programs. This enables OTs to maintain a client-centered approach and provide a just-right challenge by modifying settings to meet client needs. It also provides clients with an organized, motivational activity to carry out at-home practice that has been shown to improve visual-perceptual skills that are transferable to daily life activities.

**Conclusion**

       G.A.T.O.R may be useful as a supplemental intervention to address USN experienced by survivors of R CVA who are currently participating in conventional occupational therapy or rehabilitation. Paper/pencil assessments performed immediately post-intervention (e.g. Bells Test, Line Bisection Test) yielded no statistically significant changes in participants' visual attention; however, small sample size ($n$=8) and one-time administration of this intervention are significant limitations. Functional benefits were observed in seven of eight participants in this study as measured by the Catherine Bergego Scale yielding statistically significant findings. As well, the Clock Drawing Test and figure-copying test showed qualitative improvements in a number of participants. This study re-affirmed the importance of using a battery of tests to measure presence of USN and its impact on occupational performance. Further research is needed to ascertain the effects of G.A.T.O.R to assist stroke survivors' training in visual perceptual skills and visual scanning strategies that are transferable to long-term, functional improvement.

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APPENDIX A: CATHERINE BERGEGO SCALE

| Catherine Bergego Scale (Original as written by Azouvi et al., 1996) | Catherine Bergego Scale (Format adapted for study) |
|---|---|
| 1. Forgets to groom or shave the left part of his/her face | 1. Ask subject to demonstrate how he/she would either:<br>1) wash his/her face with a wash cloth (present at midline) or<br>2) shave (simulate using razor with plastic guard on) or<br>3)put on makeup (simulate with new compact and applicator brush)<br>*adjust request for demonstration based on gender, for post-intervention assessment have subject perform the activity they chose for pre-intervention assessment). |
| 2. Experiences difficulty in adjusting his/her left sleeve or slipper | 2. Present subject with a jacket at midline. Ask subject to please don jacket if he/she is able. When subject expresses the activity is complete, instruct them to doff jacket. Provide assistance as subject requests and document. |
| 3. Forgets to eat food on the left side of his/her plate | 3. Present 4 colorful snacks on a white plate at midline. Ask the subject to vocalize the snacks they see and offer the subject the option of eating a snack if they would like. |
| 4. Forgets to clean the left side of his/her mouth after eating | 4. Score based on observation *only* if subject opts to eat a snack. If subject opts out, score based on survey format. Ask subject if anyone ever helps them check for food pocketing. |
| 5. Experiences difficulty in looking towards the left | **5.** Observe throughout session*. Use body position to provide opportunities where they would look left. |
| 6. Forgets about a left part of his/her body (e.g,, forgets to put his/her upper limb on the armrest, or his/her left foot on the wheelchair rest, or forgets to use his/her left arm when he/she needs to) | **6.** Observe throughout session*. Especially during paper and pencil assessments when the affected upper extremity would be used to stabilize the paper while writing with the non-affected upper extremity. |
| 7. Has difficulty in paying attention to noise or people addressing him/her from the left | 7. Observe throughout session*. Attempt to record specific number of opportunities to look left and if successful or non-attentive. |
| 8. Collides with people or objects on the left side, such as doors or furniture (either while walking or driving a wheelchair) | 8. Observe ambulation through doorway when entering/leaving room*. Have items located near doorway on left side of subject to set up this assessment without introducing any risk to the subject. |
| 9. Experiences difficulty in finding his/her way towards the left when traveling in familiar places or in the rehabilitation unit | 9. Set up the environment so that the subject has to walk to their left upon entering room to participate in study. Assess their ability to navigate tables/chairs. |
| 10. Experiences difficulty finding his/her personal belongings in the room or bathroom when they are on the left side | 10. Observe throughout session*. Assess subject's ability to locate pen set-up to their left side in order to complete assessments or if prompts are needed to locate pen. |

*\* If unable to observe or make an informed assessment on these items, question client and/or caregiver if this is always a problem, frequently a problem, occasionally a problem, or not a problem (Azouvi et al., 1996).*

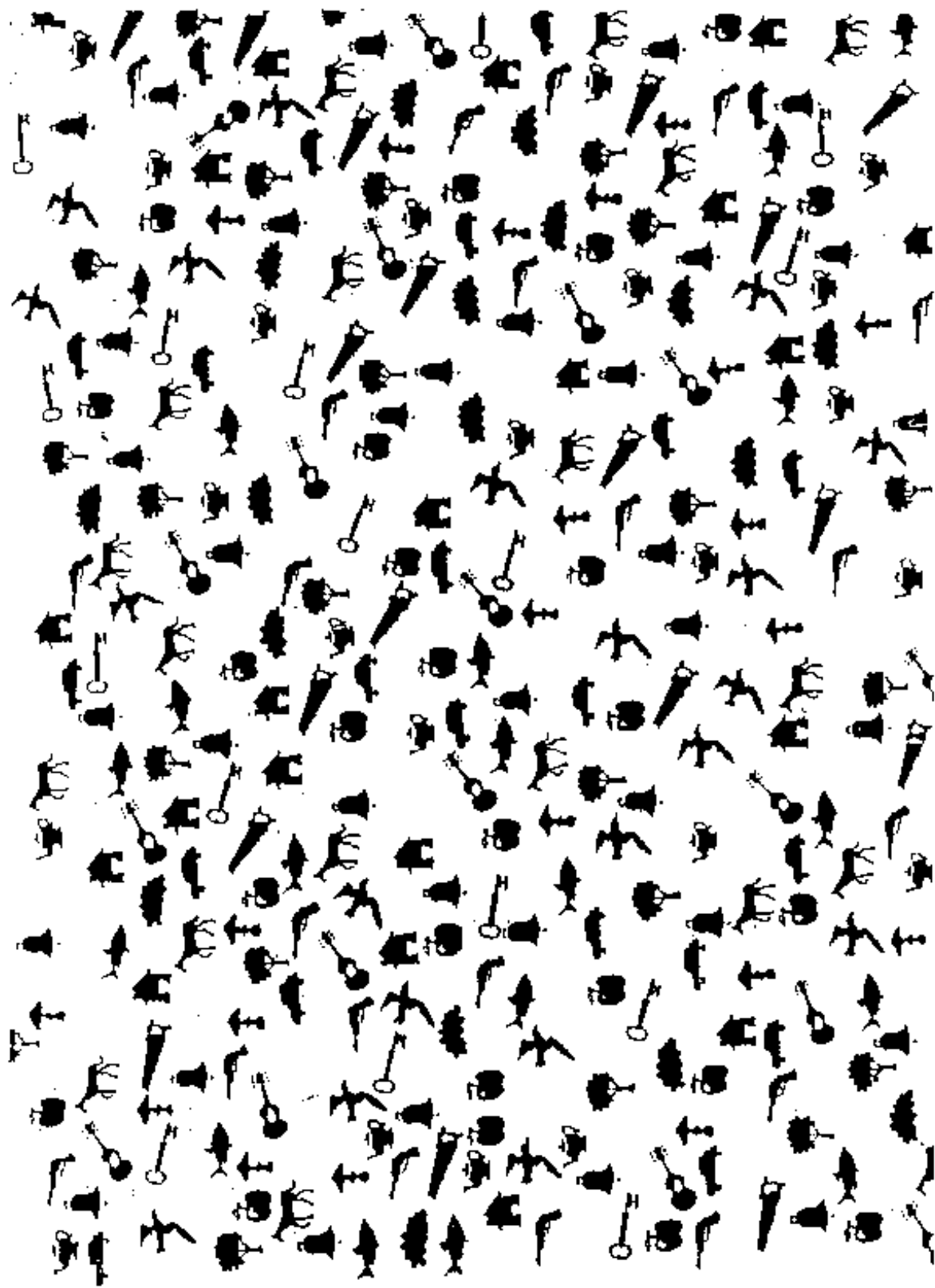Each of the 10 items is scored on the scale of 0-3. Total score calculated /30.

0= no neglect

1= mild neglect

2= moderate neglect
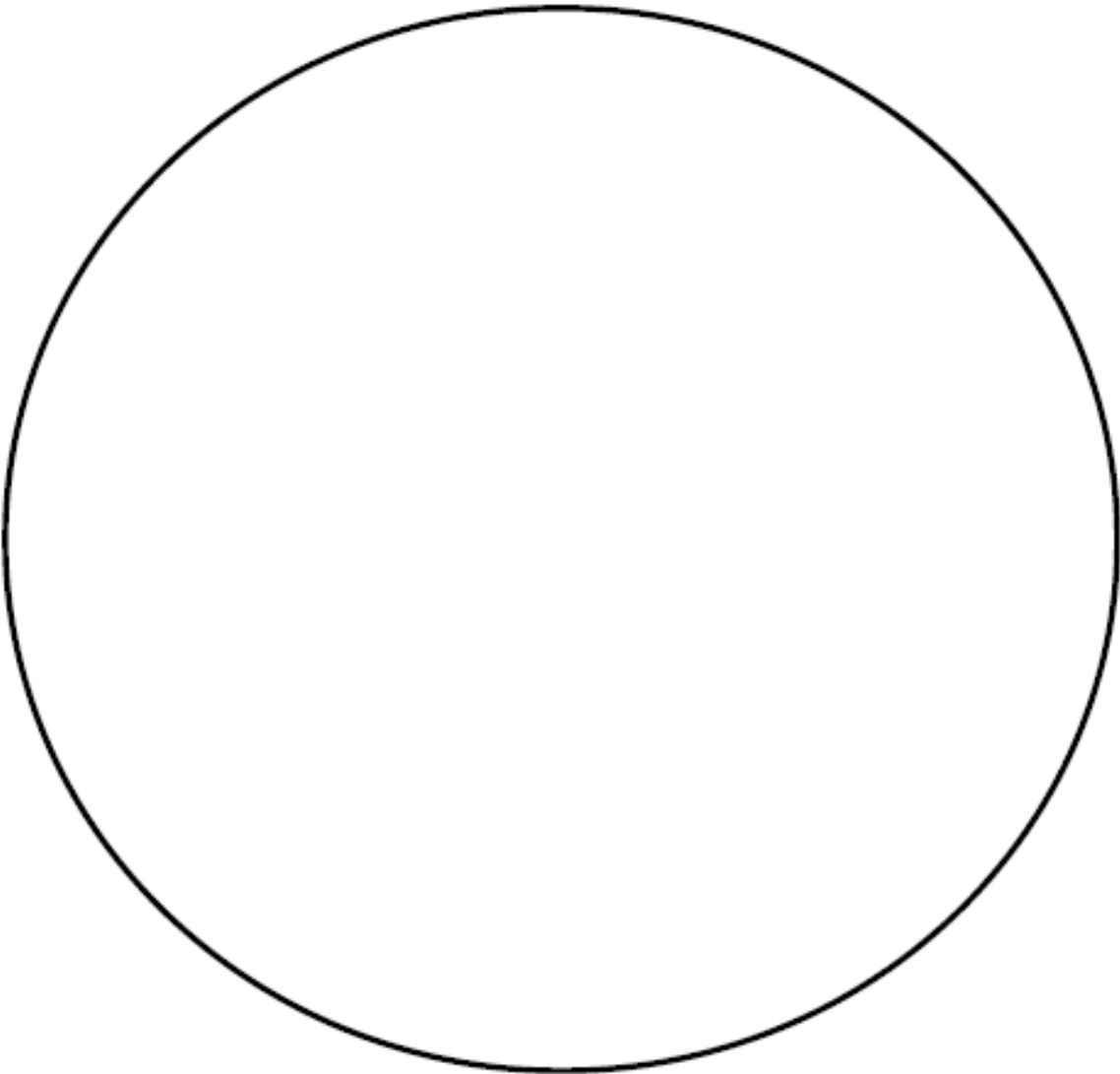
3= severe neglect

APPENDIX B: BELLS TEST

APPENDIX C: CLOCK DRAWING TEST

## Clock Drawing Test

Patient's Name: _____          Date: _____

APPENDIX D: LINE BISECTION TEST

APPENDIX E: FIGURE-COPYING TEST

APPENDIX F: PHONE CALL SCREENING

Hi Ms./Mr. ___,

#1: My name is Roxie McFarland and I am a graduate student at Colorado State University working on my Master's degree in Occupational Therapy. I am contacting you because I am wondering if you would be willing to be screened for and potentially participate in another study that I am carrying out for my thesis project. Do you have a few minutes for me to describe what your participation in this study may entail or is there another time that would be better for me contact you?

**Yes**- Great. Our study will be looking at the potential benefit of a newly developed computer program for stroke survivors to use at home and practice using their affected arm while playing games. If you are interested in participating, I would ask that you come to the Center for Neurorehabilitation Services (CNS), where you usually attend therapy, for a research session that would last no more than two hours. This would involve a series of assessments to measure your visual-perceptual abilities, using the computer system for 20-30 minutes with rest breaks, and a re-assessment period afterwards. Also, it is important to note that unfortunately, you will not be compensated for your participation in this study. Do you have any questions at this time or needs for clarification? (skip to #2)

**No**- No problem, thank you for your time and please contact us if you reconsider. I hope you have a wonderful day.

#2: *Answer any questions.*
*If uncertain about participating*: Would you like me to e-mail or mail you additional information about the study?


*If willing to participate*: *Determine if they meet inclusion criteria and do not disqualify based on exclusion criteria (below).*

a) ≥1 month post-stroke
b) have a motor deficit affecting the upper limb
c) have a mini-mental status exam score of ≥ 24 (TBD)
d) able to tolerate two 30-minute therapy sessions separated by at least 15 minutes per day;
e) ≥ 18 years of age.

*Exclusion criteria:*
a) presence of another neurological disease or injury other than stroke or TBI
b) presence of a musculoskeletal injury or disease that may affect the unaffected/affected upper limb (e.g., that will be used to participate in the study)
c) presence of a visual deficit or disease that affects the individual's ability to easily see objects on the computer screen (e.g., blindness or macular degeneration).

*If subject qualifies:*
"I would like to schedule a time for you to come to CNS. We can schedule it before or after your appointments with OT, if you'd like." *Coordinate a time and set appointment.*

APPENDIX G: AUGMENTED REALITY TECHNOLOGY FOR REHABILITATION

RESEARCH PROTOCOL

<div align="center">

**Consent to Participate in a Research Study**

**Colorado State University**

</div>

**TITLE OF STUDY:** Augmented Reality Technology for Rehabilitation

**PRINCIPAL INVESTIGATOR:**  Matt Malcolm, PHD, OTR
Department of Occupational Therapy
Colorado State University
(970) 491-5202

**CO-PRINCIPAL INVESTIGATOR:**  Sudeep Pasricha, PHD
Department of Electrical and Computer Engineering
Colorado State University
(970) 491-0254

**WHY AM I BEING INVITED TO TAKE PART IN THIS RESEARCH?** You are being asked to participate in this study because you have had a stroke or traumatic brain injury (TBI) and have some difficulty using your arm or hand and/or some difficulty attending to all of your visual environment.

**WHO IS DOING THE STUDY?** This study is being conducted by researchers in the Colorado State University Department of Occupational Therapy and Department of Electrical and Computer Engineering and has been partially financially supported by the Department of Occupational Therapy.

**WHAT IS THE PURPOSE OF THIS STUDY?** The purpose of this study is to determine how easily a computerized, internet-based system of rehabilitation games may be used by individuals with a stroke or TBI and if the system helps to improve arm and hand movement and/or visual skills.  The rehabilitation games use a technology known as "augmented reality".  In this study, augmented reality technology will allow for you to use your own body movements to control aspects of a computerized game.

**WHERE IS THE STUDY GOING TO TAKE PLACE AND HOW LONG WILL IT LAST?** The study will take place in Dr. Malcolm's laboratory and at your place of residence. The study will consist of a pre-test evaluation session, intervention period, post-test evaluation session, and 1-month follow-up evaluation session.  Each of the three evaluation sessions will last approximately 2 hours, for a total of 6 hours.  The intervention period will be delivered over 10 consecutive week days (for example, two work weeks: Week 1-Monday through Friday, no intervention on Saturday and Sunday, and Week 2-Monday through Friday).  On each of the intervention days, you will practice with the computerized system for 1 hour per day, for a total of 10 intervention hours.  So, the total time to participate in this study will be approximately 16 hours (6 hours of evaluation and 10 hours of intervention).

**WHAT WILL I BE ASKED TO DO?** You will be asked to participate with four major activities in this study in the following order: (1) pre-test evaluation, (2) intervention period, (3) post-test evaluation, and (4) 1-month follow-up evaluation. Details of these activities and their timing are provided in the following table:

| Activity | Description | Timing |
|---|---|---|
| Pre-test evaluation | This approximately 2-hour session will evaluate your abilities related to arm and movement; visual perception; daily activity performance; community and social participation; daily routines; and your experience with rehabilitation programs carried out in your place of residence. This session will take place in our laboratory. | This will occur 1 to 3 days prior to starting the intervention period. |
| Intervention period | The intervention period will take place on 10 consecutive weekdays. The first two days of the intervention, you will come to the laboratory; days 3 through 10 of the intervention will be at your own home. On each day, you will complete two 30-minute intervention sessions (with a rest break of at least 15 minutes between these sessions). On the first two days, we will ask you to come to the laboratory to use the computerized rehabilitation system, which is called the "AR system". Using the AR system, you will participate with a variety of computerized games. You will use your more-affected arm and hand to control an "effector" (such as a space ship) in the game to either hit targets or avoid obstacles. The games will require you to use your eyes to scan the computer screen for targets or obstacles and your arm/hand to move the effector to hit a target or avoid an obstacle. Your arm and hand movements will be detected by a motion sensor that will be placed above your arm and hand (which will rest on a table). The motion sensor will be connected to the computer. We will adjust the game controls to make the games challenging but not too difficult to perform. On intervention days 3 through 10, you will use the AR system in your own place of residence. We will lend you a small laptop computer and the motion sensor to take with you during the intervention period. You will access the games through an internet website, for which we will provide you with your own unique username and password to log in. We will schedule phone call "check ins" with you on intervention days 3, 5, and 8 to find out how the games are working and if you have any questions or problems in using the AR | 10 consecutive weekdays. For example, intervention days 1 through 5 will occur on Monday through Friday, followed by a weekend of no intervention, followed by intervention days 6-10 occurring Monday through Friday. |

| Activity | Description | Timing |
|---|---|---|
| | system. We will also provide you with a phone number to call our laboratory should you encounter questions or problems when using the AR system. Finally, one of our staff will monitor your daily progress through the website that delivers the AR games. You will also be able to check your performance and progress on the website. | |
| Post-test evaluation | As in the pre-test session, the 2-hour post-test session will again evaluate your abilities related to arm and movement; visual perception; daily activity performance; daily routines; and community and social participation. We will also ask you to participate with a brief interview to learn about your experience in using the AR technology. This session will take place in our laboratory. | This will occur 1 to 3 days following the intervention period. |
| 1-month follow-up evaluation | As in the post-test session, the 2-hour 1-month follow-up session will again evaluate your abilities related to arm and movement; visual perception; daily activity performance; daily routines; and community and social participation. This session will take place in our laboratory. | This will occur 1 month following completion of the intervention period. |

**ARE THERE REASONS WHY I SHOULD NOT TAKE PART IN THIS STUDY?** You should not take part in this study if any of the following apply to you:

1. You had a stroke or TBI less than 1 month ago
2. You cannot voluntarily lift your more affected arm to table-height or move your arm across the table
3. You lack the thinking and communication skills necessary to understand the study procedures
4. You are unable to tolerate two 30-minute sessions of activity using your more-affected arm
5. You are under the age of 18 years
6. You have another neurological disease or injury besides a stroke or TBI
7. You have a muscular, bone, or joint injury or disease that affects your more-affected arm/hand
8. You have a visual condition or disease that prevents you from easily seeing objects on a computer screen
9. Your primary physician expresses concern over you participating in the study. We will ask you to provide us with contact information for your doctor. We will send a letter to she or he letting them know about this study, and will provide our contact information

should your doctor have questions or reservations about your participation.  We will also provide your doctor with a copy of this informed consent form.

**WHAT ARE THE POSSIBLE RISKS AND DISCOMFORTS?**  It is not possible to identify all potential risks in research procedures, but the researchers have taken reasonable safeguards to minimize any known and potential, but unknown, risks.

There may be a risk that you experience fatigue (for example, tiredness) or pain (for example, sore muscles) during the intervention period because you may be using your more-affected arm/hand more than you are used to.  To help reduce this risk, you will need to take breaks between game trials and between game sessions.  We will give you a schedule to help you know when to take such breaks.  We will also ask you if you are experiencing fatigue or pain during phone call "check ins".  You may also call the laboratory if you are experiencing fatigue or pain.  In the event that you are experiencing lasting fatigue or pain, you should stop playing the intervention games and notify us.

There may also be a risk of you experiencing frustration when playing the games.  Individuals who participate with rehabilitation sometimes experience frustration because therapeutic activities are challenging.  We will help to reduce the risk of frustration by doing the following a) regularly check in with you to help problem solve if you are frustrated; b) provide you with a phone number to our lab so you can call if you are frustrated; c) we will monitor your performance with the games to see if the difficulty settings are set too high so that we may adjust them to a better level for you.

**ARE THERE ANY BENEFITS FROM TAKING PART IN THIS STUDY?** There may be no direct benefit to you associated with participation in this research, but potential direct benefits <u>may</u> include improved arm/hand movement and improved visual-perceptual skills.  The study results may also benefit future individuals who have experienced a stroke or TBI by developing a new rehabilitation technique to promote better recovery.

**DO I HAVE TO TAKE PART IN THE STUDY?** Your participation in this research is voluntary. If you decide to participate in the study, you may withdraw your consent and stop participating at any time without penalty or loss of benefits to which you are otherwise entitled.

**WHO WILL SEE THE INFORMATION THAT I GIVE?** We will keep private all research records that identify you, to the extent allowed by law.  For this study, we will assign a code to your data (for example, "AR01") so that the only place your name will appear in our records is on the consent and in our data spreadsheet which links you to your code. Only the research team will have access to the link between you, your code, and your data. The only exceptions to this are if we are asked to share the research files for audit purposes with the CSU Institutional Review Board ethics committee, if necessary. When we write about the study to share with other researchers, we will write about the combined information we have gathered. You will not be identified in these written materials. We may publish the results of this study; however, we will keep your name and other identifying information private.

**CAN MY TAKING PART IN THE STUDY END EARLY?** If you are unable to show up to all sessions you may be removed from the study.

**WILL I RECEIVE ANY COMPENSATION FOR TAKING PART IN THIS STUDY?** You will not receive compensation for taking part in this study.

**WHAT HAPPENS IF I AM INJURED BECAUSE OF THE RESEARCH?** The Colorado Governmental Immunity Act determines and may limit Colorado State University's legal responsibility if an injury happens because of this study. Claims against the University must be filed within 180 days of the injury.

**WHAT IF I HAVE QUESTIONS?** Before you decide whether to accept this invitation to take part in the study, please ask any questions that might come to mind now. Later, if you have questions about the study, you can contact the investigator, Matt Malcolm, PHD, OTR at (970) 491-5202. If you have any questions about your rights as a volunteer in this research, contact the CSU IRB at: RICRO_IRB@mail.colostate.edu; 970-491-1553. We will give you a copy of this consent form to take with you.

**WHAT ELSE DO I NEED TO KNOW?**
Following your participation with this study, we may contact you to see if you are interested in participating in additional research. Please check one of the following boxes to let us know if we may or may not contact you again.

- ☐ YES, the researchers may contact me about participating in future research
- ☐ NO, the researchers may not contact me about participating in future research

Your signature acknowledges that you have read the information stated and willingly sign this consent form. Your signature also acknowledges that you have received, on the date signed, a copy of this document containing __4__ pages.

_____     _____
Signature of person agreeing to take part in the study            Date

_____
Printed name of person agreeing to take part in the study

_____     _____
Name of person providing information to participant               Date

_____
Signature of Research Staff