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Gaze-Driven Video Games as Vision Training:

A Case Study in Cerebral Palsy

A Thesis

Presented to

The Faculty and the Honors Program

Of the University of San Diego

By

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Behavioral Neuroscience

2018

Abstract

Cerebral Palsy is a disorder that primarily affects motor control, but frequently impacts gaze behavior as well. Due to the primary therapeutic emphasis on motor symptoms, there is a dearth of therapies available for gaze behavior in Cerebral Palsy. Based on research suggesting that video games and Augmented Reality have been useful for improvement of gaze behavior and rehabilitation for other impaired individuals, this case study applies a set of therapeutic gaze-dependent Augmented Reality video games to an adolescent male with Spastic Diplegic Cerebral Palsy. The video games were determined to be a good fit for the participant by the specificity of their incorporated training principles targeting fixation and saccadic control. The participant underwent training using the video games in order to determine their effects on fixation and saccadic control, the results of which indicate practice-dependent improvements. Further, results support the participant's ability to engage with gaze-driven accessibility software, providing for augmentation of his communication options.

Cerebral Palsy (CP) is a developmental disorder caused by an insult or injury to the Central Nervous System (CNS) during early development (i.e., pre-, peri-, or post-natally). The injury or insult promotes formation of abnormal neural connections, producing motor impairment in the form of diminished limb strength, control, or both. The neural maldevelopment of CP is static and nonprogressive, providing for treatment of symptoms with rehabilitative techniques (Aisen et al., 2011; Bax et al., 2007). Because CP diagnosis is predicated on the relatively vague terms “insult or injury”, there is variety in the downstream motor symptomology. This variety is classified into different forms by topology and motor characteristics. The participant in this case study has the Spastic Diplegic form of CP, which represents roughly 30-40% of all CP cases. Spastic Diplegic CP topographically affects the bilateral lower extremities (i.e., diplegia), and has less effect on the muscles of the upper extremities. Physiologically, leg muscles are typically in stiff or tensed muscles postures in which muscle tension increases with speed of limb movement (i.e., spasticity) (Abdel-Hamid, 2016; Jones et al., 2007; Sandkar & Mundkur, 2005).

Most literature and resources concerning CP center on these motor symptoms and therapy. However, CP may be associated with a host of additional developmental disabilities dependent on the degree of damage caused by the initial insult or injury. These deficits may include cognitive impairment, speech and language disorders, and ophthalmologic (i.e., vision) impairment, among others (Ashwal et al., 2004; Krigger, 2006). The range of visual impairment, specifically, may include cerebral visual impairment (CVI), as well as deficits of the oculomotor system, typically presenting as abnormalities of fixation, smooth pursuit, and saccadic movements (Fazzi et al., 2012; Good et al., 1994; Good et al., 2001; Dutton et al., 2001;

Schenk-Rootlieb et al., 1994). The profile of oculomotor impairment in diplegic CP includes an incidence of abnormal ocular movements at about 30%, greater than 20% incidence of altered fixations, greater than 70% incidence of altered smooth pursuit, and greater than 80% incidence of altered saccadic movement (Fig. 1) (Fazzi et al., 2012).

Incidence rates of these deficits make them a high-profile target for therapy. Further, a new perspective of CP offered by Bax et al. (2007) proposed that the visual component of the disorder is an integral part of the clinical picture of CP, effectively removing these deficits from the “additional disabilities” category and placing them into the core of the diagnosis. For these reasons, development of effective vision therapies for CP is essential.

Of these developing therapies, video games have been demonstrated as an effective and low-cost option. Using a commercially available Wii system and games, researchers were able to demonstrate the potential for greater physical mobility and control as well as improved visual-perceptual processing in CP just from regular engagement with Wii games (Deutsch et al., 2008). Even in typically developing individuals, video games have been implicated in higher performance on explicitly trained visual tasks, with evidence of transference to related, but untrained visual tasks (Green et al., 2007). Though not direct vision therapy, findings in virtual engagement, like video games, may have implications for movement-restricted individuals who can mentally engage motor imagery. Other CP therapies have forayed into Virtual Reality (VR), demonstrating elimination of aberrant activation in motor regions, enhancement of functional motor skills, and increase in use and quality of movement in the trained limb (You et al., 2005). Analogously, gaze-dependent interactions, that is, the use of eye movement as an input modality for various tasks (Bolt, 1982), may provide similar results in enhancing functional motor skills

with respect to the eye. Chukoskie et al. (2013; 2017) have developed a novel gaze-dependent Augmented Reality (AR) intervention to train deficits in attention via eye movement. A set of custom-designed gaze-contingent video games (RAD Lab gamesuite) incorporates principles that improve quality of fixations as well as saccadic accuracy and latency as a byproduct of attention training. These principles are gradually introduced so as to shape eye movement behavior over time and are paired with engaging imagery and audiovisual feedback. Targeting of eye movement deficits found in CP, as well as the gradual introduction of training principles, make the intervention a good candidate for application as a vision therapy in CP.

Originally designed for attention training in Autism Spectrum Disorder (ASD), the training principles are based in specific attention behaviors characteristically impaired in ASD: attention orienting, disengagement, and shifting (i.e. saccadic eye movement) as well as a restricted attentional field (Townsend and Courchesne, 1994; Townsend et al., 1996; Townsend et al., 1999; Haist et al., 2005; Keehn et al., 2010; Townsend et al., 2012; Keehn et al., 2016; Keehn et al., 2010). By targeting these deficits, the games' design is such that the training principles directly target the voluntary saccade circuit (VSC) of the brain (Fig. 2), which overlaps with the spatial attention circuit (Posner, 1980; Goldberg and Segraves, 1987; Corbetta et al., 1993). Theoretically, activation and training of the voluntary saccade circuit subsequently activates and trains the spatial attention circuit. Training of the spatial attention circuit enables two outcomes in individuals with ASD: proper orientation of attention in social conditions, and rapid response in tasks that require integration of multisensory information (Chukoskie et al., 2017).

Chukoskie et al. (2017) have demonstrated the ability of these games to improve the abovementioned deficits of ASD, as well as improve fixations and saccadic eye movement. Further, they have demonstrated the feasibility of gameplay in an at-home setting, making this a highly accessible therapy option and eliminating the burden of frequent in-lab training sessions of other therapies (Chukoskie et al., 2013; Chukoskie et al., 2017; Vedamurthy et al., 2015).

Participant profile

Due to the specificity of the profile of oculomotor deficits in Spastic Diplegic CP and the demonstrated ability of the RAD Lab gamesuite to improve these same oculomotor deficits, the researchers, in partnership with a vision therapist, determined that the participant may be a good fit for engagement with the games as a case study.

The participant, referred to as MA, demonstrates Spastic Diplegic CP. MA is an adolescent male with limited mobility. Unfortunately, the researchers were not able to have full contact with MA's care team during the case study, so there are some observational assumptions sewn into its design. Additionally, the researchers were not able to access imaging scans or data about the specifics of MA's brain damage. From his motor symptoms, researchers have inferred motor cortex damage, as well as damage to the medullary pyramid of the corticospinal tract, typical of spasticity (Jones et al., 2007).

Researchers assume MA is a Level V on the Gross Motor Functional Classification System, meaning that he has severe motor limitations, even with the use of supportive technology (Jones et al., 2007; Rosenbaum et al., 2002). He is wheelchair bound and demonstrates little voluntary movement of the extremities. During this study, movement of extremities most often occurred involuntarily during concentration or excitement related to

gameplay. MA does retain some voluntary movement of the trunk, neck, head, and most importantly, eyes. However, he had previously been trained to interact with pressure-sensitive pads located on either side of his wheelchair headrest as part of an accessibility system. This training produced gaze behavior such that MA relied on head movement to reorient gaze position, rather than engaging in proper fixations and saccades. Additionally, though MA is intellectually impaired and demonstrates disordered speech and language characteristic of CP, he is able to respond to simple questions and instructions with one or two words, a noise, head and/or eye movement.

Rationale

Due to his restrictions, the prospect of independent engagement with the RAD Lab gamesuite provided a novel opportunity for MA. The researchers hypothesized that engagement with the games would produce improvement in MA's gaze behavior because of demonstrated efficacy and feasibility (Chukoskie et al., 2013; Chukoskie et al., 2017). Further, building on evidence that engagement with virtual imagery in VR can improve use and quality of movement in a trained limb (You et al., 2005), researchers propose that a limb is sufficiently analogous to an eye because they are both under control of voluntary skeletal muscle. Therefore, eye movement may be improved by engagement with virtual imagery in AR.

This proposition addresses previous neglect of vision in the use of virtual systems as therapy for CP (Wang et al., 2011) and provides a low-cost and home-use enabled therapy option to address MA's specific deficits (Deutsch et al., 2008; Chukoskie et al., 2017).

Accessibility

Beyond the novel opportunity for independent engagement, the researchers hypothesized that shaping of fixation and saccadic eye movement may provide for engagement with gaze-dependent accessibility software. In the course of the case study, the researchers evaluated MA's ability to engage with a high-power remote eye tracker, the EyeTech VT3 Mini (Fig. 3) (www.eyetechds.com) and Grid3 (Fig. 4) (www.thinksmartbox.com), an accessibility software designed specifically for use by disabled youth. This system allows use of fixation and saccadic eye movement to select digital "word buttons" displayed on a computer screen and enables the user to direct the system to read the selected words aloud, drastically improving their ability to communicate. Intellectually, MA demonstrated sufficient capability to engage with this software, and it offered him the opportunity to circumvent his speech disability. However, the EyeTech requires a small head box (i.e., the amount of space in which the head typically moves), the ability to fixate steadily for a given amount of time, and the ability to make accurate saccades. The head box size requirement allows the remote tracker to maintain a line of sight with each pupil, which forms the basis for internal calculations about gaze position on the screen. A steady fixation, "dwell time", of a certain duration forms the selection command in this system (Zander et al., 2011). Accurate saccades are crucial to selecting the correct "word button" and avoiding accidental selections. In all of these requirements, however, MA did not meet the required specifications to facilitate engagement with the remote tracker and software. Therefore, improvement of these abilities for the purpose of engagement with accessibility software became a second goal of this case study.

MATERIALS AND METHODS

Materials

Eye-tracker and Software

Our at-home training system for this study used a standard desktop computer with a Pupil Labs monocular eye-tracker (Fig. 5). The monocular eye-tracker consisted of a high-speed “world camera” (WC) and an infrared (IR) “eye camera” (EC). Both cameras were mounted to a glasses frame; the world camera in an outward-facing position just above the right brow, and the inward-facing eye camera on an arm that extended from the frame in front of right eye. The world camera had 1280x720 pixel resolution at 60 frames per second (60Hz), and a 100 degree field of view lens. Sampling though the world camera had a latency of 5.7ms. The eye camera had a resolution of 200x200 pixels at 200 frames per second (200Hz) and used infrared (IR) (<https://pupil-labs.com/store/>). Under ideal computer screen viewing conditions, the eye-tracker had a maximum accuracy of 0.5° to 1° (Chukoskie et al., 2013).

The monocular eye-tracker connected to the desktop computer via USB, and the WC and EC video feeds from the monocular eye-tracker were displayed on the computer using Pupil Capture software downloaded from Pupil Labs (Fig. 6)

A Python script was written to convert gaze position data from the monocular eye-tracker to mouse position and control on the screen. This script depended on the presence of a set of four AR codes which were printed and one of four secured to each corner of the computer screen (Fig. 7). The coding recognized the four codes as a whole and used them to creates a “digital surface” on the computer screen, within which gaze position could be recorded and converted to mouse control.

In order for gaze position to be accurate, the monocular eye-tracker required a calibration procedure. The interface was simple and required only that the participant complete a short

procedure in which they sequentially fixated on a set of nine bullseye targets in nine different monitor locations.

Pupil Player software from Pupil Labs was used to trim, analyze, and export videos of in-lab gameplay.

Games

The RAD Lab gamesuite is a set of four augmented reality (AR) games originally designed to train attention in Autism Spectrum Disorder (ASD). The games were professionally designed and programmed by Angry Troglodyte game developers based on RAD Lab's specifications for training principles. Colorful and engaging with interesting sound effects, the games were designed such that they trained fixation, speed and accuracy of eye movements, and control of visuospatial attention (Fig. 8-11). All games increased in difficulty, speed and active field of view (i.e., amount of visual/attentional field used in game) as the gamer played longer and became more competent (Chukoskie et al., 2017).

From selection menus to actual gameplay, the games were completely controlled by eye position on the display. Selection actions that required a "click" using a traditional mouse were performed by fixating for a set length of time on the selection object. The original design and coding of the games was based on a computer-mounted remote eye-tracker, which was not a feasible option in this study, so visual data was made accessible to the games via the custom Python script mentioned above.

Participant

The participant of this case study, MA, is a 13 year old male with a diagnosis of Spastic Diplegic cerebral palsy (CP). The participant was referred to RAD Lab as a potential study participant by his vision therapist.

Methods

All methods and protocols were approved by the UCSD Institutional Review Board and are in compliance with international standards for the protection of human participants.

Evaluation

To determine if the RAD Lab gamesuite was appropriate for use with the participant as a vision training tool, the researchers met with MA's vision therapist to evaluate the games for vision therapy principles. The vision therapist determined that the games appeared to be applicable as a vision training tool, and recommended that we proceed with the case study.

Pre-training Assessment

MA was put through a battery of tasks normally used to determine cognitive abilities in ASD over the course of three initial lab visits. These included the WAS-II and WAS-III Matrix reasoning task and the PPVT Form A. However, because MA is so severely impacted in his ability, the results of these tasks did not produce any usable data. During this time, WC recordings were taken while the participant viewed a cartoon and while the participant played the RAD Lab gamesuite for the first time. The recording of cartoon viewing did not produce any usable data. Due to these difficulties in finding appropriate outcome measures, the researchers decided to use and analyze recorded in-lab gameplay as an outcome measure.

Timeline

This case study was designed to mimic that of Chukoskie et al. (2017) and was conducted in two phases. In Phase I, the participant was evaluated in the lab three times for pre-, mid-, and post-training assessment of attention and eye movement in addition to the initial set of in-lab pre-training visits. Recorded in-lab gameplay from the participant's first engagement with the RAD Lab gamesuite served as the pre-training assessment. At the last of the three pre-training visits, the participant's aide and family were trained to set up and use the gaming system. We then installed the gaming system in the participant's home and ensured that the participant could follow calibration procedures and play the games independently.

The participant's family was asked to ensure 30 minutes of gameplay per day, five times per week, and compliance was monitored over a secure internet connection with software that automatically recorded date, time and duration of play for each game as well as performance data. After two weeks of at-home gameplay, the participant was called back into the lab to record in-lab gameplay as the mid-training assessment. Two weeks later, the participant was called back for a final recorded in-lab gameplay session that served as the post-training assessment.

Because of poor at-home compliance with the requested amount of gameplay per week, the researchers decided to initiate a repetition of procedure, referred to as Phase II. Phase II was structured similarly to Phase I, but the requested amount of at-home gameplay time was reduced to 15 minutes per day, five times a week. Additionally, Phase II had six weeks of at-home gameplay between the pre- and mid-training assessment, and the mid- and post-training assessment.

Analyses

Pupil Player software was used to view and trim videos of recorded gameplay in order to eliminate portions of the recording that captured time not spent engaged in gameplay. Selections that exclusively featured gameplay with proper calibration were exported in a raw data Excel file that allowed the researchers to perform two different analyses. Using the “digital surface”, the first analysis totaled the number of frames¹ from the exported selections in which the participant was looking (1) on screen and (2) off screen in a given round of gameplay and divided those by the total number of frames in that round. Using the proportions generated by this procedure, the researchers averaged all proportions from an in-lab session to produce a single measure of the proportion of on-versus-off-screen attention during that session.

The second analysis totaled the number of frames from the exported selections in which 0, 1, 2, 3, and all 4 AR codes were visible. These frames were binned and summed as follows: all frames with 0-1 AR codes visible, all frames with 2-3 AR codes visible, and all frames with 4 AR codes visible. These bins were selected to represent insufficient, sufficient, and perfect digital surface tracking. The sums of the bins were divided by the total number for frames in that round of gameplay to produce proportions. All proportions generated from a single in-lab session were averaged to produce a single measure for that session.

A two-tailed t-test for two dependent means was run on on- vs off-screen data, as well as AR code detection data (www.graphpad.com). α -level was set at 0.05.

At-home gameplay was tracked and totaled in each phase to gauge engagement.

RESULTS

On/Off-screen Attention

¹ 1 frame = 1/50th second

Phase I on- versus off-screen attention changes between pre-, mid-, and post-training assessments were not found to be significant (Fig. 12). The pre-training assessment was mostly on screen [mean $\pm$ standard error] [0.62 ± 0.06 on; 0.38 ± 0.06 off]. At the mid-training assessment, attention was again mostly on-screen [0.57 ± 0.06 on; 0.43 ± 0.06 off]. At the post-training assessment, attention was also mostly on-screen [0.56 ± 0.05 on; 0.44 ± 0.05].

Phase II on- versus off-screen attention at the pre-training assessment was determined to be mostly off-screen [0.47 ± 0.08 on; 0.53 ± 0.08 off]. At the mid-training assessment, attention was mostly on-screen [0.67 ± 0.08 on; 0.33 ± 0.08 off]. At the post-training assessment, attention was again mostly on-screen [0.45 ± 0.10 on; 0.55 ± 0.10]. On-screen attention increased between the pre- and mid-training assessments and decreased between mid- and post-training assessments (Fig. 13). The difference between pre- and mid- training assessment values was not significant, however the difference between mid- and post- training assessment values was significant [$t(6)2.5179$, $p=0.0454$].

AR Code Detection

Phase I AR code detection changes between pre- mid- and post-training assessments were not found to be significant (Fig. 14). Detection at the pre-training assessment primarily fell into the four code bin [0.08 ± 0.01 zero to one; 0.34 ± 0.04 two to three; 0.58 ± 0.04 four]. Detection at the mid-training assessment fell mostly in the two to three code bin [0.13 ± 0.02 zero to one; 0.52 ± 0.06 two to three; 0.35 ± 0.06 four]. Detection at the post-training assessment was primarily in the four code bin [0.10 ± 0.06 zero to one; 0.34 ± 0.09 two to three; 0.56 ± 0.09 four].

Phase II AR code detection changes between pre- mid- and post-training assessments were not found to be significant (Fig. 15). In all three assessments of Phase II, no frames were detected with less than two AR codes visible. Phase II AR code detection at the pre-training assessment primarily fell into the four code bin [0.47 ± 0.11 two to three; 0.53 ± 0.11 four]. Detection at the mid-training assessment was again mostly in the four code bin [0.19 ± 0.06 two to three; 0.81 ± 0.06 four]. Detection at the post-training assessment was primarily in the four code bin [0.31 ± 0.08 two to three; 0.69 ± 0.08 four]. The proportion of frames with four codes visible increased between the pre- and mid-training assessment, and decreased between the mid- and post-training assessment.

At-home Gameplay

Due to instructed use, Phase I at-home gameplay time was expected to average 1800 seconds per session over 20 sessions, with an expected gross total of 30600.00 seconds. Actual at-home gameplay averaged 680.70 seconds per session over 17 sessions, with a gross total of 11571.95 seconds (Fig. 16). This means that the average at-home session was 37.8% of the expected length, the total number of sessions was 89.5% of the expected number.

Phase II at-home gameplay time was expected to average 900 seconds per session over 60 sessions, with an expected gross total of 46800. Actual at-home gameplay averaged 1747.79 seconds per session over 52 sessions², with a gross total of 90885.32 seconds (Fig. 17). This finding means that the average at-home session was 194.2% of the expected length, the total number of sessions was 86.6% of the expected number.

² All of these sessions occurred in the first nine weeks of Phase II.

All six weeks between the pre- and mid-training assessment of Phase II were compliant with the requested engagement time, as well as the first three weeks between the mid- and post-training assessment. However, there was no at-home gameplay during the last three weeks between the mid- and post-training assessment. This difference will be addressed in the discussion.

EyeTech VT3 Mini and Grid3

At the Phase II pre-training assessment, MA was unable to engage successfully with the EyeTech and the Grid3. This was determined qualitatively. During the initial attempt to engage MA with the EyeTech, MA's large head box and jumpy fixations prevented the EyeTech's two IR pupil cameras from maintaining a consistent line of contact with his pupils. Consistent contact with the pupils is required for the software to map an accurate gaze position onto the computer screen. During the mid-training assessment of Phase II, MA successfully engaged with the EyeTech and the Grid3. Qualitatively, the EyeTech was able to maintain a consistent line of contact with his pupils for long enough to map accurate gaze positioning onto the screen.

Discussion and Conclusions

Analysis of on- versus off- screen attention during gameplay explicitly provides a measure of spatial attention, indicating to what degree the spatial attention circuit has been activated. Relying on the theoretical basis of the gamesuite design, we have used this measure to imply the degree to which the Voluntary Saccade Circuit (VSC) of the brain has been engaged. In Phase I, our results indicated that MA's attention was mostly on-screen, implying that his VSC was activated during most in-lab gameplay. However, the proportion of on-screen attention time did not change significantly over the course of Phase I, indicating that there was little to no

improvement in activation of the VSC. In Phase II, our results indicated that MA's on-screen attention increased when he was engaged in regular practice (i.e., between the pre- and mid-training assessment). However, this result may be driven by the low pre-training assessment value for on-screen attention, and may not actually be indicative of improvement in VSC activation with practice. The subsequent decrease in on-screen attention without practice indicates that proper activation of the VSC is practice-dependent, and will be deprioritized without regular use. These results may be attributable to practice-dependent neuroplasticity, causing the generation of effective synaptic potentiation (You et al., 2005; Liepert et al. 2000; Carey et al. 2002).

Analysis of AR code detection provides an explicit measure of head box size. Based on the gaze behavior we observed at the beginning of the study in which he relied on head movement to produce gaze movement, we theorize that when presented with a computer screen which does not leave the field of view of a static head position, MA's eye movement will either be caused by head movement or by eye movement independent of the head, the proportions of which should add up to one. By measuring head box size, we have produced an indicator of eye movement caused by head movement, allowing us to imply the proportion of independent eye movement. That is, the number of codes detected is inversely proportional to head box size, which is inversely proportional to independent eye movement. Across Phase I, MA demonstrated no significant change in the proportion of time for which four codes were detected, indicating that head box did not decrease in size, and that MA was still very reliant on head movement. Between the pre- and mid-training assessments of Phase II, MA demonstrated an increase in the proportion of time for which four codes were detected, indicating that his primary mode of gaze

reorientation had shifted to independent eye movement. Between the mid- and post-training assessments of Phase II, however, MA's performance demonstrated a decreased in proportion of time with four codes visible, indicating some increase in head box size.

The change in MA's ability to engage with the EyeTech and Grid3 system between the pre- and mid-training assessments of Phase II indicate he had a reduced head box size, and an increase in ability to fixate steadily and make accurate saccades.

While we are not able to know which behaviors that MA demonstrates are natural, and which are from accessibility training, these results do allow us to assert that regular engagement with the RAD Lab gamesuite was able to undo MA's previous gaze behavior as well as train a new behavior in its place, improve fixations and saccadic movement of the eyes. Further, our results demonstrate that MA retains neural plasticity and, therefore, the ability to make improvements by engaging with other therapies. Together, these results indicate that training with the RAD Lab gamesuite may be applicable to other cases of Spastic Diplegic CP, as well as to other forms of CP.

Limitations

When considering these results, it is important to consider the differences in the training schedules of Phase I and II. While Phase I occurred over a total of four weeks, at-home engagement was very low, which was apparent in the time data from at-home gameplay and the lack of change across both analyses. Phase II was tested over a total of 12 weeks, with high compliance in at-home gameplay up until week nine, at which point at-home gameplay ceased due to errors in communication. The improvement seen in the mid-training assessment, and

subsequent decrease in performance seen in the post-training assessment are very likely tied to the radical change in at-home engagement time.

Accessibility

From both the positive and negative conclusions drawn from of this case study, it is important to return to a higher-level goal of training gaze behavior: accessibility. In this specific case, MA demonstrated ability to engage with gaze-driven video games and an accessibility system, which supports his ability to interact with the proliferating number of gaze-driven accessibility technologies. This case study represents an important bridge between that proliferation and the viability of the new technologies for movement-restricted individuals with impaired gaze control. Development of gaze-driven accessibility systems may continue, but for individuals like MA, who have the capacity to engage but required gaze-behavior training, these systems will be of little use unless they receive that training. For this reason, it is important that therapies available to impaired individuals are continually a subject of research to develop methods for connecting them to improved quality of life.

Future Directions

This case study relied on worn and remote eye tracking to interact with AR. Eyetracking is a good option because it has higher bitrate communication than other methods of interaction and is not restricted to binary commands like a mouse (Zander et al., 2011). Future iterations of this study may incorporate Brain-Computer-Interface (BCI) as a method of selection. For example, an electroencephalograph (EEG) may be worn while eye tracking and would offer the ability to handle different stimulus complexities by responding to the degree of electrical activity on the scalp. This technique would be ideal for study designs wishing to eliminate training of

fixations, focusing only on training saccades. It would also be ideal for individuals with extremely poor fixation, who may become frustrated by their lack of ability to achieve sufficient dwell time for selection, as well as avoiding accidental selections by individuals with naturally longer dwell time (Zander et al., 2011).

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Figure Legends

Figure 1. Neuro-ophthalmological deficits by Cerebral Palsy type. Diplegia is denoted in solid black. (Fazzi et al., 2012)

Figure 2. The Voluntary Saccade Circuit. Image courtesy of UCSD Research on Autism and Development Lab.

Fig. 3. The EyeTech VT3 Mini. The paired infrared left and right pupil cameras can be seen to the left and right of the light blue fixation point.

Figure 4. Grid3 software. An Augmentive and Alertive Communication software for people communicating with symbols, text or a combination of both.

Figure 5. The Pupil Labs monocular eye-tracker. The world camera is mounted to the glasses frame above the eye. The eye camera is mounted on an extendable arm in front of the eye.

Figure 6. In-lab gameplay setup. One screen was used by researchers to monitor pupil tracking, while another was used to play the RAD Lab video games.

Figure 7. AR Code positioning. The codes were used to detect the monitor corners and create a digital surface.

Figure 8. RAD Lab gamesuite home menu icons.

Figure 9. “Shroom Digger”. A RAD Lab gamesuite game.

Figure 10. “Space Race”. A RAD Lab gamesuite game.

Figure 11. “Whack the Moles”. A RAD Lab gamesuite game.

Figure 12. Phase I location of gaze during in-lab gameplay. On screen attention is denoted in blue. Off-screen attention is denoted in grey. Error bars represent standard error.

Figure 13. Phase II location of gaze during in-lab gameplay. On screen attention is denoted in blue. Off-screen attention is denoted in grey. Error bars represent standard error.

Figure 14. Phase I AR code detection during in-lab gameplay. Proportion of gameplay time with four marker detection is represented in dark blue. The proportion of two to three marker detection is represented in grey. The proportion of zero to one marker detection is represented in light blue. Error bars represent standard error.

Figure 15. Phase I AR code detection during in-lab gameplay. Proportion of gameplay time with four marker detection is represented in dark blue. The proportion of two to three marker detection is represented in grey. The proportion of zero to one marker detection is represented in light blue. Error bars represent standard error.

Figure 16. Phase I at-home gameplay tracking. Individual at-home gameplay sessions are represented by blue dots. The grey line represents the goal time for an individual session.

Figure 17. Phase II at-home gameplay tracking. Individual at-home gameplay sessions are represented by blue dots. The grey line represents the goal time for an individual session.

Figures

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