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Pupil Size: A Unique Variable Used to Improve AAC Display Design for Individuals with Down syndrome

JESSICA SAGANOWICH
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Reviewed and approved* by the following:

Krista Wilkinson
Professor of Communication Sciences & Disorders
Thesis Supervisor

Carol Miller
Professor of Communication Sciences & Disorders
Honors Adviser

* Electronic approvals are on file.

ABSTRACT

Augmentative and Alternative Communication (AAC) is a set of tools and intervention methods created for individuals whose speech is not meeting their full language capacity. Most AAC systems are designed for individuals who will use symbols or graphics to express emotions, identify objects, or use description words. Previous studies support that current AAC displays are not successfully utilized by every user due to the following challenges: limited vocabulary size, limited number of trained communication partners, and most important to this study, AAC display design. In order to better design AAC displays, researchers have looked to the field of cognitive neuroscience to investigate why certain designs may be more successful than others (Wilkinson & Jagaroo, 2004). Based on these works, it has been found that internal color and the spatial arrangement of display images induces variable amounts of cognitive load on the user (Wilkinson & McIlvane, 2013). This study sought to investigate previous conclusions and their applicability to individuals with Down syndrome via a unique variable, change in pupil size. This variable will add a physiological measure to help researchers better understand how cognitive load and cognitive neuroscience can contribute to improving AAC display design specifically for use by individuals with Down syndrome.

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Chapter 1

Introduction

Today, there are many individuals who lose or are not born with the ability to produce understandable speech due to genetic or acquired conditions such as autism spectrum disorder (ASD), learning disabilities, or brain injury (Elsahar, Hu, Bouazza-Marouf, Kerr, & Mansor, 2019). However, just because a person cannot speak does not mean the individual cannot communicate (Elsahar et al., 2019). Rather, the individual needs an alternative method to express language. Language expression is not only important for alerting others to one's physical wellbeing and wants, but to communicate for social purposes as well. If an alternative method for communication is not established, a barrier is created between the individual and the world around them. This exclusion from social communication has been found to negatively influence the level of an individual's participation in social groups and the development of self-advocacy (McConachie, Clarke, Wood, Price & Grove, 1999). Therefore, it is important for research, clinical, and medical communities to continue to develop methods for an individual to share not only physical needs but express themselves in a variety of situations.

Augmentative and Alternative Communication (AAC) is a set of tools and interventions created for individuals whose current speech is not meeting their language needs. Most AAC systems are designed for individuals to use symbols, graphics, or written language to assist them in expressing emotions or articulating needs. AAC technology may be classified based on the device's technological capabilities and how the individual plans on using the device. When categorizing AAC based on technical capabilities, the devices include "no technology" or unaided (sign language), “low technology” (books and drawings), or “high technology” (devices and displays that are presented through a computer or tablet, often with speech output) (Wilkinson, & McIlvane, 2013). AAC displays can also be differentiated based on the user’s language competencies and whether the individual requires external technology to use the device. If additional materials such as a symbol card or tablet are required, the device is referred to as aided. If no additional technology is required, the device is referred to as unaided. Lastly, individuals may use AAC primarily as an alternative language to speech, or on a temporary basis, for instance, while being intubated in a medical setting (Simion, 2014).

In the past, AAC has encountered some drawbacks. First, many who were offered AAC technology abandoned the device due to slow speech production and lack of usability in diverse social situations (Elsahar et al., 2019; Waller, 2019). Second, research has shown that current AAC models may lack usability for some users due to the following challenges: limited vocabulary, limited number of trained communication partners, and most important to this study, complicated AAC display design (cf. Wilkinson & Jagaroo, 2004).

In order to improve AAC usability, it is important to understand how specific AAC design elements benefit certain populations of users in order to better customize and optimize their experience (Elsahar et al., 2019). This study will primarily focus on the design of high tech AAC displays used by individuals with Down syndrome.

There are three main reasons in which AAC devices should be researched and tailored for individuals with Down syndrome. First, most studies which have investigated AAC display design have focused primarily on individuals who are typically developing or on individuals with ASD. This means that little to no research has been conducted on how individuals with Down syndrome utilize AAC devices. It has been found that males with ASD initiate conversation less and demonstrate increased amounts of nonresponses to questions in comparison to males with Down syndrome. (Martin, Bush, Patel, & Losh, 2018). Therefore, if individuals with Down syndrome prefer to communicate differently than individuals with ASD, these preferences may affect how individuals with Down syndrome utilize AAC technology. Lastly, it is important to research AAC specifically for individuals with Down syndrome due to the high probability that these individuals will have difficulty producing intelligible speech (Bunton & Leddy, 2011). Individuals with Down syndrome can display a variety of oral dysmorphologies. Features such as reduced bone growth in the head and face, and comparatively small oral cavities may appear benign in respect to the individual's overall health, but these slight differences in facial and oral anatomy can have profound effects on speech production and make conversation difficult for communication partners to understand (Bunton & Leddy, 2011).

A review performed by Wilkinson and Jagaroo (2004) revealed how AAC display design can affect the user's understanding of the display's information. Due to the lack of studies focusing solely on AAC use by individuals with Down syndrome, similar research studies were investigated in order to determine important parameters to consider for this study. Previous studies which investigated AAC use by individuals with Down syndrome and individuals with ASD utilized three different AAC display designs which incorporated two independent variables, AAC display image configuration and image background color. These previous studies and review indicate the need to investigate visual attention, memory, spatial processing aspects of sensory motor functions, and how these variables change during diverse social situations (Wilkinson & Jagaroo, 2004; Wilkinson & Madel, 2019; Wilkinson & McIlvane, 2013).

It is also important to not only think about the physical design of the AAC display but to consider how different design elements affect one's cognitive load in the contexts in which the device will be used. The interaction between the participant, activity, and communication partner is elegantly summarized by the Human Activity Assistive Technology Model. This model emphasizes the use of AAC display as a tool instead of the sole focus of the individual's attention during communication acts (Cook & Polgar, 2015). Therefore, our study aims to use concepts from neuroscience and physiology to investigate which AAC display design would be most optimal for individuals with Down syndrome to use in a realistic social setting. In order to provide this support, our study measured a unique variable obtained through eye tracking technology, that is, change in pupil size.

As Laeng et al. (2012) noted, pupil size enlarges due to two main mechanisms. The first mechanism is the inhibition of the body's parasympathetic nervous system (PNS) which is responsible for general body functions commonly called "rest and digest." Pupil size also enlarges with the concurrent activation of the body's sympathetic nervous system (SNS), commonly referred to "fight or flight." The inhibition and activation of the PNS and SNS occurs due to a release of norepinephrine, a neurotransmitter from the locus coeruleus (LC) (Laeng, Sirois, & Gredebäck, 2012). The release of norepinephrine has commonly been associated with changing awareness of internal or external stimuli. Additionally, change in neurotransmitter concentration and corresponding pupil size has been correlated to task dependent attentional states (Laeng et al., 2012).

Measuring pupil size can be easily quantified and recorded via eye tracking goggles. Observed changes in pupil size have been found to correlate to attentional capacity and cognitive effort exerted by a subject during a task (Unsworth & Robison, 2017). A previous study utilized fMRI and associated brain imaging to support how increased pupil size is correlated with increased cognitive load based on which areas of the brain were upregulated and downregulated during increasingly difficult tasks (Alnaes, Sneve, Espeseth, Endestad, van de Pavert, & Laeng, 2014). This study highlighted the advantages of pupil size data over gaze data, stating that gaze behavior alone does not reflect the subject's allocation of cognitive resources or "cognitive load" (Alnaes et al., 2014).

With the addition of background information provided by pupillometry studies, it is reasonable to predict that pupil size will further inform researchers on how participants are affected by different AAC design elements based on physical and quantifiable changes in physiology (Laeng et al., 2012). In this study we asked how pupil size is influenced by the cognitive load associated with different AAC designs. We predicted that the display design which induces the smallest pupil size in subjects with Down syndrome will be the most optimal AAC display design due to the reduced amount of cognitive load imposed upon the subject during AAC use.

Chapter 2

Methods

Participants

Nine participants with Down syndrome were recruited for this study after approval from the Institutional Review Board. Participants were recruited through a contact list from previous studies with the Wilkinson Lab. All communications were conducted via email or over the phone with the participant's legal guardian by the Principle Investigator. If the participant was interested in partaking in the study, the Principle Investigator scheduled a date and time to participate. Before beginning the study, each participant was informed of the procedures and asked to sign the consent form. No participant was allowed to participate until they signed or co-signed the consent form with their legal guardian.

Participants' vocabulary was assessed with the Peabody Picture Vocabulary Test – Fourth Edition (Dunn, & Dunn, 2006). Table 1 displays participant information listing gender, chronological age (years), PPVT-IV Standard Score, and PVVT-IV AE (years; months). Participants were tested by clinicians or trained professionals

Although the mean chronological age was 24 years, participants' mean age equivalent score was 6;8 (years;months). The mean standard score was 49 (range = 20-74), indicating vocabulary deficits that ranged from mild to severe. All of the participants were successfully calibrated to the eye tracking technology.

Table 1: Participant Characteristics

Code	Gender	CA in years	PPVT-IV Standard Score	PPVT-IV AE (years; months)	Calibrated
S1	F	24	64	9;1	Yes
S2	M	17	52	4;1	Yes
S3	M	24	58	8;3	Yes
S4	F	26	74	8;4	Yes
S5	F	22	50	7;2	Yes
S6	F	28	55	7;0	Yes
S7	M	35	43	6;7	Yes
S8	F	20	20	2;9	Yes
S9	M	22	22	N/A	Yes

Note: Code = Participant identification code; CA = chronological age; PPVT-IV=Peabody Picture Vocabulary Test-4th Edition; AE=age equivalence.

General Procedure

Each participant wore Tobii eye tracking goggles during the study. The goggles included one wide-angle and four individual eye cameras to detect real-time pupillometry data (Tobii Pro, 2015). Before use, participants were calibrated to the goggles. To calibrate, the participants fixed their sight on a specific position (a dot on the wall) in order for the glasses to synchronize the data collection to the point of the participant's gaze.

The first five participants who underwent the study were pilot participants. Based on observations from initial participants, two adjustments were made, one to the technology used and the other to the script. The three initial pilot participants utilized a Mac desktop computer accessed via a computer mouse, while the remaining six accessed the storybook and AAC display images via a Windows touch screen tablet, pictured in Figure 1. The change from a mouse-based interaction was due to the observed difficulties participants had controlling the mouse/cursor. This adjustment also made the study more realistic based on how many AAC displays are accessed via touch-screen tablets.

In regards to the script change, the first script was tightly controlled with rigid open-ended questions that sounded more “test” like than conversational. Initial videos displayed unnatural conversation that did not align with the goal of designing AAC devices used for natural, typical, and diverse forms of communication. Therefore, the research team made three changes to the script in order to foster more natural communication between the participant and research assistant. The three changes included, adjusting the verbiage, types of questions asked, and incorporation of modeling by the research assistant. The research team opted to include the data from the three pilot and six following participants in the study.

Five participants underwent the pilot (initial) script and technology. After the change was made, seven participants underwent the new script (three of these had also served as pilot participants). In order to characterize all of the data, data are first reported for the total nine participants (across both scripts) and then separately for the initial five who underwent the first script and the seven who underwent the second script.

Storybook Reading

After calibration, each participant listened to three chapters of a selected story book along the with the trained research assistant. The story book was picked by the participant. The participant was offered four different chapters within the selected story to pick from. The goal was to always give the participant a choice. In order to randomize the selection process and balance the order in which the participants listened to a story, each participant was assigned to an initial condition via a Latin Square design. Therefore, the condition of the participant’s first chapter would be predetermined regardless of which chapter was selected first. By doing this, the study aimed to randomize the order in which the participants viewed each condition. During the trial, the eye tracking goggles recorded visual gaze and pupil size data during each frame.

Throughout the study a trained research assistant sat next to the participant and played the role of the communication partner. As the story progressed, the communication partner would read off a pre-written script which consisted of comments, questions, and acts of modeling. The participant was given the opportunity to interact with the 16-symbol display throughout the duration of the study. The communication partner would also pause and allow for the participant to interact with them or the display images after each chapter of the story was complete. If the participant chose to click or tap on a display image, the associated, pre-recorded noise would play. Once completed, the data from each subject was analyzed via Tobi software which allowed researchers to observe the participant's real time change in pupil size.

Storybook & AAC Components

The story book images were obtained from three Disney Movies: Beauty in the Beast (live action), Toy Story (cartoon), and Star Wars (live action). The story book images were picked based on participant age and general popularity of the films in order ensure appropriate themes and interest. The AAC display images were obtained from the Mayer-Johnson Board Maker Picture Communication Symbols (PCS; Mayer-Johnson, 1992) and were selected for the study based on their relevance to the characters and topics of the selected story and included chapters. For the participants who used the Mac desktop, a speaker was also provided so the participant could hear the pre-programmed verbiage or associated sounds when AAC display images were selected.

Figure 1: Windows Tablet

Experimental Conditions

Each subject participated in three conditions. Two out of the three conditions were experimental, while the third was considered the control or Standard of Care. The two experimental conditions included three independent variables. The first variable was the configuration of the AAC display, specifically whether the display images surround the story book image or were located adjacent to the story book image in block fashion. The second variable was integration, or whether the AAC display board was located on the same or separate device as the story book image. The third variable was the presence or absence of background color surrounding the AAC display images.

As illustrated in Figures 2, the Circular Integrated condition consisted of the AAC board and the story book image on the same device. The Integrated-Circular condition also featured the symbol array around the perimeter of the story book image, with the symbols having no background color. The Integrated Block condition, as seen in Figure 3, shows the 16-symbol display board adjacent to story book, both located on the same device with no background color for the AAC symbols. The Integrated Circular and Integrated Block condition demonstrated the difference between array configurations. Lastly, in Figure 4, the Standard of Care condition consisted of the AAC display on the Windows tablet and the story book image on a separate tablet device with AAC symbols featuring background color. The control or Standard of Care condition was present in order to demonstrate the difference between integrated and non-integrated AAC displays in addition to the presence of symbol background color.

Figure 2: Integrated Circular

Figure 3: Integrated Block

Figure 4: Standard of Care

Dependent Measure and Data Analysis

The dependent measure in this study was pupil size. After data collection, the participant pupil data from the left and the right eyes were averaged, by condition. It is important to note that the data associated with the left and right eye were not differentiated in mean calculations. There were two participants who participated in the study twice due to loss of data resulting from user error or lack of calibration. For these subjects the data was averaged between the two sessions. It also important to note that standard error was used instead of standard deviation in order to highlight overarching trends and minimize the mathematical weight of outliers.

Chapter 3

Results

Table 2 displays mean pupil size data of all participants in the study (n=9) for each condition. Generally speaking, the mean pupil sizes associated with the Integrated-Circular condition and Integrated-Block condition were both lower when compared to the Standard of Care condition for all except S9. When comparing the Integrated-Circular condition to the Integrated-Block condition, the results varied as to which condition produced the lower mean pupil size for each subject. It is important to note that two subjects, S1 and S6, participated in the study twice due to missing data. To account for the loss in data, the two subjects were asked to participate in the study again. For the conditions in which S1 and S6 participated in twice, the average of the two numbers were calculated. These calculations had minimal effects on the overall trend of the data as illustrated in Figure 5 and Figure 6.

Table 2: Summarization of average pupil size data for each participant per condition

Subject	Integrated-Circular	Integrated-Block	Standard of Care
S1	3.70	3.62	3.91
S2	3.74	3.99	3.69
S3	4.19	4.36	4.26
S4	3.55	3.66	3.68
S5	2.76	2.76	3.03
S6	3.17	2.31	3.33
S7	3.62	3.62	4.02
S8	3.34	3.28	3.44
S9	4.30	4.13	4.27

Figure 5 displays the mean pupil size among the nine participants according to each condition. The average pupil size for Standard of Care condition was 3.70. The average for the Integrated-Block condition was 3.64. Lastly, the average for the Integrated-Circular condition was 3.66. From these data, an overall decreasing trend in pupil size can be observed in Figure 5 when analyzing the participants using an AAC display configured in the Standard of Care display design, to utilizing a device configured in the integrated-circular display design. S9 had the largest pupil size out of the nine participants. The pupil size of S9's Standard of Care condition was also smaller than their Integrated-Block Condition. This trend was the opposite to what was observed in the eight other subjects included in Figure 5's analyses. In order to account for the large difference in pupil size between S9 and the rest of the subjects, standard error was calculated instead of standard deviation. Standard error can be observed via the error bars located in Figure 5.

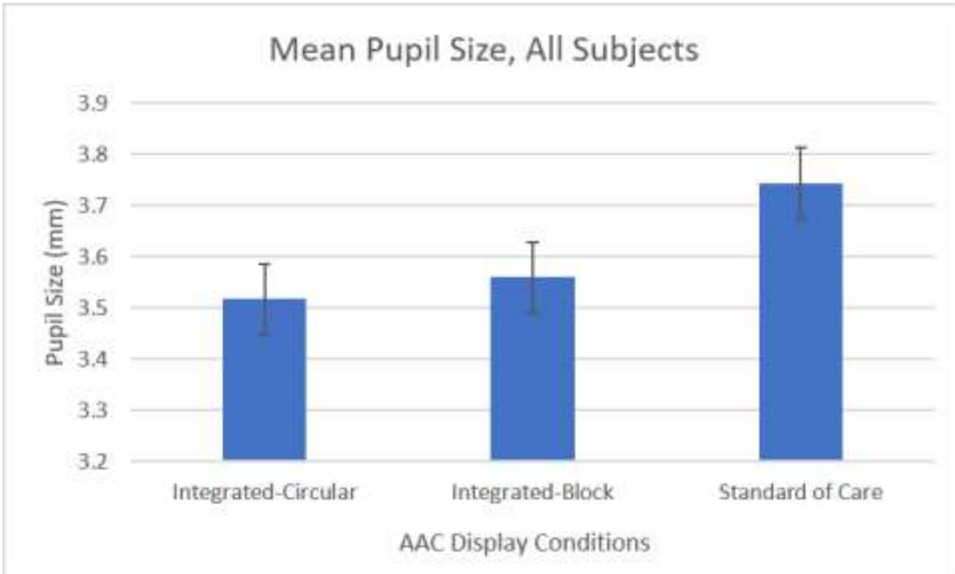

Figure 5: Summarized average pupil size data per condition

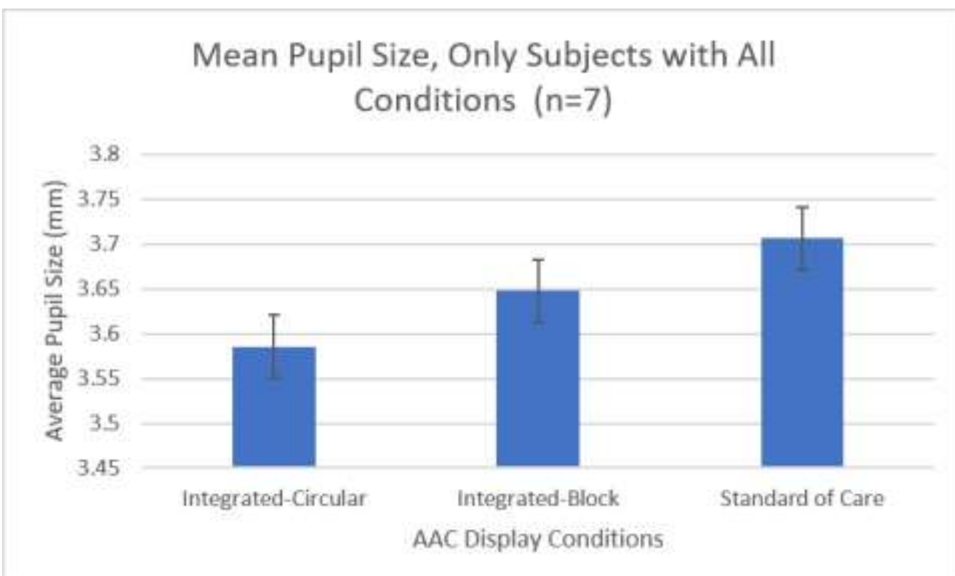

Figure 6: Summarized average pupil size data per condition of subjects without averaged data (n=7)

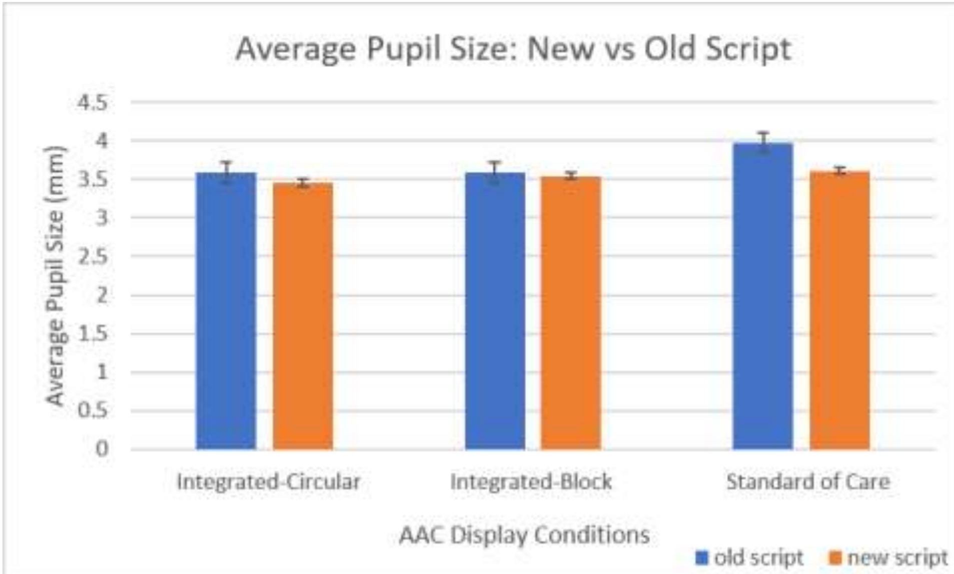

Figure 7: The difference in average pupil size between participants who completed the study with the new script vs the pilot script.

Figure 7 compares the average pupil size data of the pilot script which was utilized for participants S1, S3, S4, S5, and S6, with the new script which was utilized for participants S1, S2, S4, S6, S7, S8, S9. It is important to note that participants S1, S4, and S6, participated in the study twice, under the pilot and new script. From the graphs it can be observed that there are few differences between the average pupil size of the participants who completed the study with the pilot vs the new script.

Chapter 4

Discussion

The goal of this study was to contribute to the improvement of AAC display design in order to provide more effective AAC interventions for individuals with Down syndrome. The current study used pupil size to learn more about the cognitive load associated with different AAC designs. Our research was the first of its kind to investigate and quantify the physiological effects of AAC display design on individuals with Down syndrome using mobile eye tracking technology. Additionally, this study was the first to observe how these physiological effects corresponded to the cognitive load associated with variations in AAC display design.

The pupillometry data showed differences in mean pupil size between conditions. The largest mean pupil size was in the Standard of Care condition; while, the Integrated-Circular design corresponded to the smallest mean pupil size. This suggests that the Standard of Care condition exerts greater cognitive load in comparison to the Integrated-Circular condition (Alnaes et al., 2014). In addition, it appears that the Integrated-Block design induces a medium degree of cognitive load in relation to the Standard of Care and Integrated-Circular condition. Lastly, it is important to note that the presence of additional modeling, via the edited script, did not appear to influence the mean pupil size data as observed in Figure 7. The lack of effect modeling had on the results may prompt the further investigation to determine modeling's influence on AAC usability.

Overall, the results of this study support the notion that current AAC display designs are not optimally designed. To improve current designs, the data suggests integrating the AAC display board with the designated activity (story book) as a possible method to reduce the amount of effort or cognitive load induced. The results of this study also suggested that AAC display design matters not only in laboratory but in social situations as well. The latter outcome is of the upmost clinical importance due to the field's effort to make AAC display design more effective and applicable in a variety of social situations.

By using pupil size, this study revealed how individuals with Down syndrome are physiologically affected by different AAC display designs. Pupil size is an objective, noninvasive variable used to examine neural parameters such as cognitive load. The implications of this study show the importance of what this simple measurement can record and explain from a cognitive neuroscience perspective. This study also showcased the change in physiological response which can be induced by varying visual configurations. These observations offer greater insight into how individuals with Down syndrome process visual information. Therefore, it is important that future studies to continue to investigate what changes in pupil size reflect from a cognitive and physiological perspective.

This study was limited by sample size. Even though the Standard of Care condition showed large numerical difference from the Integrated-Circular condition, an increased sample size would have provided additional support for observed trends. Another notable limitation, was the presence of strabismus in four participants, which may have affected the level of calibration and accuracy of data collected. An additional limitation was the change in script. It was noted in the methods that five out of the nine participants interacted with the pilot script that was later improved to mirror more realistic conversation. The change created an inconsistency in the procedure between the nine participants. However, Figure 7 shows no major differences in mean pupil size for any of the conditions due to the change in script. Similarly, at this time researchers transitioned the story display device from a Mac computer to a Windows tablet due to participant difficulties of controlling the mouse. The change in story display device, in addition to the changing independent variable, creates a possibility for confounding variables. Therefore, it will take additional experimentation to more precisely determine the effects of changing the story display device in relation to the two experimental conditions and the Standard of Care control.

In the future, it may be possible to customize AAC displays based on how information is specifically perceived and processed in the brain. Customization is a milestone which would bring research, clinical, and medical communities one step closer to our goal of best meeting all communication needs of individuals with Down syndrome (Shane et al., 2012; Giesbrecht, 2013).

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ACADEMIC VITA

Jessica Saganowich

Pennsylvania State University, University Park, PA
B.S. in Biology – Vertebrate Physiology: Minor in Hearing & Deaf Studies
Schreyer Honors College Class of 2020

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