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Designing and Evaluating Alternative Channels: Visualizing Nonverbal Communication through AR and VR Systems for People with Autism

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Designing and Evaluating Alternative Channels:
Visualizing Nonverbal Communication through AR and VR Systems for People with Autism

DISSERTATION

submitted in partial satisfaction of the requirements
for the degree of

DOCTOR OF PHILOSOPHY

in Informatics

by

LouAnne Erin Boyd

Dissertation Committee:
Professor Gillian R. Hayes, Chair
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2018

DEDICATION

To my family:

Chris, you are my sky.

Alex, you are my sun.

Natalie, you are my moon.

You mean the world to me.

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ABSTRACT OF THE DISSERTATION

Designing and Evaluating Alternative Channels:
Visualizing Nonverbal Communication through AR and VR Systems for People with Autism

By

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Doctor of Philosophy in Informatics

University of California, Irvine, 2018

Professor Gillian R. Hayes, Chair

Social communication is one of the key components of successful interaction. People with autism can have significant challenges with social communication, resulting in some of the highest rates of depression and anxiety. In fact, young adults with autism have suicide rates that are 28 times higher than the general population. Thus, supporting social skills of people with autism could have a positive impact on both the social and mental wellbeing of individuals with autism. Although much research has focused on supporting social skills broadly, little attention has been paid to developing effective nonverbal behaviors, which are necessary to initiate, maintain, and gracefully terminate a social interaction.

The aim of the dissertation work is to design and evaluate the effect of realtime visualizations of prosody and proximity. To this end, the research questions are: 1. Does visualizing nonverbal behavior increase the percent of intervals users demonstrate normative proximity and prosody during neurodiverse interactions, and 2. What factors surrounding technological social skills intervention impact its efficacy and acceptance?

These research questions are answered through three lab-based experiments that include measuring prosody and proximity in controlled and experimental conditions, as well as interviewing the participants and family members about their experience with these novel technologies.

By using sensory perceptual strength associated with an autistic profile, (i.e., superior visual perception regarding details), I have designed and evaluated three technological systems to assist people with autism to engage in socially expected behavior during a brief conversation in a laboratory setting. The single-case experiments show that visualizations of real time feedback improve nonverbal communication during social interactions for close to half of the participants (i.e., young adults and children with autism). The results from the interviews with participants and parents about their experiences highlight issues of usability, learnability, and comfortability of the systems. Deeper analysis of these combined findings culminates in an assistive technology design concept-Sensory Accommodation Framework-which provides four strategies for supporting sensory perception differences through computation. The contributions to this work are: the empirical findings from the three evaluation studies, the design guidelines from the design activities, and the conceptual framework.

INTRODUCTION

She said, "Would you mind if I made of your book into an app?" That is when it began—my journey to pursue a PhD in informatics. Dr. Monica Tentori had come to a 3-hour overview I conducted for special educators on how to implement my social skills program. In just three hours she had listened to concepts that made up *The Social Compass: A Story-Based Intervention Package for Students with Autism Spectrum Disorders* (Boyd, McReynolds, & Chanin, 2013). I must admit I was flattered and skeptical. The world of innovative assistive technology was not new to me as I had acted as a community collaborator on a handful of projects with my now PhD advisor, Dr. Gillian Hayes. Dr. Hayes had suggested I invite Monica to the training as she had developed an interest in technology for children with autism, and my curriculum seemed to be a good fit. Her vision was to make the social skill concepts in my book into activities children could practice outside of classroom instruction and without the assistance of adults, to truly allow for the children to use the skills in a natural social setting, with some assistance from a mobile app. I thought then that her vision was fantastic but unrealistic. How could putting a mobile phone in front of each student actually improve their face-to-face interaction—especially for children with autism?

I wrote *The Social Compass Curriculum: A Story-Based Intervention Package for Students with Autism Spectrum Disorders* (Boyd, McReynolds, & Chanin, 2013) to fill a gap in the educational resources at the time. It follows recommendations put forth by Krasny et al. (2003), who argued that "fundamentals . . . such as nonverbal communication and affect recognition need to be practiced in a group setting." Curricula need to be based on evidence of effective practices, as well as fit into the routines of a school year. With these requirements, I wrote the 24-lesson curriculum that includes: Nonverbal Skills, Emotions, “We” Skills (*e.g.,* communication), and Social Problem Solving. Each lesson incorporates the comprehensive components outlined by (Krasny, Williams, Provencal, & Ozonoff, 2003) to include in a program. These components are: to explicitly define goals; provide visual supports; illustrate an example of a problem through a narrative; provide modeling of goal behavior; have students rehearse the skill, then role-play with less structure; provide feedback; reinforce the new learning by supporting self-monitoring; and provide a take-home letter to encourage generalization of skills. Instead of a letter to take home with direction for more practice, Monica and her team built an app with 6 steps, including multiple metaphors from the book. We ran a field study in one of the public schools for which I was an autism consultant, and the app was a huge success. That was it for me. My future changed. I saw with my own eyes, from conception through deployment, my work – an evidence-based program for schools - turn into something fantastic.

CHAPTER 1: SOCIAL SKILL INTERVENTIONS FOR AUTISM

Social communication is one of the key components to successful interaction (Baron-Cohen, 1988; Chamberlain, Kasari, & Rotheram-Fuller, 2007; Gerhardt & Lainer, 2011; Krasny et al., 2003; Reichow & Volkmar, 2010; Williams White, Keonig, & Scahill, 2006). Our ability to express our needs and wants as well as to understand others is central to our connection to one another. Poor social communication may lead to being perceived as "socially inappropriate" and thus trigger low self-esteem (Krasny et al., 2003; Williams White et al., 2006). Lastly, loneliness is a common report of adolescents with autism (Locke, Ishijima, Kasari, & London, 2010). These challenges with social communication skills put youth at risk for bullying, social isolation, and consequently, serious mental-health concerns (Gerhardt & Lainer, 2011).

People with autism can have significant challenges with social communication resulting in some of the highest rates of depression and anxiety (Ghaziuddin, Ghaziuddin, & Greden, 2002; White, Scarpa, Conner, Maddox, & Bonete, 2014). Mothers "very often" reported suicidal ideation in their children with autism (Mayes, Gorman, Hillwig-Garcia, & Syed, 2013). In fact, young adults with autism have suicide rates that are 28 times higher than the general population (Mayes et al., 2013). Thus, supporting social skills could have a positive impact on both the social and mental wellbeing of individuals with autism.

How do we support this growing population when the prevalence of autism is increasing at a rate beyond the available resources (Gerhardt & Lainer, 2011)? Intensive therapies can be effective; yet it takes an extended period of time and effort to master social skills (Gerhardt & Lainer, 2011). For example, intensive social skill training requires time, money, and highly trained professionals—all of which are scarce resources for many families. One solution to this growing concern is development of assistive technologies that can support people with autism in a variety of ways and across a variety of contexts more efficiently and cost-effectively.

In this work, I hypothesize that using reduced channels of sensory input will increase comfort, as well as the understanding and demonstration of the hidden rules of social interaction. The remainder of this first chapter reviews social skill intervention, related technologies, and a gap in the literature. I present my research questions and contributions and conclude with a synopsis of the remaining chapters.

Steps to teaching social skills

Social skill training for people with autism is taught sequentially as a series of steps that culminate in using the skills in a natural environment, with generalization to a natural context taught last (Krasny et al., 2003). These steps begin with making the skill concrete so that the learner becomes aware of a social rule. *Making the skill observable* is usually accomplished by providing many examples through which the hidden social rule becomes "visible." The next step involves *practicing the skill with immediate feedback*, and lastly putting it to use in the highly-varied opportunities that occur in day-to-day life. The last step of *generalizing social skills* to everyday interaction is the most critical step for newly mastered skills to be adopted (Krasny et al., 2003). Yet it is also the place where families and therapists are less able to provide support, as skill practice occurs outside of therapy (Gerhardt & Lainer, 2011; Williams White et al., 2006). Technology has the potential to support any of these steps, particularly the generalization of skills through automated feedback that can be provided in countless environments (Odom et al., 2014).

In addition to targeting different steps in the social skill training process (*i.e.,* making behavior observable, practicing with feedback, generalizing to natural environments), a range of social skills has been targeted in autism. Educators and behavior therapists have broken social skills into broad domains that include: recognizing emotions in the self and others, engaging in conversation and social problem solving skills (*i.e.,* coordinating, collaboration), and nonverbal skills (White et al., 2006).

Much attention has been paid in the assistive technology literature to teaching emotion recognition (Abirached et al., 2012; Indumathi et al., 2015); conversation skills (Trepagnier, Olsen, Boteler, & Bell, 2011); and collaboration (Hourcade, Bullock-Rest, & Hansen, 2012; Piper, O'Brien, Morris, & Winograd, 2006). Little attention has been paid to developing effective nonverbal behaviors, which are necessary to initiate, maintain, and gracefully terminate a social interaction. Much of social interaction is made up of the nonverbal communication that consists of both recognizing others' and using one's own body language to regulate the interaction. Nonverbal communication difficulties in autism include difficulty with: making eye contact, physically entering and standing in a group, using body language, and understanding facial expressions (Reichow & Volkmar, 2010). These behaviors add to the verbal component of face-to-face communication. Not having the skills to participate face-to-face impoverishes the opportunities to meet people. Proximity, the physical distance between people, and body orientation, the position of each body to one another, both play a role in understanding the dynamics of face-to-face interaction (Marshall, Rogers, & Pantidi, 2011). Opportunities for social relationships increase merely by being proximate to others (Rivera, Soderstrom, & Uzzi, 2010).

Related Work in Assistive Technology

Emerging technologies provide new opportunities for understanding and supporting the dynamic nature of social interactions, across a variety of contexts. Designing technology for a social context is complex. Assistive technology researchers have found that, "the domain of social interactions between adults and children poses significant new challenges, since they are inherently dyadic, loosely structured, and multi-modal," (Rehg et al., 2013). Therefore the focus of assistive technology for social communication is concerned with the "interplay between agents," interacting through multiple modes that result in the quality of engagement and reciprocity (Rehg et al., 2013).

Technological mechanisms can parallel the steps of teaching social skills by: making target skills observable, practicing with feedback, and generalizing use to real world contexts, or even combining some steps. Making skills observable has been accomplished by technology that provides repeated practice scenarios for users to explore outside of natural social interaction. In live interactions, assistive technologies have supported engagement with step-by-step cues, and automated, or manual, feedback. The related work that follows includes projects that target social skills and use technological mechanisms to support one or more steps in learning social skills.

Technology for Emotion Recognition

Recognizing emotions in conversation partners has been a persistent target of assistive technology (Abirached et al., 2012; el Kaliouby, Teeters, & Picard, 2006; Madsen, el Kaliouby, Goodwin, & Picard, 2008; Voss et al., 2016). Computer-based programs teach children with autism to process emotions of the face through digital games on 2D screens (Abirached et al., 2012). Recently, teaching emotion recognition has expanded to wearable systems that allow for real-time learning. Leveraging the affordances of head mounted displays in the context of spontaneous physical world interactions, technology addresses the challenge of understanding the emotions of others for children with autism by *making behavior observable through visualizations*. Multi-device systems to monitor the emotions of others in natural environments use cameras and computation to track, analyze, and "intuitively present various interpretations of the facial-head movements" of a teen's social environment (Madsen et al., 2008). Projects like these *generalize* the wearer's understanding of others' emotions "just in time" to reflect and take action (el Kaliouby et al., 2006; Madsen et al., 2008). More recently, single devices such as head mounted displays that both utilize the camera to detect the facial expression of others and display a simply visualization to the wearer (*i.e.,* emoticon of emotion that was recognized on the face of another) have proven effective for families with young children with autism (Voss et al., 2016; Washington et al., 2016).

Robots also offer the ability to manipulate the environment and adapt to the user. Robots offer both "human-like social cues" and "object-like simplicity" in a face-to-face interaction where the expression of emotions can be manipulated to support the understanding of facial expressions and gestures, thus extending *practice with feedback (*Thill, Pop, Belpaeme, Ziemke, & Vanderborght, 2012; Wainer, 2012)*.* Collaborative virtual environments have been shown to improve children with autism's recognition of emotions of avatars, also extending methods for *practice with feedback* (Cheng & Ye, 2010).

Technology for Communication and Coordination

Assistive technology projects dedicated to communication have focused on groupware as a platform to target collaboration and communication. Groupware allows for group behavior to be distributed across members. A number of projects have used the innovation of multi-touch screens to afford and constrain turn taking in order to equalize the participation of group members. Projects using multi touch tabletops and touchscreen tablets leverage the co-location of participants as the close proximity creates a social context (Boyd et al., 2015; Gal et al., 2009; Giusti, Zancanaro, Gal, & Weiss, 2011; Hourcade et al., 2012; Piper et al., 2006). These studies address the skill of collaboration by employing “cooperative gestures” (Morris, Huang, Paepcke, & Winograd, 2006) that constrain interactions in such a way to foster collaboration such as turn taking (Boyd et al., 2015; Gal et al., 2009; Giusti et al., 2011; Piper et al., 2006). Turn-taking has also been explored using robots (Wainer, Dautenhahn, Robins, & Amirabdollahian, 2010; Wainer, 2012); thus the user is *practicing social skills with feedback* during therapy sessions.

An additional way to conduct group therapy is using virtual reality. In virtual reality projects, conversation skills have been addressed for general social graces such as saying “please” and “thank you” in single user virtual reality systems (Parsons et al., 2006) and greeting others (Trepagnier et al., 2011). The work by Tartaro et al., 2014 targets turn-taking in the conversations that occur through collaborative virtual reality systems (Tartaro et al., 2014). In Tartaro et al.’s 2014 work, the user authors her own interaction with a virtual peer in a 2D virtual environment on a desktop computer. By giving the student “the ability to construct their own understanding of skills by building those skills into a virtual peer,” the authors aim to expand the methods of practicing reciprocal interactions (Tartaro, Cassell, Ratz, Lira, & Nanclares-Nogués, 2014). Reciprocity is targeted in the conversations that occur through collaborative virtual reality systems

(Moore, Cheng, McGrath, & Powell, 2005; Tartaro et al., 2014). These works demonstrate that 2D VR is a viable platform for extending practice of social communication.

The newest type of VR system creates a 3D space the size of a room so that a user can move through their physical space (approximately 8 feet by 8 feet) while tethered to a headset that displays a virtual environment that is tracking their movement and changing the virtual environment to be in sync with their actions. Multiple players can occupy this virtual space and interact with one another in realtime, opening new opportunities for teaching social skills.

Technology for Nonverbal Communication

Nonverbal skills are a subset of a broad category of social skills that are critical for communication and an important target for intervention (Mundy, Sigman, Ungerer, & Sherman, 1986). Nonverbal communication begins as soon as a person approaches another, makes eye contact, positions their body in relation to others, and continues as one speaks and listens. These subtle behaviors occur over very short time periods (0-3 seconds) that result in ongoing micro-interactions. These behaviors come together to convey intention. One's tone of voice, use of gestures, and body language all convey messages about the intentions of the people in the interaction. Nonverbal skills are described in the behavioral literature as invisible or hidden to some people with autism (Myles, Trautman, & Schelvan, 2004a). One way to make a nonverbal communication *observable* is through realtime visualizations of nonverbal communication so that a person who is struggling due to confusing information can see that information represented as a visual image as the interaction is occurring. This visual information can be delivered in near real time, thus providing information during an interaction so it is actionable.

Lastly, eye gaze is another common target for assistive technologies, with projects focusing on joint attention. Joint attention is when two people visually attend to the same object or event at the same time. Alcorn's work leverages virtual characters whose cues require the users to attend to the virtual character's nonverbal behavior to complete an interaction (Alcorn et al., 2011). Alcorn et al found that children with autism could follow a 2D virtual character's gaze or gaze plus gesture, opening up virtual environments as effective places for social skill support.

My work builds on the literature reviewed in the previous sections by using sensor technology. Designing and evaluating innovative technology for these under-researched nonverbal communication skills are the focus of my work. With newer technologies, such as 3D VR, multiple nonverbal behaviors could simultaneously be captured and displayed in real time, thus allowing the user to move through space, be monitored, and mediate an interaction in a virtual environment through realtime visualizations.

Introduction to Nonverbal skills: Prosody and Proximity

Because prosody and proximity are the primary behaviors of interest in my work, I briefly define and describe each here. Prosody includes the rhythm and sounds in speech and refers to the acoustic way words are spoken to convey meaning through changes in pitch, volume, and rate of speech. Atypical prosody is one of the most noticeable characteristics of autism (Kanner, 1943)—making speakers inadvertently sound angry, bored, or tired. It is also one of the most difficult social skills to change over a lifetime, often requiring intensive and extensive intervention (Diehl & Paul, 2009a; Lindgren & Doobay, 2011). A few projects have detected atypical prosody for early detection of an autism diagnosis (Brosh et al., 2013) and as a speech therapy support (Simmons, Paul, & Shic, 2014). I apply sensor data to a wearable system to explore the impact visualizations of prosody have on the user's use of prosody.

In this work, I also explore proximity. Proximity regulation is the ability to sense and respond to the physical distance between individuals (Gatica-Perez, 2009; Kennedy, Constantino, & Adolphs, 2010; Kennedy & Adolphs, 2014). Proximity regulation is critical for successful social interaction, as its disregulation can lead to personal space violations (and ensuing feelings of discomfort), as well as the inadvertent miscommunication of social intentions (*e.g.,* aggression, defensiveness, social interest or disinterest, etc.) (Hall et al., 1968; Hall, 1966)

Thesis Statement

Visualizations of real time feedback improve nonverbal communication for people with autism during social interactions.

Research Questions and Mapping to Data

RQ1: Does visualizing nonverbal behavior increase the percent of intervals users demonstrate normative proximity and prosody during neurodiverse interactions?

Approach: To answer this question, I use quantitative data from my experiments with AR and VR systems for proximity and prosody (*i.e.,* sayWAT, ProCom, and vrSocial)

RQ2: What factors surrounding a technological social skills intervention impact its efficacy and acceptance?

Approach: I use the qualitative survey data from my AR and VR work. This includes parent and volunteer reports of perception of proximity from the Procom study and the quality of the conversation reported by participants in the sayWAT study. Additionally, I support my findings with survey and interview data from users from all three studies.

Contributions of Dissertation

This body of work provides evidence of the effectiveness of visualizations on nonverbal communication through experimental studies of Augmented Reality and Virtual Reality systems. The Sensory Accommodation Framework is presented that provides design implications for supporting neurodiverse people through the use of technology. Additionally, through empirical investigations, this work deepens our understanding of how design impacts the quality of social interactions for people with autism.

Summary of the Following Chapters

In the second chapter I provide background related to the social skills I have centered this work around-proximity and prosody. I provide perspectives from anthropology as well as clinical perspectives to explain the variations in sensory processing that has been described in autism, and I apply these theories to my practice of design and development.

In chapter 3, I review the details of the design and development of my three assistive technologies (sayWAT, ProCom, and vrSocial). This chapter includes the multiple phases of the design process. In the first section, I discuss how I elicited the user requirements, then how I operationalized these requirements, and finally how these requirements were translated into interface designs.

In chapter 4, I provide an overview of the evaluation methods I employed, single case experimental design with visual analysis. I discuss the rationale for each study's implementation of alternating treatment design. In this chapter, I also provide details of the surveys and interviews I conducted for each study.

In chapter 5, 6, and 7, I provide the evaluation results for each variable (*i.e.,* pitch, volume, proximity) in session by session data for each participant across the three studies.

I explain each case in terms of the data trends and stability, and I draw conclusions as to the effectiveness of the tools as interventions.

In chapter 8, I reflect on the feasibility results across the three works, paying particular attention to the strengths and weakness of each platform (AR and VR) as it relates to supporting the targeted behaviors. This chapter concludes with design strategies related to using visualizations to assist with access to nonverbal communication.

In chapter 9, the discussion, I reflect on the entirety of the work and discuss in more detail how this work contributes to the knowledge of users of assistive technology as it relates to a new concept—the Sensory Accommodation Framework.

CHAPTER 2: BACKGROUND

A wide variety of nonverbal social behaviors are important to socialization, such as head nodding, making eye contact, gesturing, monitoring proximity, and touch (Hargie, Saunders, & Dickson, 1994). Nonverbal communication has been shown to convey over 90% of all face-to-face communication with 55% made up of gestures, 38% voice inflection, and 7% word meaning (Knapp, Hall, & Horgan, 2013). These social behaviors tend to be underrepresented in the intervention literature, perhaps because they can be more difficult to quantify and are less well-understood from a neurobiological perspective. In this work, I tackle two nonverbal communication issues as they relate to autism: proximity regulation, which is the ability to sense and respond to the physical distance between individuals (Gatica-Perez, 2009; Kennedy et al., 2010; Kennedy & Adolphs, 2014) and prosody, which is the way voice conveys meaning beyond the meaning of the words (*i.e.,* tone of voice)(Diehl & Paul, 2009a; Paul, Augustyn, Klin, & Volkmar, 2005).

This chapter is divided into three parts. In Part 1, I discuss nonverbal communication from the perspective of the field of anthropology and how the cues revealed by nonverbal communication transcend cultural differences; then in Part 2, I discuss the sensory differences in autism that disrupt the communication intent of these universal cues. I provide a rich description of the nonverbal behaviors of interest in this work—volume and pitch and proximity— as they impact people living with autism in terms of their neurological basis. In Part 3, I discuss my insight into how to address nonverbal communication through technology, employing a strength-based intervention to support nonverbal communication through dynamic visualizations.

Part 1: Universality of Nonverbal Communication

Nonverbal communication has been the focus of anthropologists who in the late 1960s-early 70's became interested in the persistence of communication patterns across cultures (Hall et al., 1968; Hall, 1966; Mehrabian, 1968, 1971). From these canonical works sprang the idea that nonverbal communication has some universal foundation. Researchers debated if and how people of all cultures could appear similar in terms of the use of foundational nonverbal communication. They discovered commonalities in the neurology related to facial muscle patterns as they relate to discrete emotions (Ekman & Friesen, 1971). These anthropologists acknowledge that cultures do prescribe their own unique practices regarding how to manage one's behavior in response to these biological responses. The result is different customs to minimize or exaggerate these behaviors, but the underlying behaviors are hard wired. Mehrabian describes nonverbal communication through a series of metaphors of the types of understandings communicated through nonverbal means (Mehrabian, 1971):

> *Our consideration of the underlying metaphors shows that the descriptions of nonverbal behavior need not be physicalistic and arbitrary. Despite the absence of dictionaries and grammar for nonverbal behavior, there is a consensus among the people of one culture and even people of different culture (Ekman & Friesen, 1971) as to how they translate their feelings into behaviors or in infer other people's feelings from other's behaviors. This consensus supports our thesis that the codes are based on interested and universal metaphors that are basic parts of human experience*

Nonverbal communication is cues about the status of the interaction: "cues of like and comfort as well as dislike and discomfort (like, power, status, dominance)" are transmitted in the silent messages' content in nonverbal behavior (Mehrabian, 1971). More than cues to focus a listener or emphasize a point, nonverbal communication can be employed to completely change the meaning of spoken words, such as in the case of conveying irony though one's tone of voice. Additionally, emotional messages conveyed with nonverbal communication relate to how we feel about the person we are talking with face-to-face. Mehrabian (Mehrabian, 1971) concluded that nonverbal communication outweighs the importance of words and that when we are conveying the degree to which we like someone our facial expressions (55%) have the greatest impact on the meaning of a message with tone of voice next (30%), followed by the words (7%). Thus, living with nonverbal communication challenges can impact the ability to make and maintain social relationships. Mehrabian describes the impact of having challenges with nonverbal behavior when he discusses: "the nonverbally handicapped—often the difficulty here is fear of not knowing how the other feels about them resulting in negative behaviors on their part," (Mehrabian, 1971). Mehrabian also describes therapies to desensitize people to feeling tense when meeting strangers—an early behavioral attempt to address the diversity of human experiences so that people with difficulties can benefit from the silent signals that support relationships.

It is these "silent signals"(Mehrabian, 1971; Myles et al., 2004a) that I wish to highlight for people with autism. Autistic people can be marginalized because they may not be processing other's universal signals in an expected way. Because nonverbal communication makes up a large amount of the communication in face-to-face interactions, it could be helpful to use technology to translate some of the nonverbal communication to a user. By highlighting otherwise hidden information, social relationships for those with autism could improve—therefore improving one's quality of life. Given anthropologists and speech pathologists alike (Knapp et al., 2013; Mehrabian, 1971) proportion 55% of a message meaning to body language, and 30% to tone of voice, I have targeted a skill from each component that contributes: proximity and prosody.

Defining Proximity

Proximity is a basic spatial requirement of humans to mediate behavior, communication, and social interaction (Perry, Nichiporuk, & Knight, 2015). In general, proximity includes two concepts: personal proximity and social proximity. Personal proximity, often referenced as personal space, travels with each individual everywhere they go and may expand or contract depending on context. Usually only people with an intimate relationship to the person enter this zone. Social proximity is the space that is maintained by people engaging in a social interaction.

There are well established metrics regarding proximity, or "personal interaction bubbles," in which space is divided into four parts: intimate space, personal space, social space, and public space (Hall, 1963). Estimating the appropriate proximity to stand from someone is a complex and dynamic social judgment (Hall et al., 1968; Kennedy et al., 2010; Kennedy & Adolphs, 2014; Monge, Rothman, Eisenberg, Miller, & Kirste, 1985). The expression of this skill depends on many factors, such as age, gender, emotions, culture, and the relationship between the people in the interaction. Despite the complex reasoning required, most people naturally learn where to stand during social interactions (Hall et al., 1968; Hall, 1966; Kiesler & Cummings, 2002; Monge & Kirste, 1980; Monge et al., 1985) by the age of five (Lomranz, Shapira, Choresh, & Gilat, 1975). However, for people with autism, this may not be automatic (Kennedy & Adolphs, 2014; Perry et al., 2015), leading them to act in ways that are unexpected by others (Garfin & Lord, 1986). These unexpected behaviors can make people feel uncomfortable, and result in limited opportunities to make and maintain relationships (Gessaroli, Santelli, Pellegrino, & Frassinetti, 2013).

Defining Prosody

Prosody includes the rhythm and sounds in speech and refers to the acoustic way words are spoken to convey meaning through changes in pitch, volume, and rate of speech--to name just a few of the dimensions. Prosody helps people understand the meaning of spoken words. For example, when using sarcasm, the words being spoken do not match their meaning. In this example, prosody helps people understand that the speaker is not being sincere. An understanding of sarcasm and irony typically emerges around six years old, with the intentions of the speaker not understood until later in middle childhood (Glenwright & Pexman, 2010). Contextual cues and strong intonational cues (lower pitch, longer tempo, greater intensity (Rockwell, 2000)) support children in learning when a phrase is ironic (Wang, Lee, Sigman, & Dapretto, 2006). The qualities of voice contribute to the emotion state of the speaker.

> *"During speech communication, listeners attend to changes in pitch, loudness, rhythm, and voice quality (emotional prosody) to form an impression about the speaker's emotion state in conjunction with linguistic decoding"(Wilson & Wharton, 2006).*

I selected two of the many dimensions of prosody for this work: volume and pitch. Volume, measured in Hertz, refers to the magnitude of the sound (loud or soft). Pitch, measured in decibels, refers to the frequency of the sound (high or low). These dimensions can be measured with sensors and analyzed with free software such as *Praat*[1]. Because these measures yield a continuous measure through discrete numbers, I chose volume and

[1] Praat is a free software and can be found at the link: www.fon.uva.nl/praat.

pitch over other dimensions of prosody such as timbre (spectrum describing quality of the sound) and tempo (rate of the sounds and pauses between sounds). I explore if these dimensions are interpretable and actionable through visualizations in realtime.

Part 2: Neurodiversity drives the need for Nonverbal Communication Interventions

Not all people can access the hidden messages conveyed through nonverbal communication. People with autism have differences in sensory processing, making interpreting the universal patterns associated with emotional states a difficult task. Sensory processing differences in autism may impact virtual every sensory channel such as visual (sight), auditory (sound), vestibular (movement/orientation in space), olfactory (smell), proprioceptive or tactile (pressure/touch), and interception (body awareness/pain). These differences have been characterized in autism as either an over or under sensitivity, also referred to as hypersensitivity or hyposensitivity (Myles et al., 2004a; Sánchez, Vázquez, & Serrano, 2011).

Visual Processing

Visual processing is complex. There are many dimensions to what is processed visually. While researchers have identified typical scores in visual processing for children with autism, they find that visual attention may not be on the expected object (e.g., "enjoys looking at visual details in objects, watches people as they move around a room" (Little, Dean, Tomchek, & Dunn, 2017)). Other studies have suggested that visual processing is a strength in autism (Baron-Cohen, Ashwin, Ashwin, Tavassoli, & Chakrabarti, 2009), leading educators and therapists to use the visual channel to augment learning environments for children with autism with visual supports (Little et al., 2017).

Auditory Processing

Children with autism have demonstrated a hypersensitivity to sound as compared to typically developing children in the auditory domain, as "auditory processing items primarily reflect sensitivity (*i.e.,* 'Is distracted when there is a lot of noise around', 'Holds hands over ears to protect them from sound')" (Little et al., 2017). Therefore, it is crucial to minimize distracting noises and reduce the number of verbal cues for an individual with autism who has difficulties with auditory processing. Additionally, Sánchez et al. (2011) argue that individuals with auditory processing difficulties may struggle to comprehend their environment due to noise and verbal demands. These individuals then must rely heavily on their other senses, such as their visual and tactile sensory systems to understand their environment.

Pain channel/Introception

This sensory system related to pain perception has been flagged as hypo or hyper sensitive for some people with autism. In the case of hyposensitivity, a person with autism can get hurt from not feeling the sensation of pain, for example "a child –or an adult– with autism may suffer from severe burns if he washes his hands or has a shower with water at high temperature, as he will not pull away" (Sánchez et al., 2011). In the case of hypersensitivity to internal indications, researchers hypothesize that "heightened attention to internal cues may lead to decreased attention to external stimuli, which provides a putative link between decreased social interaction and repetitive patterns of behavior that directs the focus of attention inward" (Schauder, Mash, Bryant, & Cascio, 2015). Therefore, focusing the user's attention to sensory input originating from outside one's body needs to occur before someone can process the information.

Fear and anxiety has been attributed to the large distance that some people with neurodiversity maintain between themselves and people with whom they are not familiar. Additional difficulties interpreting interpersonal space in people with autism have also resulted in people standing within other peoples' personal space (Gessaroli et al., 2013). This duality in presentation for people with autism (*e.g.,* both too far and too close) demands that interventionists take into account the various combinations of sensory profiles that need to be accommodated. On top of this need for individualization is the challenge of processing multichannel input.

Tactile/Proprioception

The sense of touch is a powerful modality in learning about one's environment. The tactile system responds to the sense of touch, pressure, texture, temperature, and pain. Touch receptors are located in the skin. Individuals with autism may have a heightened sense of touch which can lead to the avoidance of touching objects or people. A tactile modality found to be successful in learning is the use of a haptic device. An example of an input/output device is a joystick or haptic gloves. These types of haptic devices are used for individuals with tactile hyposensitivity that may need more physical contact between themselves and the computer (Jeffs, 2010).

The use of a haptic device is also beneficial for individuals with proprioception issues. Proprioception is body awareness. Individuals with sensory difficulties in this area may lack awareness of certain body parts and how those parts move. Proprioception is located within the muscles and joints and is activated when the muscle contracts (Myles, 2000).

Olfactory (Smell) and Vestibular (Balance)

The olfactory system provides information to the brain about the smells in the environment. This powerful system can trigger memories and allows individuals to embed learning through the sense of smell. Chemical receptors are located in the nasal structure and react to the smells in the environment and can be under sensitive in autism (Myles, 2000; Robertson & Baron-Cohen, 2017). By contrast, individuals with hypersensitivity to smell (*i.e.,* perfume) may not be able to participate in everyday outside activities, and VR may be a necessary tool for learning in a contained environment.

The vestibular system is another component of the sensory system that provides a sense of balance. This system "provides information about where our body is in space, and whether or not we or our surroundings are moving. The vestibular system also informs the body about speed and direction of movement,"(Myles, 2000).This system is regulated by the inner ear and it is "stimulated by head movements and input from other senses," (Myles, 2000).

Temporal Processing

Temporal processing is the perception of time and impacts perception of multiple channels. An example of temporal processing in autism is the rate with which one processes auditory information. Temporal processing in autism has been described as altered in that "individuals with autism demonstrate an elongated window of audio-visual temporal binding: relative to control individuals, they are less able to discern the presentation of a tone and a flash at close temporal offsets and more likely to perceive asynchronous events as synchronous" (Robertson & Baron-Cohen, 2017). This means that the processing of global information may take longer for people with autism.

Multichannel Processing

In addition to single channel sensitivities, integrating information received through multiple channels can be burdensome (Foss-Feig et al., 2010; Sánchez et al., 2011). Combining sensory information from visual and auditory channels "is fundamental to language perception, as it facilitates the integration of vocal and facial cues (Kuhl & Meltzoff, 1982)."

Researchers hypothesize that children with autism engage in channel switching when they need to reduce the overload from multiple channels—such as "using visual processing, versus auditory, as a strategy to engage with their environments" (Little et al., 2017). Another processing phenomenon found in autism is the preferential attention to local information (*i.e.,* the details of a leaf) over global information (the overall concept of a forest). This has been reported in the processing of specific types of stimuli, thus complicating the sensory profile as one of hyper- or hypo-sensitivity (Robertson & Baron-Cohen, 2017). This local bias or overselectivity has been described as *seeing the trees but not the forest* (Robertson & Baron-Cohen, 2017). This phenomenon has been illustrated in studies that show superior responding to visual information, except in the case of visual social information such as people's faces (Robertson & Baron-Cohen, 2017). Researchers have found that people with autism may have challenges processing voices and emotional states based on voice (Helene et al., 2004), while other researchers have reported the prevalence of perfect pitch in people with neurodiversity (Mottron, Dawson, Soulières, Hubert, & Burack, 2006). These complex patterns of perception add to the challenge of interpreting social interactions (Robertson & Baron-Cohen, 2017):

…dynamic sensory information is the medium of social communication: subtle fluctuations in the pitch of spoken language cue prosody, coordinated motions of the face communicate emotions and cues relevant to empathy (Bassili, 1978), and the preparatory motions of a person's body relative to other objects in the world communicate intentions and requests(Crane & Gross, 2007). Thus, a child who struggles to integrate dynamic sensory information may also struggle to build social information into meaningful representations or, alternatively, may find social information confusing and therefore self-select away from exposure or engagement with social information (Brock et al., 2012; Markram, Rinaldi, & Markram, 2007)

Therefore, using nonverbal communication is challenging for someone whose sensory system behaves differently (*e.g.,* input of social information does not register, is confusing, or is even painful). This impacts the output of nonverbal communication. Challenges in the use of prosody to convey meaning can be a major hindrance to making oneself understood by others. Atypical prosody in people with autism has been described as being "monotone" (Paul et al., 2005; Shriberg et al., 2001). A monotone voice is one that is "flat," robotic, or mechanic resulting from the narrow range in pitch along with short pauses between phrases. Speaking too softly or too loudly can also negatively impact a social interaction, as can standing too far or too close. These displays of nonverbal communication (*e.g.,* unexpected outputs, miscommunication) can result in rejection and social isolation without the person even being aware of this consequence. My solution is to provide single channel information about nonverbal communication through a strong domain—visual in a manner that conveys dynamic information in a simple way. Building on the theory of sensory processing differences in autism, as stated in my thesis statement, I hypothesize that using reduced channels will increase comfort as well as understanding and demonstration of the hidden rules of social interaction. Manipulating the channels of communication through the use of technology has existed for some time, as have several theories about computer mediated communication. What has not been addressed in the literature is the systematic manipulation of multiple modalities to support sensory processing differences for users with autism.

Part 3: Theory to Practice

In my work, I use augmented and virtual reality systems to manipulate the modalities employed to transmit social information to a user. My goal is to increase the likelihood they will engage in socially-expected behavior when they are given social information in a visualization format. Building on the theory that people with autism process visual information more easily than auditory, proprioceptive, temporal, and multichannel, I use this theory to build my interventions.

CHAPTER 3: SYSTEMS DESIGN AND DEVELOPMENT

In this chapter, I discuss the design and development process across the three systems (sayWAT, ProCom, and vrSocial). Designing the experimental systems involved several phases: defining a context, choosing target behaviors, gathering user requirements, analyzing, specifying the requirements and validating system (operationalizing variables), as well as interface design. The culmination of these steps results in three functional prototypes that I evaluated for their effectiveness, usability, and usefulness in the following chapters. This chapter describes the process I used to design and develop sayWAT, ProCom, and vrSocial. The sections move from the context I used for all three projects, how I matched target behaviors to technologies, to eliciting the requirements from one technology to the next. Each project section ends with design recommendations that drove that particular project. These guidelines are synthesized in the designing interfaces section, and this chapter concludes with a summary.

Defining the Context of Use

With the mobility of technology in this year of 2018, the context of use becomes a central consideration in design and development. Given the research questions for this work, the effectiveness of the visualization intervention in real time for single users, the three technological systems were developed to be experimental prototypes for one specific context—a brief, casual, face-to-face conversation with an acquaintance in a controlled setting.

Choosing target behaviors and technologies

In this work, I engaged in simultaneous decision-making processes about what behavior to target and what technology to utilize. I am interested in supporting social skills for people with autism, with a specific focus on nonverbal communication as it plays such a large role in face-to-face interactions. Knowing what can be accomplished from a technical standpoint impacts both the choice of technology and the scope of social interactions. With the abundance of ubiquitous computing systems available, designers can leverage sensor data to illuminate social behavior in realtime. Interested in automated and alternative forms for information newly available from sensors, I then learned about the capabilities of wearables and plotted the feasibility of the resources I had available for the technical implementation of realtime feedback for social skills, using the conceptual models in my social compass curriculum (Boyd et al., 2013).

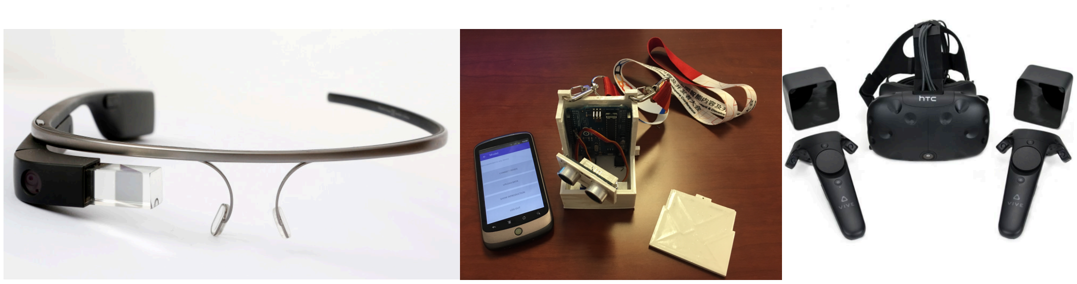

Figure 3.1. Illustration of Hardware Used For sayWAT, Procom, and vrSocial.

I explored the functionality of three platforms: Google Glass™, a head mounted display; I used off the shelf sensors paired with a mobile phone; and HTC Vive™, an immersive virtual reality system. See Figure 3.1. I matched the measurable dimensions of prosody and proximity with hardware capabilities. This pairing resulted in reconciling the types of log data a system could collect with intervention concepts. The next task was to make the variables' data operational so that the three interventions, based on log data, could be transformed into visualizations meant to convey meaningful information to the user.

Eliciting User Requirements

I incorporated a variety of strategies to gather requirements across the three projects—sayWAT, ProCom, and vrSocial. These methods ranged from review of literature about the needs of users of assistive technology, my experience using low fidelity interventions, and interaction with stakeholders in the form of interviews, design sessions, and technology probes with low and high-fidelity prototypes. These requirement elicitation strategies resulted in design guidelines for each project. Lastly, I merged these guidelines to understand them more holistically for the dissertation work.

Interviews with therapists and experience with observations for sayWAT

My design process aimed to explore the manner in which adults with autism might use and experience wearable technologies to improve their face-to-face communication style. After identifying prosody as a key issue, I then worked to understand whether detecting atypical prosody was even possible in real time in such a way that an intervention can be delivered. These questions inherently require answers that can only be found in use. Thus, these wearable designs had to work in real time without distracting the wearer from the primary task.

I conducted empirical work to drive design efforts. Specifically, I conducted a series of interviews and my collaborator also conducted design workshops with experts (*i.e.,* a speech pathologist I know through my previous employment in public schools and his workshops with school psychologists in a segregated school in Mexico for children with autism) to develop design guidelines that eventually led to the implementation of sayWAT. In these sessions, we independently elicited requirements for a system that would support volume and rate (my collaborator), and pitch (me). Between the two of us, we interviewed two psychologists and a speech pathologist with expertise in treating children and adults with autism that commonly face social missteps during real-life social situations. Interviews lasted between 90 minutes and two hours and were conducted in person at the schools where the professionals worked. Interview topics focused on understanding the supports and strategies used to teach age-appropriate social skills. Specifically, the psychologists explained how they teach conflict avoidance, and the theme with the speech pathologist was on gestural ways he gives feedback on atypical prosody and how this might be translated into visualizations.

All field notes and interview transcripts were analyzed together iteratively by a subset of the research team. A combination of deductive and inductive analysis was used. I explicitly looked for deviations from, as well as agreement with, the social skills literature and best practices learned from my years as a practitioner. I also coded for emergent themes, particularly in relation to the potential for new designs and technologies that have not previously been possible. The combined findings yielded five key design guidelines specific to the creation of the experimental prototype, sayWAT[2]:

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[2] More details of the development of sayWAT appear in Boyd, L. E., Rangel, A., Tomimbang, H., Conejo-Toledo, A., Patel, K., Tentori, M., & Hayes, G. R. (2016). SayWAT: Augmenting Face-to-Face Conversations for Adults with Autism. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems* (pp. 4872–4883). New York, NY, USA: ACM. https://doi.org/10.1145/2858036.2858215.

1. Focus on awareness, not instruction.

Given the challenges seen in the clinical and educational literature around teaching people about atypical prosody (Diehl & Paul, 2009b; Paul et al., 2005), it is perhaps unsurprising that I often observed students in therapeutic settings who appeared unable to understand how to “appropriately” use prosody. Statements like, “Change the rhythm of your voice when you are happy,” are extremely hard to act on in practice. Additionally, feedback like, “Speak higher when you are asking a question,” requires that the person giving the feedback knows that the utterance will be a question, which is often indeterminable until after the utterance has been made. Thus, I recognized early in the design process the need to focus on supporting awareness of atypical prosody for the user rather than direct instruction. In this way, users can understand their own behaviors and possibly even experiment with modifications.

Additionally, therapists I interviewed stressed the need for this awareness to be built during the social interaction. Existing therapeutic practices and social skills interventions already do a fairly good job in helping students to reflect on their performance *after* an interaction. However, currently little is possible in the way of support during the interaction without substantially disrupting the conversation through, for example, therapist intervention. In the design, I focused on providing real-time feedback through a wearable platform. In this way, the user can begin to build awareness visually *during* conversations without disruption of those interactions. By simply being worn, such a device can provide information that allows the wearer to observe the social misstep in a natural context. Ideally, by building real-time awareness, wearers can then develop their own strategies to respond to these alerts rather than having to interpret specific instruction on the fly.

2. Make alerts rapidly understandable.
Given the goal of providing awareness in real-time, some mechanisms for specific feedback are required. In the design sessions, I explored the idea of using visual, audio, and even haptic feedback for conversation missteps. As the audio channel is already occupied with understanding and attending to tone of voice, volume, and other audio cues in the conversation, visual feedback for social communication is recommended (Crissey, 2009). Haptic feedback can be challenging as well during social conversations, particularly when trying to convey a variety of information. Thus, although also a crowded channel, in terms of body language and facial expressions, I focused my attention on providing understandable visual feedback that would not distract too much from the visual channel and the conversation at hand.

Because alerts could easily distract the wearer from the primary task of interacting with another person, visual cues must be able to be consumed or ignored quickly. Using simple shapes, figures, colors, or minimal text can particularly support people with autism who often have difficulty ignoring details (Crissey, 2009) or filtering out information in their environment (Seiler, 2007). Alongside the need to provide feedback frequently but not too frequently, this feedback must be displayed for an appropriate amount of time to be interpreted without being overwhelming. At some point, providing awareness of a pervasive issue on a constant basis will likely create information overload or people will learn to ignore it.

3. Provide feedback only when you need it.
Individuals receiving social skills training often struggle with the amount of feedback they receive. In my observations, students commonly needed to stop the role-playing activity to attempt to process all of the information being thrust upon them. Likewise, teachers and

therapists can have trouble identifying when a student is struggling and needs information about performance and when to stay quiet and let the practice session play out. Technologies are notoriously unhelpful when it comes to knowing when not to bother users with "help" and often require some shared agency with the human user (Horvitz, 1999). At the same time, not providing support when it is needed—or expected—could also be problematic.

Alerts that are rare and attention grabbing could pressure the wearer to act upon them at each occurrence, without necessarily knowing how to do so. On the other hand, alerts that are too frequent may lead wearers to ignore them altogether, presuming an error in the system or just getting overloaded by the feedback. Thus, in this work, I aimed to provide continuous monitoring of the audio stream. As described in the following implementation section, sayWAT ultimately supported this continuous monitoring for two dimensions of prosody (volume and pitch) as a first step towards a comprehensive solution for monitoring social communication.

4. Support data collection and reporting for both users and clinicians.

Collecting clinically–meaningful data may be in tension with what information the user is interested in receiving in live conversations. Additionally, although clinicians I interviewed wanted massive amounts of data—including the audio recordings themselves—considerations around the privacy of users—and their conversation partners (Nguyen et al., 2009) with potentially sensitive personal information needs to be thought through. Who can see the alerts? Who knows the alerts are occurring? Who has access to performance data after the interaction? How much should a conversation partner know about the assistive device?

To support sensitive data collection for any kind of assistive technology, designers must consider the privacy and security levels the platform permits. In the case of prosody support, recording of audio in particular can be sensitive or even illegal (G.D. Abowd et al., 2005; Hayes et al., 2004; Truong & Hayes, 2007). Thus, the system should store as little conversation audio as needed to process the prosody levels. Although clinicians invariably request support for performance data of any intervention, this data collection must be secondary to the primary task (Abowd & Mynatt, 2000; Truong & Hayes, 2007). To support data collection without distracting from the primary task, systems to support prosody interventions should collect only meta-data such as pitch range, volume, and alerts triggered in the background.

5. Build self-efficacy over time.

The long-term goal of many assistive technologies and interventions is not to improve skills just while wearing the system but ideally to build those skills without need for the device. In terms of social interactions, awareness as noted above and confidence in one's ability to respond to that self-awareness are major steps towards improvement. A variety of strategies are available for creating confidence and feelings of self-efficacy, including allowing the users to determine their own goals and to customize thresholds for intervention based on those goals.

Additionally, it may take time for the alerts to be meaningful to the wearer. Thus, practice over time—both of the skills supported and in using the device itself—can make a dramatic difference in the acceptability and usefulness of the system. Systems should allow users to easily navigate out of an assistive mode for brief periods of time to allow wearers to practice their skills both with and without the support, without alerting their conversation partner to whether or not they are receiving alerts. Over time, it is my expectation that wearers might use the system less and less frequently but have it available in case they need it. In this way, they may better be able to internalize the initial awareness provided by such a support.

Parallel design workshop for ProCom

As mentioned through this work, social rules of interaction are dynamic, context-sensitive, and often hidden (Myles, Trautman, & Schelvan, 2004b). Usable technology to support this dynamic context must be designed with an understanding of norms for interpersonal space based on precise measurement. Likewise, a comprehensible interface must provide information precise enough to avoid violations of interpersonal space. This requirement is complicated by the reality that even a slight change in body position or closeness can dramatically change the interpretation from friendly to dominating (Gatica-Perez, 2009). At the same time, these precise measurements must be representable, comprehensible, and actionable for a person with autism during a live interaction. I used parallel design (Nielsen & Faber, 1996) with six adults and five typically developing children, ages 9-11. Participants were selected by accepting an invitation to volunteer to draw at a departmental graduate student social event at my university and in a community-sporting event. The designer group was told to design an interface for a mobile phone that will communicate interpersonal space to be used for children with social skills challenges, then the six adults made drawings simultaneously but independently. The lead author privately asked for a quick explanation upon collecting each drawing. The typically developing children in the targeted age range were asked one by one to draw a screen to help other children with neurodiversity understand "when they are not facing a person or standing too close or far."

I collected eleven sets of designs from participants (see Appendix), totaling 65 sub-components (*e.g.,* widgets, screens, and so on). I analyzed designs with attention to the repeated components for insight into the group's thinking about interpersonal space. I evaluated each design component and the designs as a whole to identify central themes and outliers that make up metaphors (Sengers, Boehner, David, & Kaye, 2005) about interpersonal space. A member of my research team and I analyzed each component separately in form and concept. Then we met together to group common and diverse features from among these sets. From these groupings, the most common features were identified. Four primary themes related to face-to-face interactions emerged from the parallel design sessions: precise measurements, zones of proximity, direction and movement, and type of awareness feedback (these guidelines also appear in (Boyd, Jiang, & Hayes, 2017) .

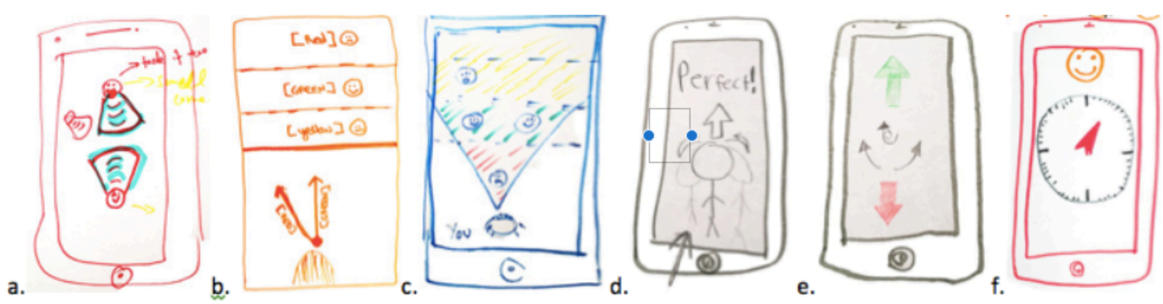

Figure 3.2. Interface Sketches from Parallel Design Activity.

1.Precise Measurements

Porting physical measurement tools into the virtual space was a common design choice for proximity, though less so for orientation. Visual references of common measurement tools can aid in the comprehensibility of a sensing system that is likely to be unfamiliar to its users. Nearly all of the designs included a notion of "zones" indicating ranges of appropriate personal space and orientation. Specifically, nine elements illustrated distinct areas or zones to indicate multiple spaces between people, suggesting there is a range of spaces associated with proximity. See Figure 3.2a, 3.2b, 3.2c, & 3.2f. Without discussing each other's designs, participants demonstrated consensus about the relative size and number of zones—personal space, a social space, or a space beyond an interaction. These components then became central to our final design.

2. Motion and Directionality

Designing for appropriate proxemics behavior requires a basic understanding of individual users' proximity and orientation. The social proxemics literature indicates that there are thresholds that, when crossed, convey a change in the interaction. For example, moving across the personal space threshold is detectable and becomes uncomfortable within 45 centimeters of a person (Ballendat, Marquardt, & Greenberg, 2010). Therefore, any assistive technologies in this space must be sensitive to changes as small as 10 centimeters at the personal and social boundary. This level of accuracy can be challenging for wearable systems. In particular, most that are that sensitive (*e.g.,* (Zhang, 2012)) cannot be mobile, and most that are mobile (*e.g.,* (Torres-Solis, Falk, & Chau, 2010)), are only accurate at 30 centimeters or greater.

Although I did not ask participants to explicitly consider motion in their designs, nearly all (9 of 11) explicitly addressed whether the user was observing or approaching others or others were approaching the user, such as through the use of arrows or dials pointing towards or away from the user. See Figure 3.2b, 3.2d, & 3.2e. This result indicates that any sensing system I might employ to support social proxemics should update rapidly, at least as rapidly as most people walk when approaching someone in a social setting, and the visualization of those sensor readings must indicate directionality and support prediction of future proximity and orientation.

3. Feedback: Balancing Judgment with Awareness

I gave no explicit instructions to the design participants regarding how they might convey information regarding proximity and orientation. However, the methods exhibited by the participants tended towards either providing judgment or providing awareness, with some limited overlap between these categories. In terms of judgment, people used a variety of approaches to convey when the user is doing something "right" or "wrong." For example, some designs included text reading "Perfect," or green and red arrows indicating that the user should move or go in the green direction. See Figure 3.2d & 3.2e. Even in the case in which the participant used a physical metaphor (the compass, as described above), this feedback also included emoticons as a means for providing additional feedback. See Figure 3.2f.

4. Holistic View vs. User Perspective

Given the prompt to design a tool to support *individual* awareness of proximity, it is perhaps surprising that the designs tended to use an overhead view of the scene (9 of the 11 designs) rather than a first-person perspective (at ground level, 2 of the 11 designs). An overview perspective suggests an understanding of space that extends beyond the immediate interaction and could extend to other kinds of environments, such as a party or other larger group gathering. A "street level" approach would be closer to the user's actual experience and interpretation and may have its own benefits. In discussions, participants in the design study described grappling to some degree with this decision and ultimately modeling it on an overhead view. This choice connects closely to the default design pattern for online mapping applications, which may have had some influence in professional designers' views. The children participants, however, did not have the same experience with these kinds of applications, suggesting that more investigation may be needed to unpack the differences in these views. Regardless of the specific view chosen, research indicates the importance of rapidly comprehensible information to support the ability of a single user to privately access a tool before, during, or after a face-to-face conversation (Saffer, 2013a).

Technology Prototyping with End Users in vrSocial

To understand the system requirements for the therapeutic VR applications, I incorporated three prototyping strategies with a local group of ten developmentally disabled adults. This process provided an understanding of the opportunities and challenges of design for and with developmentally disabled adults in a social skills system. I first conducted a card sort (Baxter, Courage, & Caine, 2015) to prioritize specific social skills challenges. I then used low fidelity (paper prototype) and high fidelity (visualization prototype in VR) (Preece, Sharp, & Rogers, 2015) technology prototypes to iterate on these designs. I employed a modified version of a card sort to validate, scope, and prioritize focus areas for VR social skills. I presented the ten design partners with a worksheet containing 24 icons (see Appendix) designed to represent specific social skill concepts from a poster of a social skills curriculum (Boyd et al., 2013).

Results of the card sort indicated that greatest priority in social skill interventions was in reading other's body language, modulating speaker's volume, positive self-talk, and balancing friendship (*e.g.,* taking turns talking or picking an activity). I translated these metaphors into actionable and measurable variables of proximity (one aspect of body language), volume, and time spent talking (balancing friendship). Although positive self-talk was highly ranked, the challenges of teaching this skill in any environment combined with the difficulty in visualizing and implementing it as an intervention resulted in the design team abandoning it as a target.

Low Fidelity Prototyping

I built on past work demonstrating visualizations for proximity and volume in an AR environment (Boyd et al., 2016, 2017) as well as visualizations of turn-taking (Donath, Karahalios, & Viégas, 1999; Hailpern, Karahalios, & Halle, 2009) as they related to the considerations for time spent talking. Four researchers then independently designed a paper prototype to explore visualizations of time spent talking, which had not explicitly been examined before. The group convened to discuss their sketched designs and created one testable prototype, which used a status bar to visualize time spent talking, thereby illustrating the "friendship balance" concept from a social skills curriculum (Boyd et al., 2013). In this session, I explained the concept and then asked two participants to role-play for the group with the paper prototype made from a manila folder and construction paper. All ten developmentally disabled adults, two staff members and four researchers participated in the collective co-design work and discussions following this role play. I learned through the role play with the paper prototype that conversation pairs could visually reference the prototype to modulate their duration of speaking with ease.

These low fidelity prototypes provided information on the user's desired functionality (card sort for features in the app) and comprehension of the proposed visualization (paper prototype for interaction).

High Fidelity Technology Prototypes

The same designer collaborators (*i.e.,* ten developmentally disabled adults and two staff members worked with four researchers) used the VR system to interact with one of two research assistants who were in the system but physically located at the lab. During the first visit, I learned that using the paddles to teleport around the city was a primary focus. In subsequent visits, I did not bring the paddles, and I greatly reduced the details of the landscape to improve attention to the conversational partner.

In the following visits with the simplified environment, the participants did not, however, change their proximity in relation to the circle on the virtual floor or small icons of the volume. To improve attention to the proximity cues, I added a filter to obscure the other person and textual cues when prompting would be warranted. To increase the likelihood that study participants would engage with the volume visualizations, I made the volume icons larger and made them move across the dashboard to increase intensity of the interaction when a trigger event occurred (*i.e.,* too close or too loud). Thus I provide a tool that is both "ready to hand" but remains unnoticed until needed and "present at hand" by being ever-present in one's line of sight (Thiselton, 1996).

In this work, the high-fidelity technology prototypes enabled me to learn: a.) Users can tolerate five minutes but are distracted by the early cityscape design system; b.) The visualization of proximity circles alone did not result in changing one's proximity when needed; and c.) The static visualization of volume did not appear to motivate changing one's volume when too soft or too loud. The iterations resulted in the adaptations to the final version for the efficacy study.

The combination of the iterative and collaborative design process and the results of the empirical evaluation provide key insights into the design of therapeutic VR systems. Many scholars have claimed that VR will become an important tool for psychologists, therapists, and researchers (*e.g.,* (Rizzo & Koenig, 2017)). Thus, these design considerations contribute to both scholarly and clinical knowledge about the design of and potential for therapeutic interventions in immersive VR for autism and also appear in (Boyd et al., 2018).

Balance 'attention to' and 'distraction from'

VR provides immense flexibility for displaying information; yet one must be mindful about strategizing where and when to place this information. Explicit cues can provoke an immediate response by the user in the moment action is expected. Continuous feedback about the status of a behavior, on the other hand, should be subtler and glanceable to not overwhelm the user. This balance is determined by the purpose of the system's main task.

In the proximity mode, I gave feedback of one's proximity through the circles at their feet. This was constantly available with a glance at the floor. The visualizations did not demand attention and yet were always available to the user for reference. However, to change targeted behavior when the user was not in the correct proximity zone during probes, I implemented dominant and obvious cues through the colored screens and text. This promptly grasped the attention of the user, leading to nearly everyone correcting themselves, almost immediately, every time. The short intermittent feedback brought about immediate attention without distracting from the goal of having a conversation. Perhaps unsurprisingly, the colors of the display indicating nearness appear to have created a sense of urgency that the white filter indicating "too distant" did not convey.

Given my intent to address the higher risk behavior with more salient cues, I chose to use yellow and red for encroaching on and intruding into their partner's personal space; I used the white filter for when the user was standing too far away.

In keeping with the type of behavior I aimed to support, I employed a different approach to the time-taking bar and volume feedback. These variables were also constantly in the user's *horizon* (Thiselton, 1996). In vrSocial, the voice feedback is in line of vision, often resting just above the horizon. Although users referred to the time-taking bar, they did not respond as much to volume cues. I infer that this may be due to small changes in intensity among the alerts. Additionally, in this case, the status information was on the horizon and not as ubiquitous as the filter for proximity.

VR enables creation of information-rich environments. However, the richness of the information must be balanced with the attention required to manage it. While the idea of notifications as being distracting is certainly not new (*e.g.,* (Costanza, Inverso, Pavlov, Allen, & Maes, n.d.; Tanveer, Lin, & Hoque, 2015)), immersive VR offers new opportunities and challenges to directly influence people, hide things or subtly notify in their peripheral vision, or distract them using a variety of sensory inputs. Therefore, I suggest categorizing objects by the pattern of attention required: visualizations that require constant monitoring remain on the *horizon* (Thiselton, 1996) to be in sight whereas objects that require less concentration or can be checked occasionally should be placed out of sight. The latter can be brought to immediate attention by implementing a corresponding "microinteraction" to trigger an alert when behavior change is needed (Saffer, 2013b). Therefore, precedence is given to social cues that that require *interaction immediacy* (Tentori & Hayes, 2010). These cues should be balanced against the potential for distraction from the visualizations. The goals of the system must be prioritized to ensure appropriate placement, coloring, and salience of the status and notifications to promote social fluency.

Customize sensory input for the user and the goal

VR, particularly fully immersive VR, offers an intense sensory experience, far beyond that of a traditional screen-based interaction. At the same time, children and adults with autism often struggle with sensory integration and sensory input (Bogdashina, 2016). Thus, a primary advantage to hosting an intervention for children with autism in VR is the ability to control the sensory load in the system, adapting it to meet the sensory needs of the child. To achieve the most attention to the task, VR systems should create an experience with minimum distractions in both the environment and the avatar's behavior. In the intervention, I created the environment as an empty space of floor and sky, allowing users to concentrate only on their goal of practicing social skills while having a conversation with an inanimate avatar. I tested the system several times and changed this environment iteratively to have it fit best with the users and their goal. I also limited the feedback to just visual cues, which did not burden the users with sensory information. I opted for a full body avatar without moving parts to reduce the nonverbal communication down to the variables of interest: proximity, volume, and time spent talking. The empty space also brought about an unintentional effect as it spurred on the children's creativity as they imagined the space to be an airport, a bus terminal, and ocean. From a therapeutic standpoint, the environment can be highly customized for the individual's needs. Sensory information and other forms of distractions can be added or removed from the virtual environment, thus making VR a flexible interface for therapy.

Broaden collaborative interaction

Immersive VR inherently supports collaboration, often at a distance. During the iterative design process, I probed the system with participants and two researchers at the work site of potential end users and two researchers in the lab. The flexibility of VR allowed us to conduct a distributed user test by having communication partners at a distance. Collocated systems have been employed to explore how people become aware of their nonverbal communication and react to cues to create a more balanced conversation (Bergstrom & Karahalios, 2007). Immersive VR can go beyond co-location to support those challenged by face-to-face interaction and those who need support at a distance (*e.g.,* rural populations). Additionally, immersive VR can allow clinicians to create customized therapeutic interactions, such that individuals can attend group social skills sessions or other kinds of group therapies without sharing a sensory space. The flexibility of controlling the sensory environment opens opportunities to be more inclusive. By designing a space that is tailored to individual needs (*e.g.,* agoraphobia, autism, sensory processing disorder, post-traumatic stress disorder, etc.), more people could participate in virtual face-to-face interactions. This configuration allows unique collaboration with users who otherwise would not have the opportunity to interact with each other.

Lastly, in the vrSocial system, the time-taking bar encourages collaborative work from both users to achieve the target. Interactions can be simultaneously open-ended and collaborative yet purposeful and goal directed. Individual feedback can be provided privately, publicly, or collaboratively, as I attempted in this work. Thus, immersive VR broadens collaboration by providing remote access to face to face interaction as well as opportunity to create shared apps that provide shared progress on social skills. These shared goals also change the focus on performance away from one person but to the pair as the unit to change.

Designing the Interface for the sayWAT system

Based on the results of the fieldwork and design sessions, I developed a prototype system

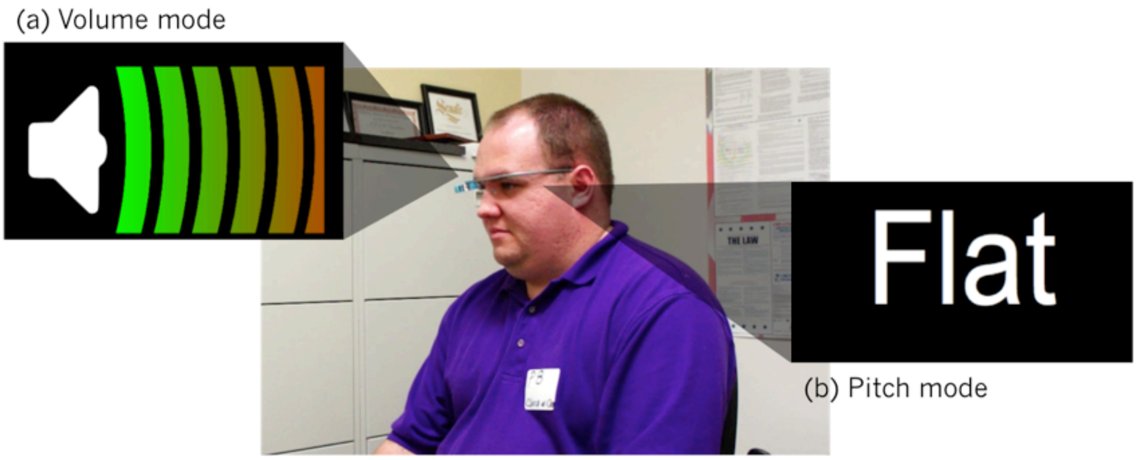

Figure 3.3. A Participant Receiving Alerts on SayWAT for Volume Alert (left) and Pitch.

that provides awareness of prosody missteps during face-to-face social interactions. sayWAT encourages microinteractions using a hands-free and heads up Google Glass™ display, in two modes. In Volume mode, users receive an alert when their volume is "too high." In Pitch mode, users receive an alert when their pitch range is "flat."

To support rapid interpretation—and potential dismissal—sayWAT provides either iconography or a single word for rapid processing of the feedback. For example, when sayWAT detects that the user is substantially louder than the ambient sound, it displays a voice meter animation with a color spectrum from green to yellow to red (Figure 3.3a left). Similarly, users receive an alert when their pitch range is atypically small in the form of the single word "flat" in white text on top of a black background (Figure 3.3b right). This design leverages recent recommendations to use a simple static word for nonverbal communication support while speaking (Damian et al., 2015a). The feedback loop focuses on opportunities to improve, similar to a sign held up for "um" during a speech. I found in early trials that constant feedback was too overwhelming, and users preferred warnings only. Alerts are automatically dismissed once the system either detects a change indicating the user has corrected the issue or a timeout window has been reached.

Designing the Interface for the ProCom System

The ProCom mobile interface includes an aerial view with the user depicted at the bottom and concentric slices of a wedge to represent proximity zones, which represent the normative distance for social interactions (see Figure 3.4).

Specifically, ProCom shows the change in proximity as two people get closer, in this case two acquaintances. The green zone is a good comfortable social space at a distance from the user of 120 to 370 cm. The yellow zone (45 to 120 cm) is getting too close, and the red zone is much too close for an acquaintance at 45 cm or less. These zones represent the space of a person in a vis-a-vis formation (90°), one of two most common formations for pairs of people in a social interaction (Hall, 1963; Kendon, 1990; Mead, Atrash, & Matarić, 2011). The zones are customizable depending on the level of intimacy the user has with another person, but in this implementation, I focused on stranger or new acquaintances to test the viability of the system.

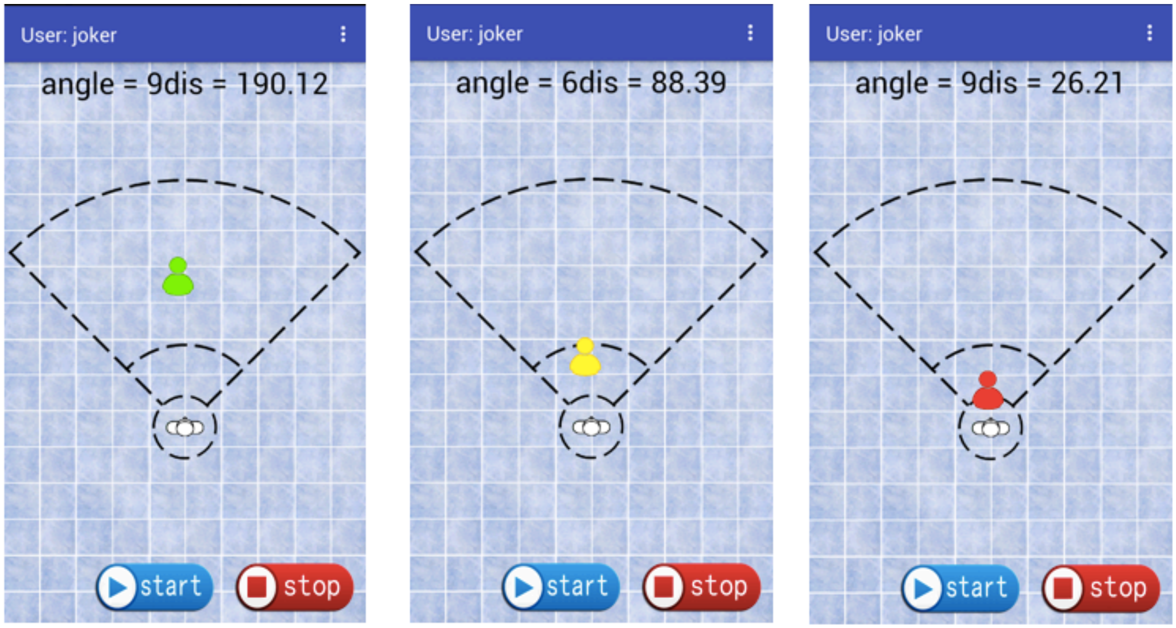

Figure 3.4. Three Conditions of ProCom Interface: Social Zone (left), Personal Space (middle), Intimate Space (right).

Designing the Interfaces for the vrSocial System

vrSocial is a multi-user game that builds on the prototype from the collaborative design work and provides real-time feedback on proximity with respect to the other user, their speaking volume, and time spent talking. In this way, the intervention visualizes otherwise hidden information about the user's participation in the conversation. The game was developed in Unity3d with the Steam VR plugin along with Photon Unity Networking platform for developing multi-user games in Unity. I developed four versions to create four conditions for the study as described below.

Baseline (no visualizations)

The first condition gives no visualized feedback on targeted behaviors of proximity and prosody. Additionally, the baseline condition consisted of an open space where a user can only see and converse with the other user's avatar, which can float to move but otherwise is a static image, (see Figure 3.5A). This version was used as an initial exploration in a virtual environment and as the baseline condition for the experiment.

Proximity Visualization

The second version contains a visualization of the current state of proximity. Each user has concentric circles on the floor, right below their feet with red indicating personal space, blue signifying the correct social space. See Figure 3.5B. Yellow is representing an intermediate warning between the two zones. See Figure 3.5 D.

The socially acceptable distance (*i.e.,* the blue circle begins at an arm's length between the two users in physical space) between the users is achieved when both users' blue circles stayed in contact with each other. When users are no longer in each other's social space (beyond the blue circle), the screen turns white with a 60% opacity, accompanied by a text cue asking them to 'step closer'. See Figure 3.5 E. This obscures the user's vision, urging them to react by stepping into the other user's blue circle. Similarly, if

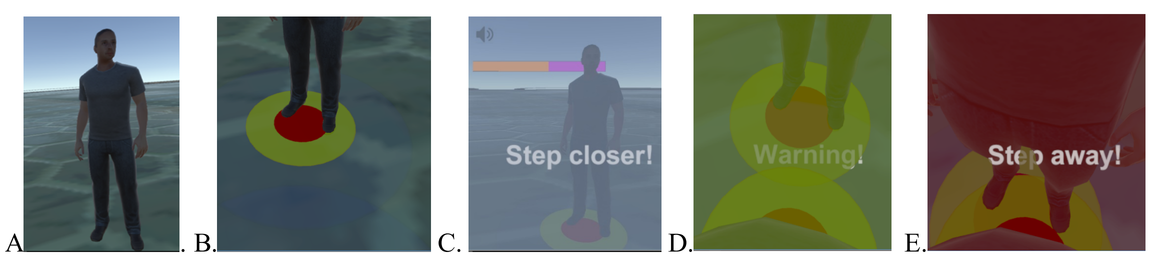

Figure 3.5. Interfaces for Proximity Mode in vrSocial. From left to right: a.) Baseline, b.) Proximity correct, c.) Too far away, d.) A bit too close for acquaintance, e.) Intrusion into Personal Space

one user steps into the other's yellow or red circle, the screen turns yellow with a 50% opacity along with the text "warning" (Figure 3.5 D) or "step away" respectively (see Figure 3.5 E).

Voice visualizations

The third version of the game has visual cues on participants speaking volume and duration of their time spent talking. Speaking volume is measured by the headset's microphone. I set the target volume range, which was calibrated across the research team before beginning the study of subsequent trials and was also dependent on the voice input equipment being used. Each user gets feedback only of their own volume and not the other's. A small grey speaker is displayed when the user is silent. A bigger green speaker is displayed when the volume of the user is at a good volume. An even larger red speaker is shown when the user's volume gets too loud. This version also has a time spent talking bar, which informed the users how much they have contributed to the conversation. The users see the bar getting filled with orange from the left side as they talk and getting filled with purple from the right side as the other user talks over the 60-second trial (see Figure 3.6-time spent talking bar).

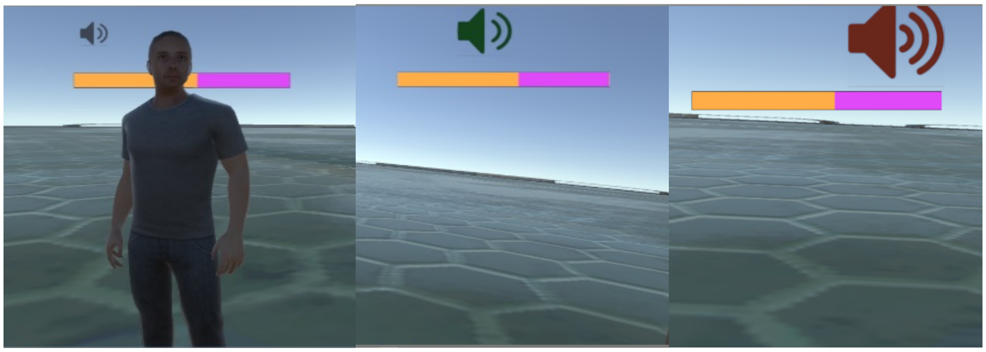

Figure 3.6. Interfaces for Voice Condition in vrSocial. The Bar is Balanced Between Speakers and the Volume Icon Is Greyed Out as the User is not Speaking (left). The Green Speaker Indicates the User's Volume is in the Correct Range (middle), the Speaker is Too Loud (right).

Combined proximity and voice visualizations

The final version gives visual feedback on all three social skills: proximity, volume, and time-talking. The purpose of this condition is to evaluate if participants respond better, the same, or worse with multiple visualizations present at the same time as this information will inform future iterations.

Platform	Guideline
AR	1. Focus on awareness, not instruction
AR & VR	2. Make alerts rapidly understandable
AR & VR	3. Provide feedback only when you need it
AR & VR	4. Support data collection and reporting for both users and clinicians
AR & VR	5. Build self-efficacy over time
AR & VR	6. Use precise measurement
AR	7. Indicate motion and directionality
AR	8. Consider trade off of holistic view versus user's perspective
AR & VR	9. Customize sensory input for user and goal
AR & VR	10. Broaden collaborative interaction

Table 3.1. Summary of Design Guidelines Across Platforms.

This work tested an interaction between a research assistant and an end user in a study. However, future interventions can be designed to hold sessions between a therapist and multiple participants together as well, irrespective of whether they are co-located or not. VR also allows the users to converse with each other, replicating a face-to-face interaction, without necessarily being face-to-face, allowing for a broader and more diverse set of potential social and group based therapeutic engagements. A summary of the design guidelines derived from empirical investigation appears in Table 3.1.

Conclusion

In summary, in the design and development of these three systems, prosody was closely tied to one's communicative intent whereas proximity seemed to be more loosely coupled. The degree of interdependence between verbal communication and dimensions of nonverbal communication may have an impact on the salience of each variables' visualization.

CHAPTER 4: EVALUATION METHODS

In this chapter, I describe the setting, participants, and measurements for all three studies (*i.e.,* sayWAT, ProCom and vrSocial); provide a description of each studies' design and rationale for the evaluation methods; provide a rationale, method, and results for the social validity surveys; and describe the interview process.

Setting

All evaluation studies took place at a lab space at the University of California, Irvine. Participants came into the lab for a one-time session that lasted anywhere from one to three hours. The session agenda for all of the studies included an orientation to the project that included exploration of the technological system, informed consent and assent for the children, the trials (with surveys after each trial for sayWAT and ProCom), an interview, payment and thank you closing statement at the end.

Participants

A convenience sample was assembled. Participants were young adults or children with autism recruited through my professional network of teachers and students with autism. I emailed autism coordinators that I know personally in the county as well as posted fliers on my Facebook page inviting participants to email me for information. Table 4.1 contains demographic information including pseudonym, gender, age, and which project(s) they participated in.

Participant ID	Age	Gender	sayWAT	ProCom	vrSocial
Aaron	25	Man	X		
Ben	24	Man	X		
Carson	24	Man	X		
Diane	22	Woman	X		
Erik	7	Boy		X	
Fred	11	Boy		X	X
Glen	12	Boy		X	X
Hanna	11	Girl		X	
Isaac	14	Boy		X	X
Jen (sib of Kent)	7	Girl		X	
Kent (sib of Jen)	9	Boy		X	X
Laura (twin of Olivia)	7	Girl		X	X
Mason	8	Boy		X	X
Noah	8	Boy		X	
Oliva (twin of Laura)	7	Girl			X
Peter (sib of Quinten)	8	Boy			X
Quinten (sib of Peter)	10	Boy			X
Roger	8	Boy			X

Table 4.1. Participants' Demographic Information and Their Corresponding Study Participation.

Measurement

The three systems evaluated in this work measured the dependent variables of interest (*i.e.,* prosody and/or proximity) by capturing and processing the data logs. These data points serve as the source of data for the single case experiential design evaluations. To transform the data from the logs into the dependent measures, the variables were operationalized.

Operationalizing is the process of making a behavior measurable, so it can be concrete, observable, and understandable for the purpose of measurement in an empirical observation. In the works presented here, I used well established operational definitions of variables and determined my own parameters for these experimental interventions. For example, in the case of interpersonal space, an operational definition has been established by anthropologists that categorizes the relationship being performed between two people in a face-to-face interaction by the distance they stand apart from each other, see Figure 4.1. Other nonverbal behaviors contribute to performing the behavior that maintain a social relationship, but the goal of the current work is to reduce the number of signals to a pivotal signal that can stand in to represent an unspoken social norm.

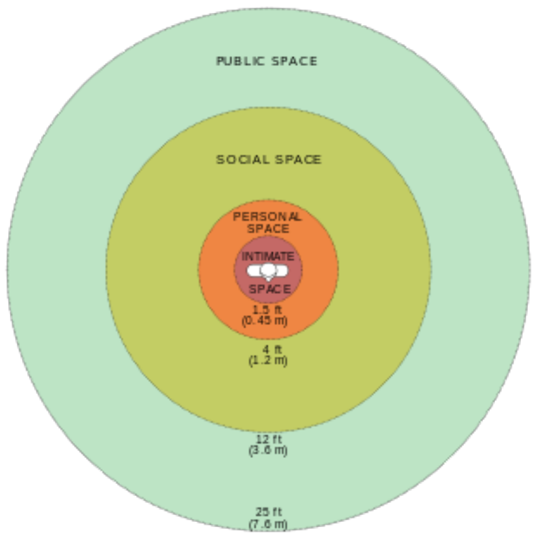

Figure 4.1. Illustration of Zones of Proximity.

Proximity

Proximity is operationally defined in this work as the distance in centimeters that the conversation partners are from one another during a face-to-face interaction as acquaintances. Therefore, the acquaintance proximity norm is obtaining and maintaining a distance between 120-360 centimeters as indicated by the third ring from the center, the social ring in Figure 4.1. To detect distance, ultrasonic and infrared sensors were swept back and forth by a servomotor at the top of the sensor box that is worn around the user's neck. See Figure 4.2.

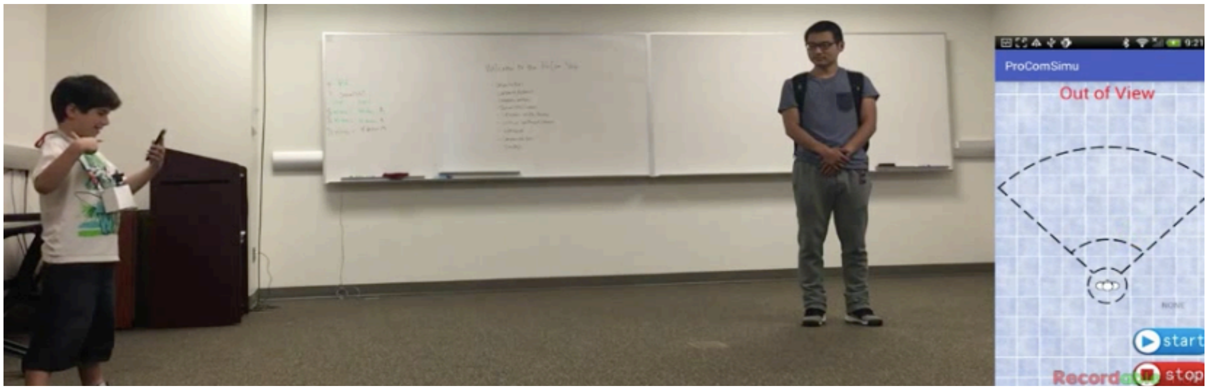

Figure 4.2. Starting Position in Procom Study with Interface Shown on the Right.

Specifications of Proximity

In the ProCom study, participants began each trial just beyond 360 centimeters away from the conversation partner. In the data analysis, there was a clear and consistent pattern of two phases to the performance of proximity: approaching within approximately the first 10 seconds and then maintaining one's standing position for the remainder in 20 seconds of the trial. In data analysis, I confirmed that generally participants stood in one position. The research participants, as required in the study protocol, maintained their position and body orientation. Therefore, the measure of proximity displays the onset moment where proximity is obtained and then maintained for the duration of the interaction, See Figure 4.3.

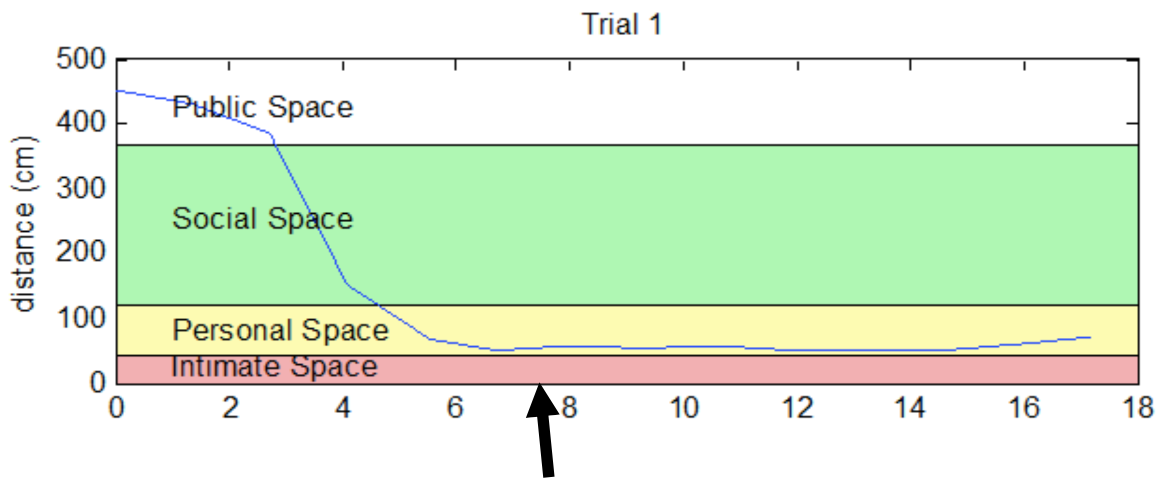

Figure 4.3. Graph of ProCom Log Data.

Measurement of Proximity

Data on the distance in centimeters the user was from their partner was captured and stored in the background. The data was also processed via an algorithm that categorized the value of the distance into the corresponding circle using Hall's parameters -intimate, social, or public space. More details on the calibration of the sensors to collect accurate data to the one centimeter can be found at (Jiang, Boyd, Chen, & Hayes, 2016). Logging the status occurred in the background at one-second intervals. The current status of proximity data was stored in CSV format for post study analysis. Because proximity is performed by first approaching the conversation partner then maintaining a distance during conversation, sessions were video recorded and used to verify the onset of proximity, see arrow in Figure 4.3. The video also served as a ground truth to clean aberrant proximity data that reflected when the sensors were occluded by the user's hand. I ported these same measurements to the VR system that tracked distance with sensors.

Volume

Volume is defined in this work as the amplitude of the speakers' voice during the face-to-face conversation. Amplitude was captured from the microphone on the Google Glass™ head mounted display and stored in the cloud as discrete values for every 100^{th} of a second. Regarding technical interventions to support volume, volume is also context-specific to the meaning of the words spoken as well, and in continual adjustment in the presence of ambient, environmental noises. In other words, in a small room, what is considered inappropriately loud differs from what is considered loud in a larger room, a crowded room, and perhaps in a virtual room. Ultimately the determination that someone is speaking too loudly is subjective.

Specifications of Volume Measure

To set parameters for too loud, too soft or just right ranges, I devised rules that defined too loud as an amplitude that is three times greater than the ambient sound for a duration of two continuous seconds; more details appear in (Boyd et al., 2016). In the AR system, sayWAT, I define volume relative to the other sounds in the room. The categorization of too loud will only occur when one person is louder than the other, rather than both people speaking loudly. In the VR system, I defined loud volume as an actual value close to screaming as volume is already mediated through headphones and is automatically adjusted for by distance (*i.e.,* volume gets softer when person is further away regardless of their actual amplitude) in the HTC Vive™ immersive VR system.

Measurement of Volume

To detect thresholds at which alerts need to be triggered, sayWAT uses a Hamming window function to cluster two seconds of audio signals from which it extracts features. To detect “loud” episodes, sayWAT calculates the root mean square (RMS) from the signal amplitude.

To ensure that alerts are understood but not bothersome, sayWAT uses thresholds both for when to provide the information and for how long to display it, with three seconds as the maximum time any alert is shown. Alerts are dismissed in less than three seconds if the user corrects the speech in that time.

Log data as Measurement

In the sayWAT study, volume was calculated across 150 two-second intervals occurring in the 5-minute sessions. Volume alerts were provided when participants spoke loudly (3 times the ambient sound for 2 consecutive seconds). This event was logged in the background. In the volume conditions, the speaker icon with red radiating rings illuminates on the Google Glass™ display for up to 2 seconds. In the vrSocial study, volume was reflected by three modes and was presented as a real-time status.

Pitch

Pitch was stripped from the audio collected on the Google Glass™ and stored in the cloud as discrete values every 100^{th} of a second. The detection of the fundamental frequency on the device uses a pitch extraction algorithm based on the Yin algorithm (de Cheveigné & Kawahara, 2002), using a sampling rate of 8 kHz and 16-bits of depth for the audio analysis. Praat, an audio analysis software, processes the audio and eliminates sounds outside of the human voice frequency, thus removing many of the nonhuman sounds captured (*i.e.,* squeaking of a door outside the room) and visualizing human voice entries.

Parameter Finding for Pitch

Because there is no clear operational definition for “flat” for young adults with autism, I empirically defined alert thresholds to establish ground truth. I conducted audio analysis of data from an available sample from previous work (Hayes et al., 2015) to determine a parameter for pitch range from a sample population. I analyzed 52 minutes of audio samples from interview recordings of 14 adults. As pitch range differs between men and women, I grouped these recordings by gender and diagnostic label. From audio samples of seven young men with autism and three without, I extracted the standard deviation from the mean pitch range derived from the fundamental frequency for the neurotypical adults (Mean SD= 31 Hz, range of SD=23-38 Hz) and from the adults with autism (Mean SD=18 Hz, range of SD=12-29 Hz). I also examined the acoustic recordings of one woman with intellectual disabilities (SD=22 Hz) and three typically developing women (Mean SD= 48 Hz, range of SD=39-60 Hz). See Table 4.2.

Group Name	Count	Mean Pitch	ST DEV
Men with autism	7	121	19
Men with Intellectual Disability	3	123	18
Women with Intellectual Disability	1	197	23
Men, Neurotypical	7	111	35
Women, Neurotypical	4	200	29
TOTAL	22	150	29

Table 0.2. Demographics of the Voice Sample for Pitch Parameter in sayWAT Study.

Specification for Pitch Measurement

Based on my analysis of pitch across the mixed group of 22 adults, I defined "flat" prosody as having frequency variation of less than 25 Hz for two consecutive seconds. This cut off falls between the standard deviation for the autistic and intellectually disabled sample and the neurotypical sample. At this cutoff point, I could reliably predict group membership. The two seconds of continuous narrow pitch reduces the amount of time the user may see an alert that they are speaking in a flat tone. Additionally, a three second reprieve occurs after two seconds of continuous flat prosody or the immediate increase in pitch change or termination of speech. These rules were devised for the experimental setting to ensure participants had ample opportunities for the user to come in contact with the information without the information being continuously streamed. Pitch was logged in the sayWAT study only.

Log data as Measurement

In sayWAT, pitch alerts were provided when participants spoke in a flat tone (>25 Hz) for 3 consecutive seconds. This event was logged in the background. In the pitch conditions, the word "flat" appeared on the Google Glass™ display for up to two seconds. In the graphs below, the data points represent the percent of intervals with no trigger events for each condition (*i.e.,* pitch, volume and baseline). The calculations of effect size are for the difference between pitch and baseline sessions.

Methods: Single Case Experimental Design

To answer whether realtime visualizations have a significant impact on nonverbal behavior, I conducted experiments, surveys, and interviews. One way to determine impact is to measure intervention effectiveness in a controlled study. Consistent with best practices for behavioral intervention research for autism, I used single case experimental design (SCED) to conduct the efficacy studies. I draw from the National Research Council's research recommendations to explain this choice in experiment design methods (*Educating Children with Autism*, 2001):

If young children with autistic spectrum disorders were homogeneous in intelligence, behavior, and family circumstances, and if researchers and educators could apply a uniform amount of treatment in nearly identical settings and life circumstances, then a standard, randomized- group, clinical-trial research design could be employed to provide un-equivocal answers to questions about treatments and outcomes.

However, the characteristics of young children with autistic spectrum disorders and their life circumstances are exceedingly heterogeneous in nature. This heterogeneity creates substantial problems when scientists attempt to use standard research methodology to address questions about *the effectiveness of educational treatments for young children with autistic spectrum disorders.*

Therefore, to accomplish the task of demonstrating effectiveness, a researcher can use the participant as her own control, such as in the case of Single Case Experimental Design (SCED). SCED contains both the baseline and intervention conditions and reply to the same participant as a way to demonstrate causal relationship (Kazdin, 2011). Across these three studies, I recruited 4-11 participants and used one of the many types of SCED—an alternating treatment design[3].

Alternating Treatment Design

SCEDs provide three ways to analyse an intervention: steady-state strategy, prediction verification, and replication. Steady state strategy refers to "repeatedly exposing a subject to a given condition while trying to eliminate or control extraneous influences on the behavior and obtaining a stable pattern of responding before introducing the next condition" (Cooper, Heron, Heward, & others, 2007). *Prediction*: By examining the first two data points in a data path, the reader can make a guess at what the next point will be given the current trend in the data. *Verification*: Because treatment has been withdrawn and reversed back to baseline, there is more than one instance of controlling baseline so that the effect can be verified by looking across the replication. *Replication*: Repeated instances of control or baseline and intervention. Application can occur across one participant or across a few participants, or preferably across both a single participant and others. Steady states are addressed in the rapid alternating of treatments (by which baseline can be

[3] Alternating treatment design has many other names in the behavioral literatures. According to Cooper et al 2007, this design is also known as *multielement design*, *multiple schedule design*, *concurrent schedule design*, and *simultaneous treatment design*.

considered a no-treatment conditon and put into the mix). The alternating treatment design connects each treatment path as they co-occur, and these paths can be compared.

In behavior analytic literature, the baseline phase is referred to by the letter A, and treatment phase by B. Subsequent treatment phases take on the subsequent letters, such as C and D. Therefore, the single case experimental design that employs phases of each conditon with counter balanced replications can be described as having a pattern (e.g. A-B-A-C), see Figure 4.4.

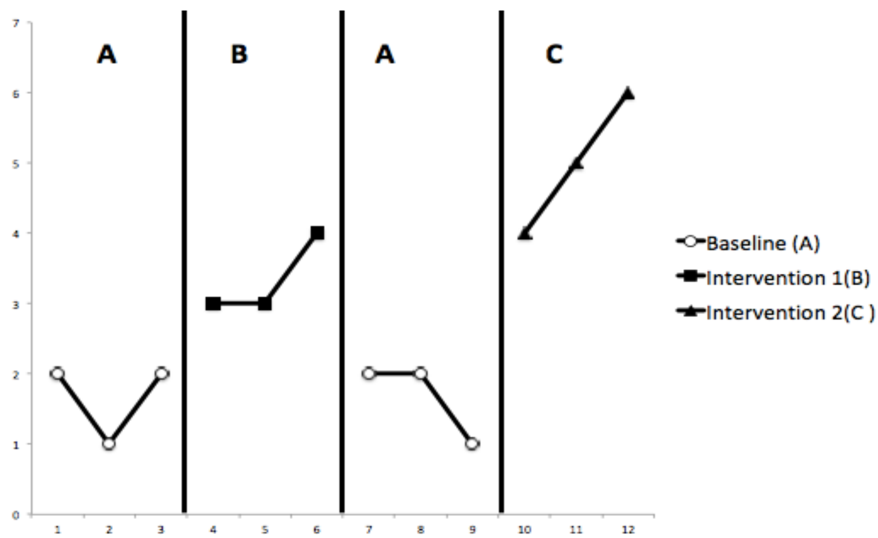

Figure 4.4. Example of A A-B-A-C Phases in a Reversal Design.

In rapidly alternating treatment design, the conditons are run in *blocks* containing most or all of the conditons, rather than in *phases* that contain only one condition at a time. It is often the case in rapidly alternating treatment designs that conditions are counterbalanced within the *blocks* so that the differential responses can be attributed to the effect of intervention rather than the order of interventions. See Figure 4.5.

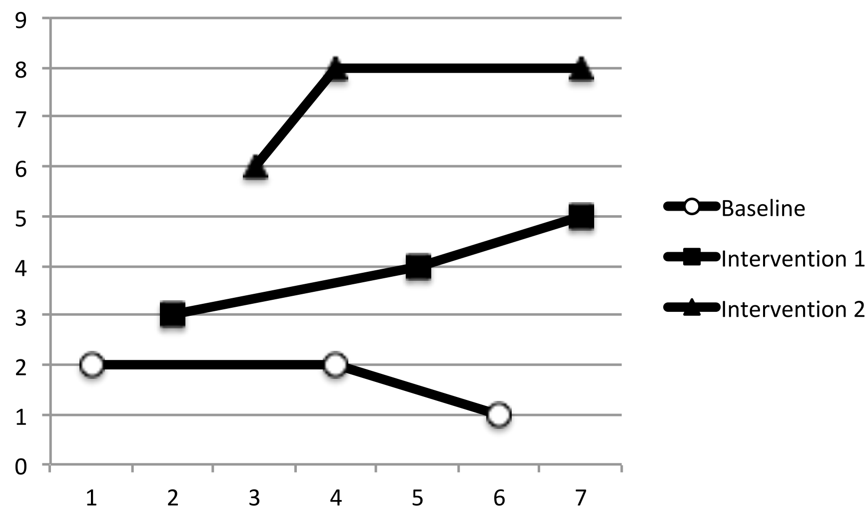

Figure 4.5. Example of a Rapidly Alternating Treatment Design in Blocks.

Counterbalancing minimizes the liklihood of carryover effects between the conditions. In alternating treatment design, there do not need to be phases of the treatment or steady-state in one condition before there is a change to a new phase. This caveate makes this design a useful choice when time is fixed or limited. Time is fixed in a one day laboratory study making it impossible to predict if a steady state would be achieved in baseline, much less in treatment.

Alternating treatment design allows for the possibility of a rapid demonstration of steady state. A steady state in this design occurs when the data paths show stable levels of behavior or clear trends (*e.g.,* are not variating), suggesting the participant is discriminating between the stimuli in each condition. The goal of a steady state is achevied here as from (Cooper et al., 2007)"

> *Each successive data point for a specific treatment place all three roles: It provides (a) a basis for the prediction of future levels of responding under that, (b) potential verification of the previous prediction of the performance under the treatment, (c) the opportunity for replication of previous effects produced by that treatment*

When these components are present, the investigator has evidence of a functional relationship between the conditions and the level of responding. This evidence is determined by visual inspection and quantification of vertical distance between the baseline and intervention data paths.

sayWAT Study Design

In the first study, I compared three conditions simultaneously: baseline, volume, and pitch. Two variables were measured: volume and pitch. Both variables were measured for every session. I conducted three blocks of 5-minute sessions. As the first three participants attended the session at the same time, I rotated the participants through each block. Session order within blocks were randomized without replacing the condition once it had been picked per block. Each condition was paired with a research assistant to increase the discrimination between conditions. The fourth participant met with a single research assistant for her uniquely ordered sessions. The session order for each participant appears in Table 4.3.

P ID	Block 1			Block 2			Block 3		
Aaron	P	V	C	C	P	V	V	C	P
Ben	B	P	V	V	B	P	P	V	B
Carson	V	B	P	P	V	B	B	P	V
Diane	V	P	B	B	P	V	V	B	P

Table 0.3. Session Order for sayWAT Participants. B=Baseline, P=Pitch, V=Volume.

ProCom Study Design

In the second study, I compared two conditions simultaneously: baseline and proximity. Proximity was measured in each session. I began with a one-minute baseline phase of two sessions then randomized two blocks with a different research assistant for all three blocks. During the first three sessions, from the periphery, parents commented that the yellow zone was a good space for their child to stand and that the green zone might to be too large; additionally, the research staff and I suspected that participants may be standing closer to female assistants than males. In response to these issues, I added a social validity survey starting with the fourth participant (see subsection for details) and adjusted the session design to control for a possible gender effect. The remaining participants interacted with two women and two men in the study in both baseline and intervention conditions, so I changed the study to allow four blocks of 30 seconds per session. Each participant attended the session one at a time. I rotated the participants through each block that was randomized at the time of the session using counterbalancing. Each block was paired with a research assistant to assure that the researcher was not a variable responsible for change. The session order for each participant appears in Table 4.4.

P ID	Block 1		Block 2		Block 3		Block 4	
Erik	B	B	P	P	B	B		
Fred	B	B	B	B	P	P		
Glen	B	B	P	P	B	B		
Hanna	P	B	B	P	B	P	P	B
Isaac	P	B	B	P	B	P	P	B
Jen	P	B	P	B	B	P	B	P
Kent	B	P	P	B	P	B	B	P
Laura	LOST DATA							
Mason	B	P	B	P	P	B	P	B
Noah	B	P	P	B	P	B	B	P

Table 0.4. Session Order by Participant for ProCom Study. B=Baseline and P=Proximity Conditions.

vrSocial Study Design

In the third study, I compared four conditions: baseline, volume, proximity, and a combination condition (volume + proximity). Two variables were measured: volume and proximity. Both variables were measured for every session. I conducted an initial baseline phase to determine eligibility and allow for multiple treatment comparison. Then, I ran five randomized blocks of the three intervention conditions in one-minute sessions. Session order within blocks was randomized without replacing the condition once and the same order was used for each participant. Each condition was paired with one of two trained research assistants for all conditions. The session order for each participant appears in Table 4.5.

Baseline					Block 1			Block 2			Block 3			Block 4			Block 5		
B	B	B	B	B	P	C	V	V	P	C	V	C	P	P	V	C	C	V	P

Table 0.5. Session Order for vrSocial Participants. B=Baseline, P=Pitch, V=Volume, C=Combined.

Visual Analysis

Visual analysis is a method used by behavior analysts to interpret quantified data on a line graph. Behavior analysts use this "systematic approach for interpreting the results of Behavioral research and treatment programs that entails Visual inspection of graft data for variability, level, and trend within and between experimental conditions" (Cooper et al., 2007). This analysis is conducted to determine if behavior change occurred in a meaningful way and to what extent the change can be attributed to the intervention (Cooper et al., 2007). By comparing multiple measurements of a behavior across the baseline and intervention conditions for single participant, a descriptive analysis can be constructed about the impact of the introduction and the level of intervention in relation to time. In the case of a within subject comparison, data points within each phase are viewed to understand the nature of behavior across time under those conditions; this pattern isn't compared to the patterns intervention. The pattern is determined in terms of variability (how much change occurs between data points within the same phase) resulting in dedicated categorizations, such as high variability to a stable pattern responding. The second dimension is a level at which the target behavior occurs. This requires the examiner to view the absolute value of each data point as well as consider the stability at a level. Level is often described as being high, low, or average and is compared to the variability. For example, one might say that the data path illustrates a low and stable level of responding: the data are on the small end of the y-axis and don't change much in terms of amount. Lastly, trend describes the direction of the data path and is usually described as increasing, decreasing, or having no trend (flat). I have provided these descriptions for each data path as a way to determine the changes between conditions. These elements are critical to interpreting if the intervention condition is responsible for change. I use each of these terms to describe line graphs for each condition in the studies as well as give a numeric indication of the treatment effect by calculating the percent of non-overlapping all pairs (%NAP).

Percent Nonoverlapping All Pairs

Percent of NAP is an effect sized calculation that is applied to the graphed data to provide a proxy for statistical measures of effect size. Parker & Vannest, (2009) state:

> *"NAP is a nonparametric technique for measuring nonoverlap or "dominance" for two phases. It does not include data trend. NAP is appropriate for nearly all data types and distributions, including dichotomous data. NAP has good power efficiency–about 91-94% that of linear regression for "conforming" data, and greater than 100% for highly skewed, multi-modal data. NAP is equal to the empirical AUC (Area Under*

the Curve) from a ROC test. Alternately, it can be derived from a Mann-Whitney U test. Also, it can be calculated by hand from small datasets. Strengths of NAP are its simplicity, its reflection of visual nonoverlap, and its statistical power. In many cases it is a better solution than tests of Mean or even Median differences across phases."

The formula I used to calculate the %NAP is taken from the seminal work of Parker & Vannest (Parker & Vannest, 2009; Parker, Vannest, & Davis, 2011) where they explain that a score is given to each intervention data point in comparison to all the data points in the corresponding baseline phase. When the points are compared, if the intervention data point is higher in value, give a score of 1, if the values are ties, give a score of 0.5, and if the intervention data point is lower than baseline point, score a zero. Next, add up for all points and subtract from N, (#a x #b) and take that number of total N as a percent. Determine where this percentile fits in the categories of effect size where "scores between 0 and .65 can be classified as "weak effects" (*i.e.,* no effect), 66 to .92 as "medium effects," and .92 to 1.0 as "strong effects". Lastly, I also incorpated suverys for social validty and interviews to gain insight into the participants' expirience.

Social Validity Surveys

The long-range goal of these three projects is to support nonverbal social skills to improve the quality of life for people with autism. Quality of life is determined by the participant, thus requiring a subjective measure. To insure the tools are valid to the people they aim to help, I conducted surveys as part of my study methods.

In the sayWAT study, I was interested to know if engaging with the system while engaging in conversation had any social value for the participants. So, I conducted a brief, one-question survey after each trial (*i.e.,* I rate this conversation as: 1. inadequate, 2. below average, 3. average, 4. above average, 5. excellent) as well as interviewed the participants at the end of the session. The participants rated the quality of their conversations higher in the volume and no treatment condition, slightly less positively for the pitch mode. Conversations in the volume mode were rated more highly on a 5-point scale (M=4.38, SD=.80) than in the other conditions (pitch M=4.1, SD=.71; baseline M= 4.2, SD=.71). Additionally, scores from the participants and their partners in the volume condition were analyzed via a paired t-test and found to be highly correlated (*r*=.94), see Figure 4.6. No such relationship was found for the no treatment condition (*r*=.10) or pitch condition (*r*=.64). Although not entirely conclusive, these results indicate that volume may be more easily addressed through an intervention than pitch. Additionally, people with autism may have an easier time assessing their own abilities in terms of volume.

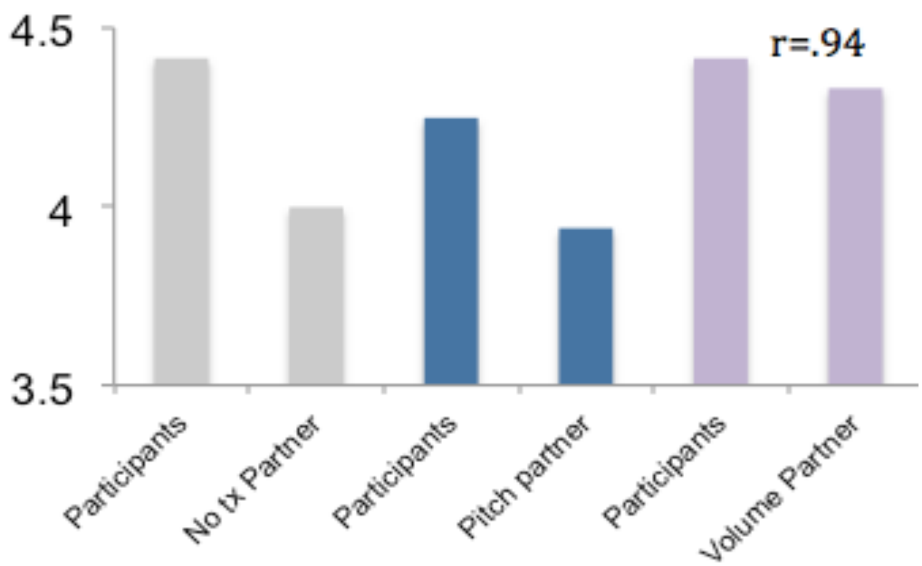

Figure 4.6. Participants' and Partners' Perception of the Quality by Condition.

I introduced a similar surveying process in the ProCom study, during which the parent who was observing their child during the trials was asked to rate the appropriateness of proximity without referring to the systems' interface after each trial, (*i.e.,* This interaction was: 1. too close, 2. A bit close, 3. Just right, 4. A bit far, 5. too far). The aim of this data was to determine the relationship between the parents' perception of a "good" distance to stand socially and the parameter borrowed from anthropology of proxemics—to see if the research measure I was using in the tool was socially valid for the participants. The scores were compared via a paired t-test to the log ratings that were translated into the same five categories. I asked parents and volunteers after each trial to rate the proximity on a five-point scale ranging from too close to too far. The scores were analyzed by running a paired t-test. Parent and volunteer independent ratings were highly correlated, indicating they agreed with each other on the specific level of proximity ranging from too close to too far (r =.83, p < .01). This high correlation confirms there was a shared understanding of what a comfortable social distance should be for each interaction. These distances also corresponded to those ProCom was reporting, indicating shared understanding of these cultural norms with the system (r = .86, p < .01), see Figure 4.7. A careful look at the graph shows that the averaged parent and research assistant raters labeled 180cm as a bit too far, where the parameters from the anthropologist rate 300 centimeters as too far.

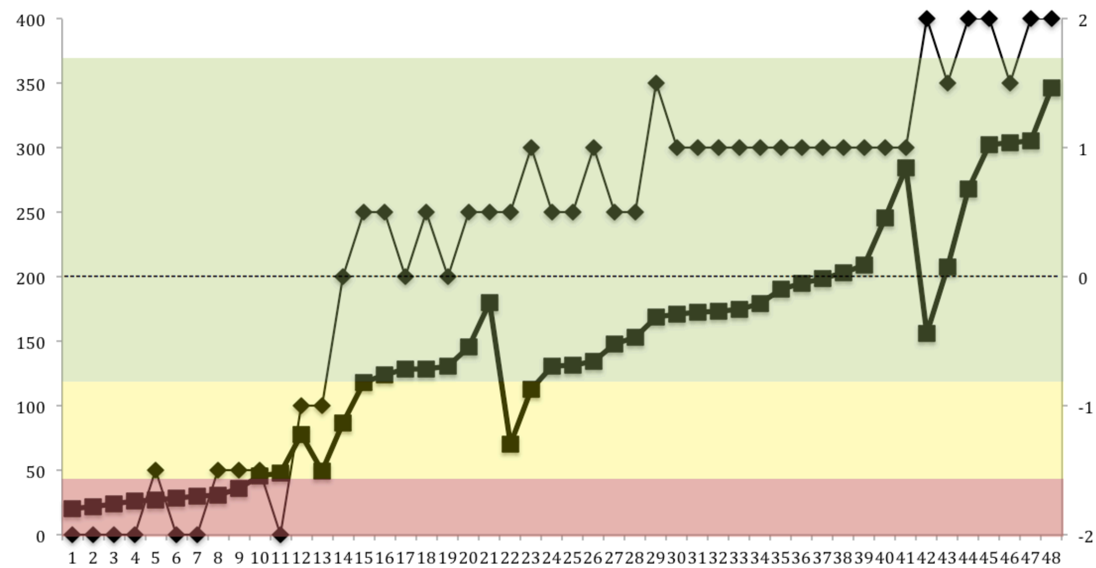

Figure 4.7. Comparing Participant Survey Responses (right axis) to System-Logged Distance of Proximity (left axis in centimeters).

Lastly, the third study did not contain a survey for social validity. Given the design of the vrSocial required a longer session length, I opted to skip the survey and rely on the interviews for validation of the intervention's design. I offered parents a chance to go into the system to get a sense or feel for the metrics from their own viewpoint, but none took me up on the offer.

Interviews

At the end of all the sessions, a brief semi-structured interview was conducted with the participant and family members in attendance. Interviews were recorded and transcribed verbatim. Both the interview transcripts and observation fieldnotes were analyzed using qualitative methods. I independently read through the materials and made notes of commonly reported or observed behaviors. Next, the research team collectively sorted our notes into categories, constantly comparing whether the definitions of the current categories were the same. I then determined axial codes for these categories and brainstormed the connection between these groups to provide insight into the experience of the participants and their family members.

Summary

I conducted three single case experimental design studies using and alternating treatment design with eighteen participants. Four of these participants were young adults with autism and of the remaining, fourteen were children ranging in age from seven to fifteen years old. Six children participated in both the Procom and vrSocial study. By employing an alternating treatment design, I was able to conduct multiple observations of conditions simultaneously during a one-day lab study. In addition to logging variables of interest, which were pitch, volume, and proximity, I also conducted surveys to validate the sayWAT and interviews. The procedures for each measured social validity as an intervention and the distance used in the ProCom study, results of which were provided here. The results of the experiments and interviews appear in the next three chapters on pitch, volume and proximity.

Participants in the first two studies were permitted to continue the study even when they did not demonstrate problematic behavior in the baseline condition. As pilot studies, their participation allowed for me to see the tool in use and collect information about their experience. For the final study, I did specify participation was limited to those who displayed less than 100% correct in either target behavior (*i.e.,* proximity and volume). The results are organized by variable: pitch, volume, and proximity.

CHAPTER 5: PITCH RESULTS

The sayWAT study evaluated pitch. The four young adults in the sayWAT experiment showed varied responses to pitch as compared to the baseline condition. The volume session is included here as the data serves as secondary comparison. These findings have been summarized by difference in means and effects size in Table 5.1. Individual performance is described below.

P ID	Baseline Mean %	Intervention Mean %	Difference between Means	Effect Size based on %NAP
Aaron	71	69	-2	weak
Ben	88	73	-15	weak
Carson	65	71	+6	medium
Diane	64	71	+7	medium

Table 0.1. Summary of SayWAT Results for Percent Correct Pitch.

For Aaron, a 25-year-old man with autism, the intervention data (solid black circles) for pitch shows a variable pattern that is slightly lower in level of correct intervals than baseline. Of interest is the volume condition with the dotted line that shows a similar variability but higher level of performance than the pitch intervention. These data paths suggest that by alternating treatments over time, no significant impact of intervention can be determined. This is echoed in the %NAP calculation, 56% NAP (5/9), as a weak effect. See Figure 5.1.

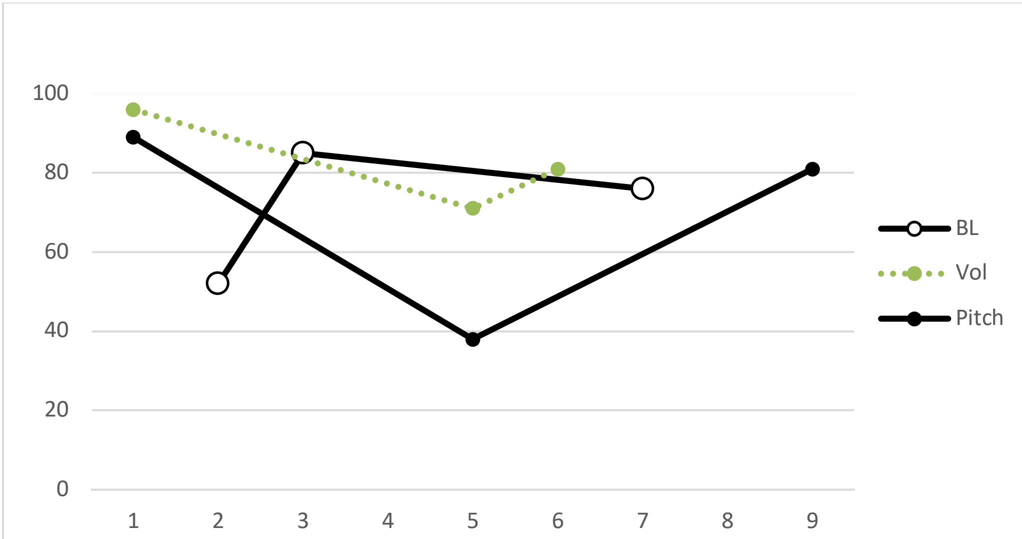

Figure 5.0.1. Aarons' Percent Correct Intervals of Pitch in the sayWAT Study.

For Ben, a 26-year-old man with autism, the data path for pitch (black circles) is increasing and approaching the high, more stable level of baseline (white circles). The volume condition is decreasing to a lower level (see Figure 5.2). These data suggest that the interventions had little to no effect on improving pitch. This is echoed in the %NAP score (1/9) 11%, a weak effect.

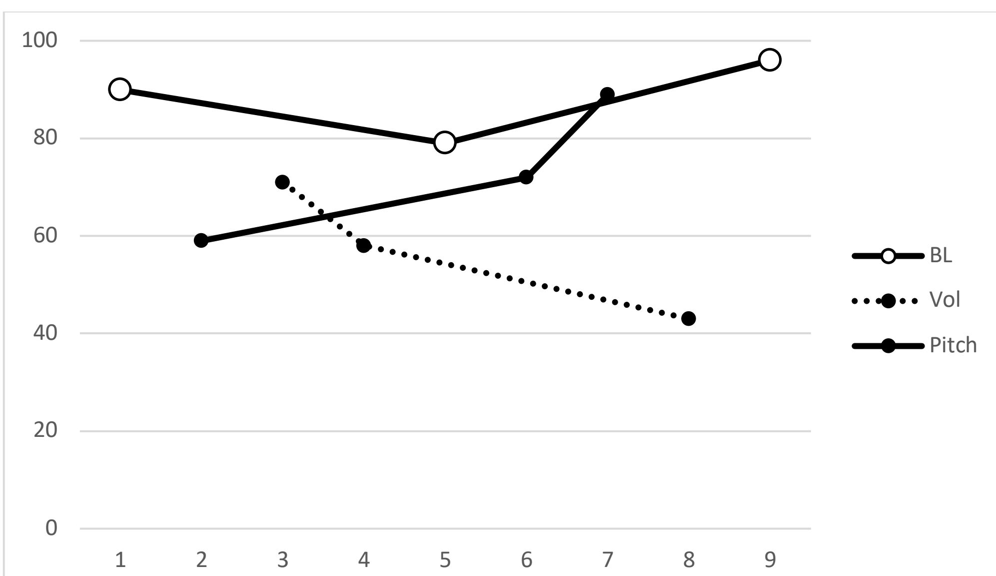

Figure 5.2. Ben's Percent Correct Intervals of Pitch in the sayWAT Study.

For Carson, a 25-year-old man with autism and sibling of Ben, the intervention data is stable and at the same average level as the highly variable baseline. This stability over the baseline points results in a medium effect size. (6/9) of 67% NAP. The volume path is decreasing showing that volume alerts had no impact on improving or maintaining correct pitch for this participant See Figure 5.3.

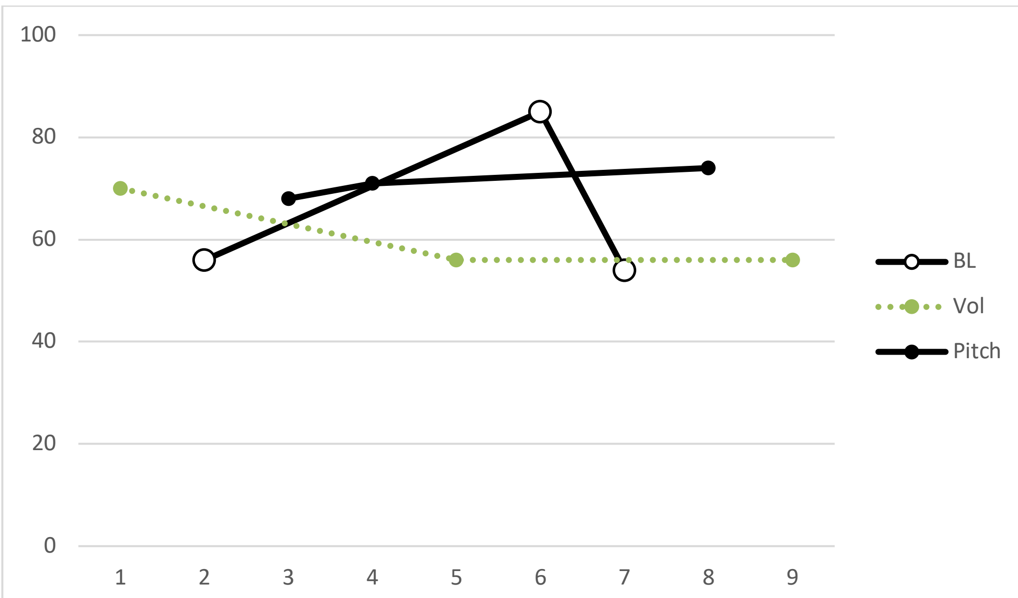

Figure 5.3. Carson's Percent Intervals of Correct Pitch in the sayWAT Study.

Lastly, for Diane, a 22 –year-old woman with autism, the data path for the pitch intervention shows an increasing trend that exceeds the increasing trend in baseline. Although both paths are increasing, the difference in change from the baseline to intervention paths is large enough to demonstrate a positive impact as reflected in (6/9) 67% NAP, a medium effect. See Figure 5.4.

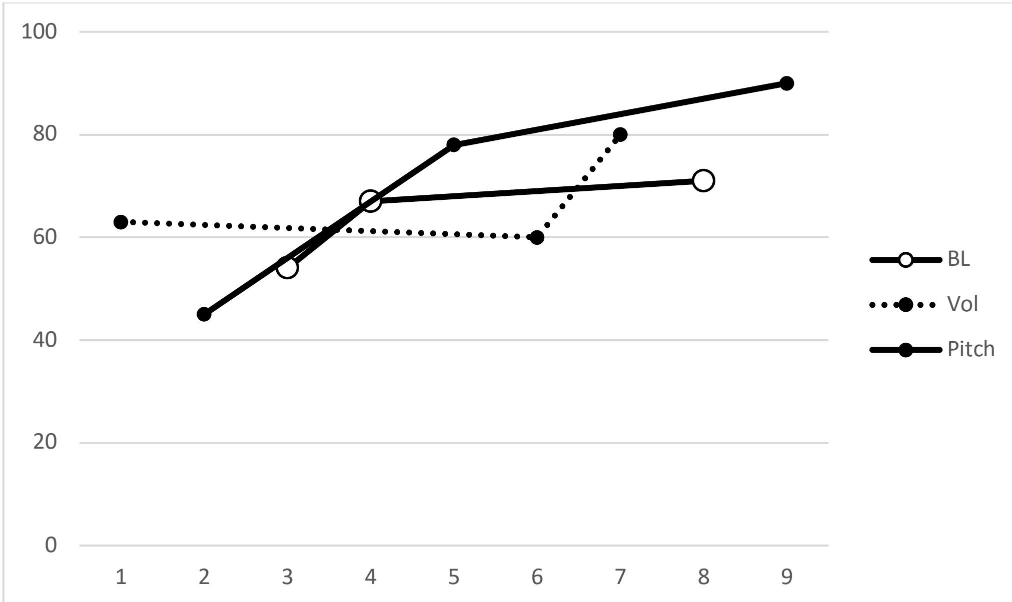

Figure 5.4. Diane's Percent Correct Intervals of Pitch in the sayWAT Study.

In summary, the intervention for pitch yielded potential for success as 50% of participants demonstrated medium effect size when alternating between intervention and baseline treatments in the lab. Additionally, the difference between means for these conditions is provided alongside these effect size calculations in Table 5.1. Lastly, as Ben demonstrated proficient (above 80% correct) in baseline (and is shown as greyed out), this participant might be excluded from a larger study as there is little room to improve with intervention, however, in this pilot work, the calculations were done after the study ended. Therefore, all input was included in terms of the experience and interest in using such as tool.

CHAPTER 6: VOLUME RESULTS

The sayWAT and vrSocial studies evaluated volume. The four young adults in the sayWAT experiment showed varied responses (50% had a strong effect, 50% had a weak effect) to the prosody cues related to volume as compared to the baseline condition. The eleven children in the vrSocial study revealed mostly weak effects. In the graphs below, the data points represent the percent correct intervals with no trigger events for each condition (*i.e.,* pitch, volume and baseline). Again, the calculations of effect size are for the difference between volume and baseline sessions. The pitch session is included here as the data serves as secondary comparison. These findings have been summarized by difference in means and effects size in Table 6.1.

Overall, in the sayWAT study, the volume condition yielded promising findings as 50% of participants had strong effects. It is noteworthy that there was little room for each participant to improve on volume as all scores are in the 89-90'range for percent correct. In the vrSocial study, the children ranged in their baseline volume from an average of 51-96% correct intervals and mostly (7 of 9) showed weak effects of the intervention.

P -ID	Mean Volume BL in AR	Mean Volume Inter-vention in AR	% Change In AR	Effect Size In AR	Mean Volume BL in VR	Mean Volume Inter-vention in VR	% Chang e In VR	Effect Size In VR
Aaron	83	89	+6	Strong				
Ben	88	86	-2	Weak				
Carson	91	81	-10	Weak				
Diane	80	85	+5	Strong				
Fred					88	77	-11	Weak
Glen					96	96	0	Weak
Isaac					63	71	8	Weak
Noah					95	97	2	Weak
Jen					57	44	13	Weak
Kent					95	95	0	Medium
Peter					51	31	-20	Weak
Quinten					87	88	+1	Weak
Roger					90	84	-6	Medium

Table 6.0.1. Summary of Volume Results for sayWAT and vrSocial Studies.

For volume, Aaron's intervention data path (black squares) is mostly at a higher level with an increasing trend compared to baseline (white squares), this is confirmed through the 94% NAP (8.5/9) which is a strong effect size, (see Figure 6.1).

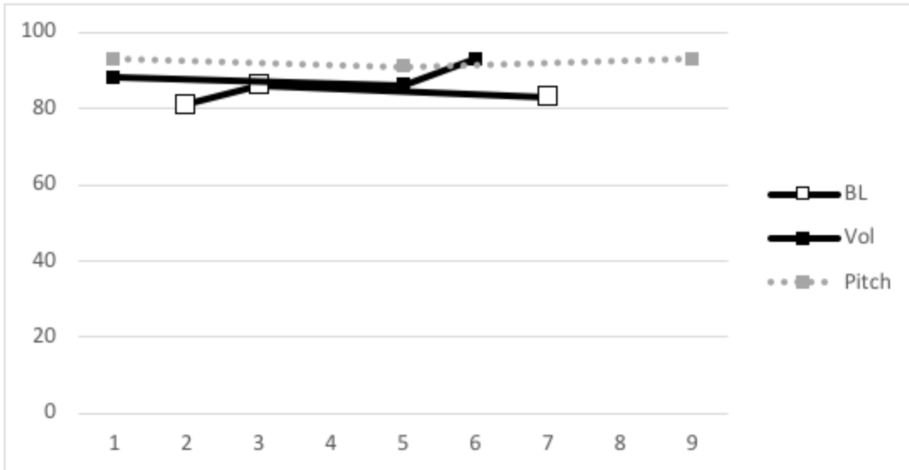

Figure 6.0.1. Aaron’s Percent Correct Intervals of Volume in the sayWAT Study.

Ben’s data path for volume baseline and intervention illustrate similar increasing trends beginning at a high level, therefore there is a weak effect of volume intervention 38% NAP (3.5/9). Additionally, the pitch path is at the same level but demonstrates no or a slightly decreasing trend, suggesting pitch alerts did not have a significant effect on volume. All but the last data point in volume suggest that time may have played a bigger role in the improvements, as all conditions are improving with time. See Figure 6.2.

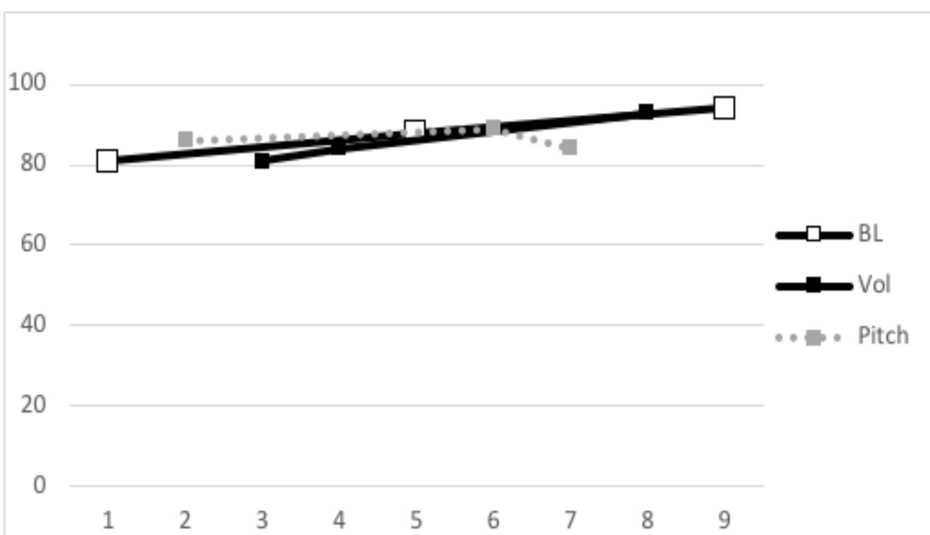

Figure 6.0.2. Ben’s Percent Correct Intervals of Volume in the sayWAT Study.

In viewing Carson's graph, the baseline (white squares) is higher and fairly stable compared to the volume intervention (black squares) data that is increasing but beginning at a lower level and just reaching the level of baseline, leading to a weak treatment effect of 22% NAP (2/9). The path for pitch (grey squares) follows the path of baseline at a slightly lower level but is mostly remaining above the volume intervention path. See Figure 6.3.

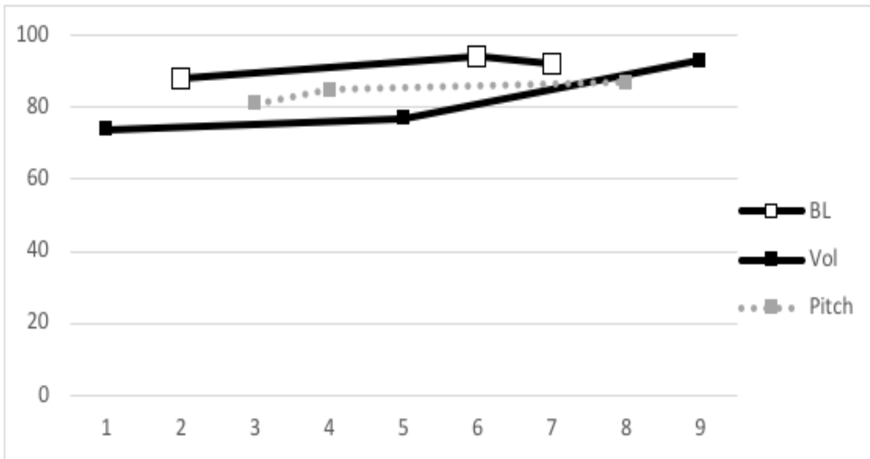

Figure 6.0.3. Carson's Percent Intervals of Volume in the sayWAT Study.

For Diane, the volume intervention is high and stable, just above the fairly stable baseline (white squares). Since her level of responding is higher in most of the treatment sessions, the effect size is strong, 94% NAP (8.5/9). See Figure 6.4.

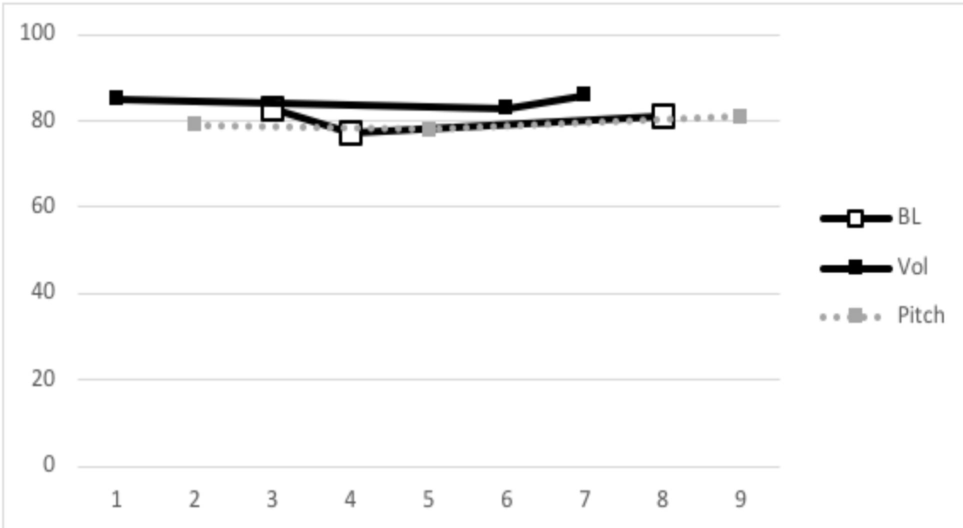

Figure 6.0.4. Diane's Percent Correct Intervals of Volume in the sayWAT Study.

In vrSocial, Fred's data path for the volume baseline is increasing to a high level (white squares) whereas the volume intervention data path (black squares) is more variable with a decreasing trend. This results in a weak treatment effect of 8% NAP (2/25). See Figure 6.5.

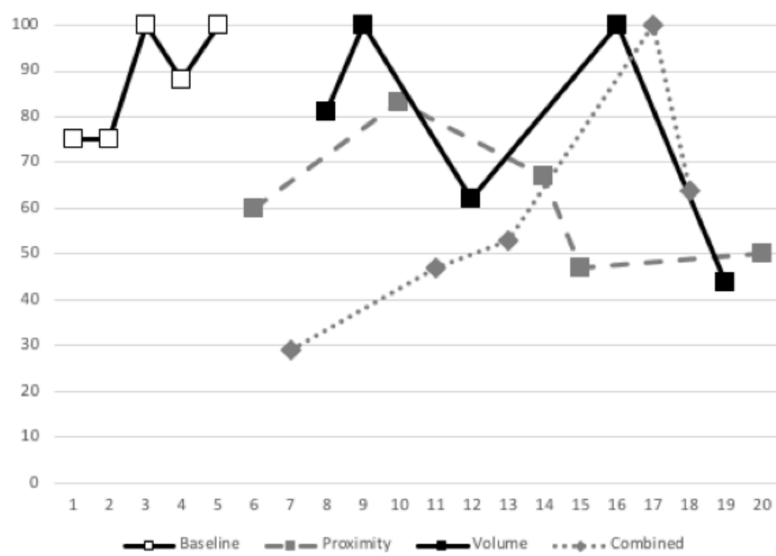

Figure 6.0.5. Fred's Percent Correct Intervals of Volume in the vrSocial Study.

In the volume condition of vrSocial, Glen exhibited an increasing trend at high levels in baseline (white squares). He exhibited a similar high level of correct volume with slight variability. Again, with his high performance in baseline, the difference between baseline and intervention condition is minimal, echoed by the weak treatment effect of 64 % NAP (16/25). See Figure 6.6.

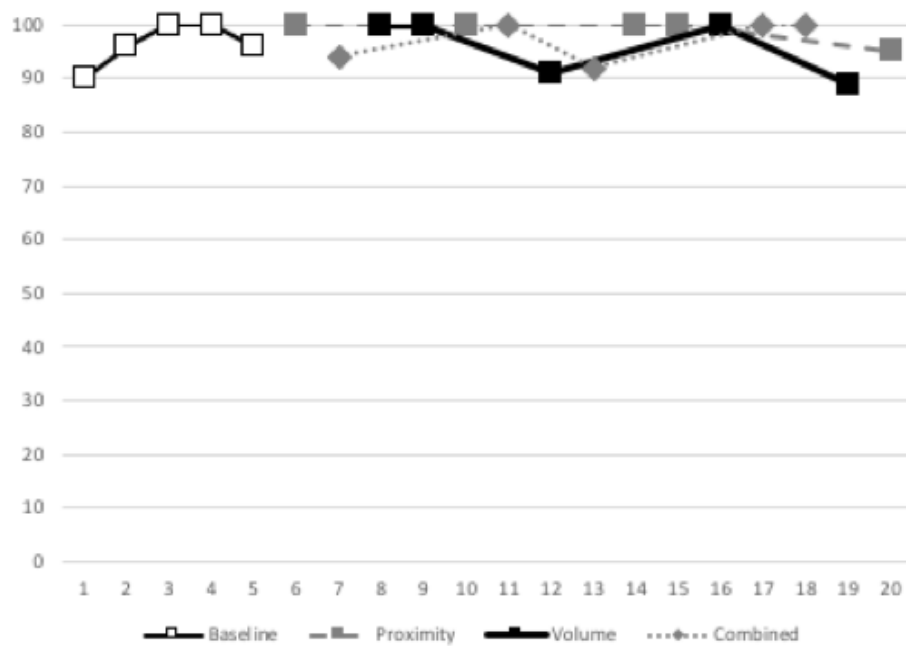

Figure 6.0.6. Glen's Percent Correct Intervals of Volume in the vrSocial Study.

Isaac displays variability in the volume intervention (black squares), spreading above and almost below baseline range resulting in a weak treatment effect at 52% NAP (13/25). See Figure 6.7.

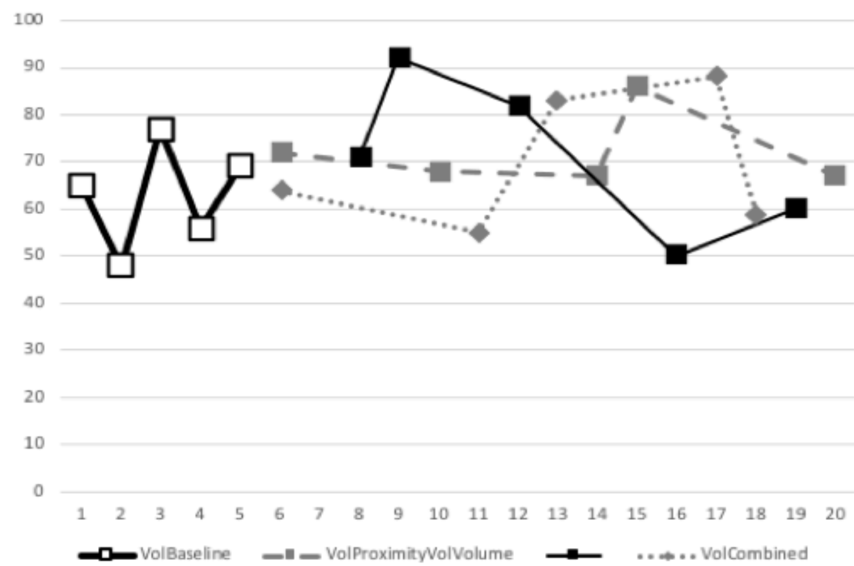

Figure 6.0.7. Isaac's Percent Correct Intervals of Volume in the vrSocial Study.

In Jen's volume condition in vrSocial, her baseline scores were variable in the mid-range and the intervention path drops to the lower end of the baseline range with some variability, showing a weak effect at 20% NAP (5/25). See Figure 6.8.

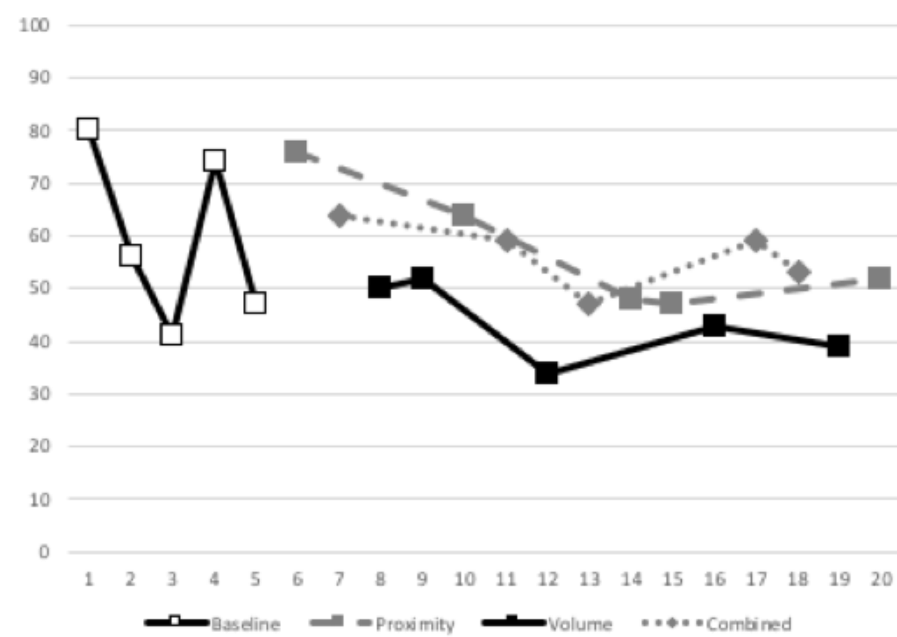

Figure 6.0.8. Jen's Percent Correct Intervals of Volume in the vrSocial Study.

In vrSocial, Kent's baseline in the volume condition was high and stable and his intervention data path is high, but is somewhat variable, resulting in medium treatment of 78% NAP (19.5/25). See Figure 6.9.

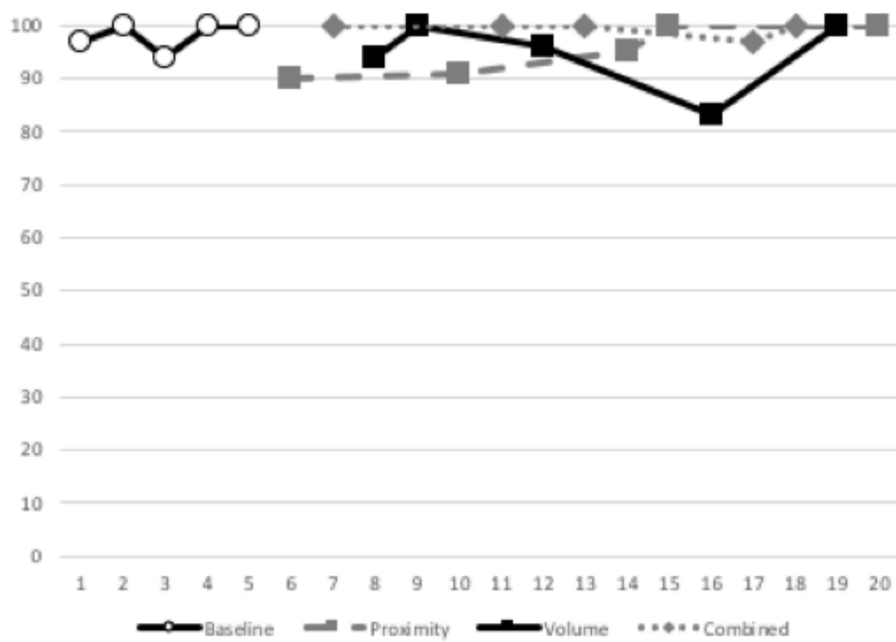

Figure 6.0.9. Kent's Percent Correct Intervals of Volume in the vrSocial Study.

In vrSocial, Noah's volume baseline (white squares) starts out high and stable. Noah's volume remains high in the volume intervention conditions (black squares), yielding little change, a weak effect at 46% NAP (11.5/25). See Figure 6.10.

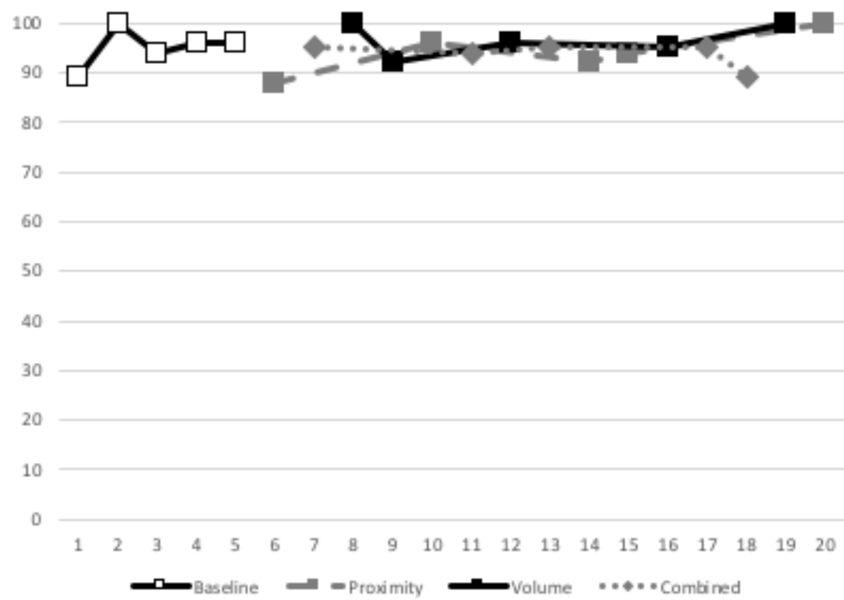

Figure 6.0.10. Noah's Percent Correct Intervals of Volume in the vrSocial Study.

For volume in vrSocial, Peter demonstrated a mid-level (around 50%) of variable performance in volume baseline (white squares) that became a lower level stable trend in the volume intervention condition (black squares), yielding a weak to no effect at 0% NAP, (0/25). See Figure 6.11.

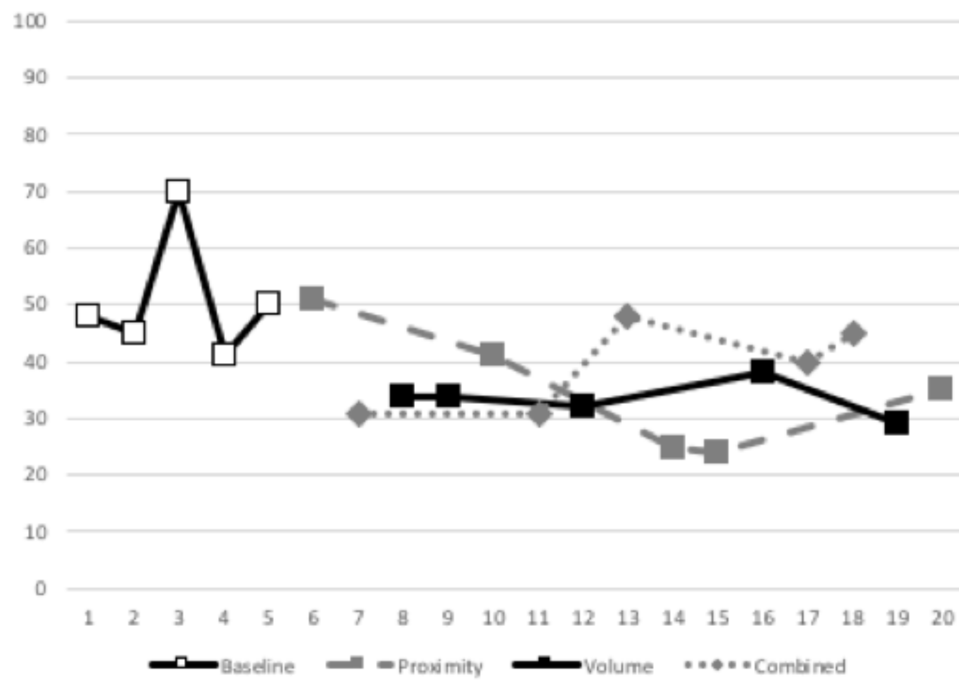

Figure 6.0.11. Peter's Percent Correct Intervals of Volume in the vrSocial Study.

In the volume condition of vrSocial, Quinten displayed a high but variable rate of correct volume intervention sessions yielding a weak treatment effect, 52% (13/25). See Figure 6.12.

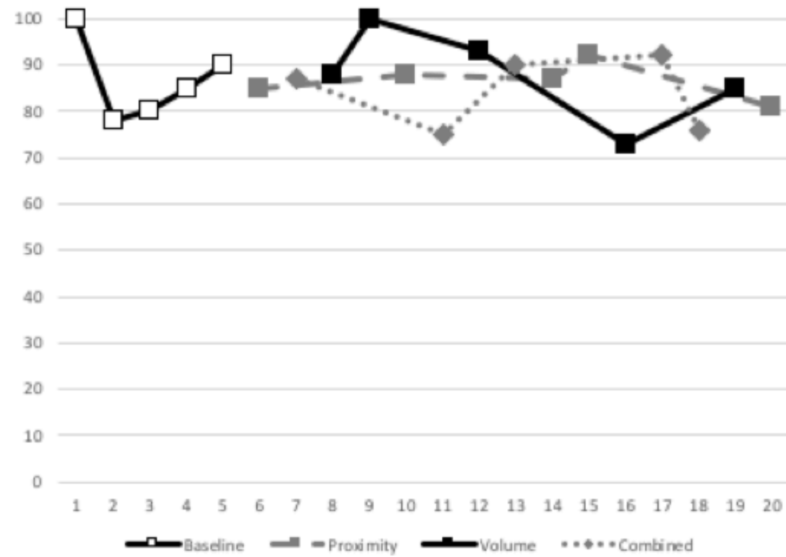

Figure 6.0.12. Quinten's Percent Correct Intervals of Volume in the Social Study.

In vrSocial, Roger's volume baseline is mid-level with an increasing trend. His volume continues to improve in the volume intervention by remaining high-level but with some variability. Due to this increased level in the intervention phase, there is a medium treatment effect for volume at 88% NAP (22.25). See Figure 6.13.

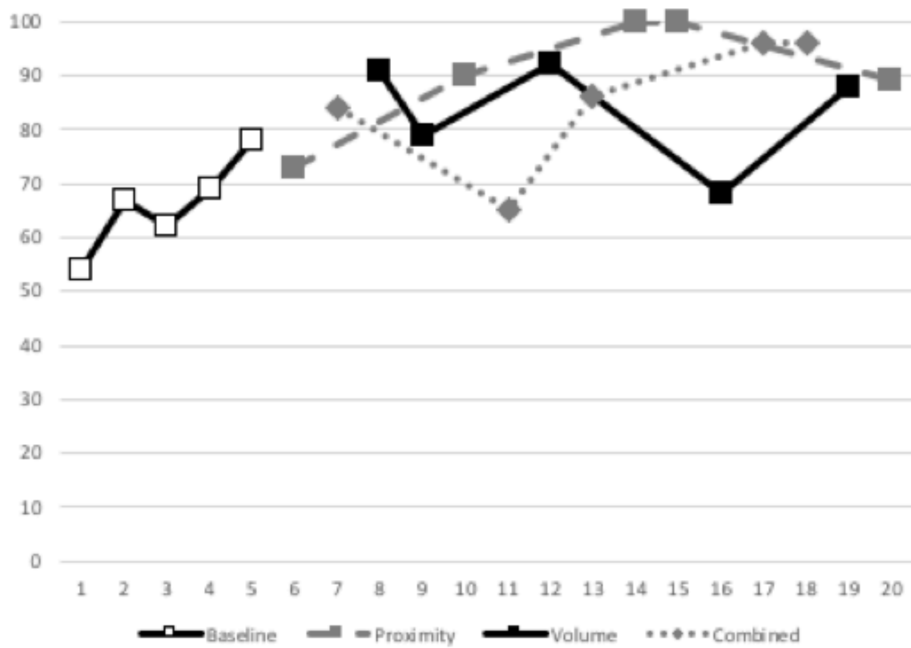

Figure 6.0.13. Roger's Percent Correct Intervals of Volume in the vrSocial Study.

In summary, the volume intervention worked better for the adult group who used the AR system than the children who used the VR system. I interpret this as both age-related improvement, as sensory sensitivity has been observed to lessen with age (Little et al., 2017), as well as a difference in the context of the study. The AR study involved chatting with three adults for 5-mintues each where the VR study involved speaking with the same partner for 20 minutes in a virtual environment, possibly a more playful setting.

CHAPTER 7: PROXIMITY RESULTS

The ProCom and vrSocial studies evaluated proximity. The ProCom study compared the distance between the participants and a research volunteer in centimeters across baseline and intervention conditions. These two conditions were randomly alternated by blocks for four blocks. The first three participants only participated in three blocks which resulted in uneven phases, so a fourth block was added (see Table 4.4 in Chapter 4). Additionally, Laura's data did not get recorded due to a technical error with the system. The experimental outcomes for the remaining nine participants are discussed next. The data presented in the graphs is the percent correct intervals (*i.e.,* seconds in the green zone).

In the vrSocial study, I screened for the presence, no matter how small, of the target behaviors by running a baseline before alternating the treatment conditions. This baseline phase allowed me to check the logs to see if the behavior was occurring and decide if the participant was eligible to continue with the interventions trials. All of the eleven participants who came into the lab qualified under one or more target behaviors. Six of the eleven participants were repeat participants who also were part of the ProCom study. These studies were conducted approximately a year apart. The ages of the participants in the table reflect their age at the time of the first study—ProCom. The ages in the descriptions below reflect their age during the current study. The data presented for each participate represents the percent correct intervals of proximity. A summary of the findings appears in Table 7.1. These data are further summarized by difference in means to reflect the change in vertical distance between the data paths; this metric captures a dimension that %NAP does not which is the degree of change in the level between the two conditions. With this metric, more weight may be given to the "medium treatment effect" assigned to these cases such as Kent and Glen who show higher responses in treatment but due to variability, this is not reflected in treatment effect size. In these two cases, that variability may be evidence that learning has occurred, as improved behavior is occurring in baseline sessions that occur *after* several treatment trials. These trends are not reflected in either difference in mean or in %NAP so visual analysis in clinical fields remains the primary mode of interpretation, supplemented by the other two metrics.

Additionally, whether a participant had room to grow should be considered when viewing results. For participants who score above 80% in baseline, an intervention may not be recommended in a community setting. Given that participants traveled to the lab for these studies and they were short term, I did not screen participants for the target behaviors. All these factors are viewed together to make a determination of the potential for an intervention.

P -ID	Mean Proximity Baseline in AR	Mean Proximity Inter-vention in AR	% Change	Effect Size	Mean Proximity Baseline in VR	Mean Proximity Inter-vention in VR	% Change	Effect Size
Erik	96	8	-88	weak				
Fred	3	0	-3	weak	8	68	+60	strong
Glen	50	100	+50	mediu m	75	96	+21	weak
Hanna	25	50	+25	weak				
Isaac	0	0	0	weak	100	54	-46	weak
Jen	99	97	-2	weak	70	85	+15	medium
Kent	22	68	+46	mediu m	40	99	+58	weak
Mason	100	100	0	weak				
Noah	100	100	0	weak	0	96	+96	strong
Peter					53	99	+46	strong
Quinten					85	96	+11	weak
Roger					56	95	+39	weak

Table 0.1. Summary of Proximity Results for ProCom and vrSocial Study.

The first participant was Erik, a 7-year-old boy with autism. Results for Erik indicate no improvement in intervention. The level is near zero with an increasing trend while the baseline before and after the intervention was fairly stable at 100%. This lack of impact is reflected in 0% NAP *(*0/8), a weak effect. See Figure 7.1. This unusual pattern of standing at a social distance (between 120-370 centimeters from partner) without the intervention and then standing closer with the intervention (in the personal space between 45-120 centimeters) could possibly be due to distraction of holding the phone. It was observed in the first session in intervention that he shook the phone, seeming to expect a specific interaction.

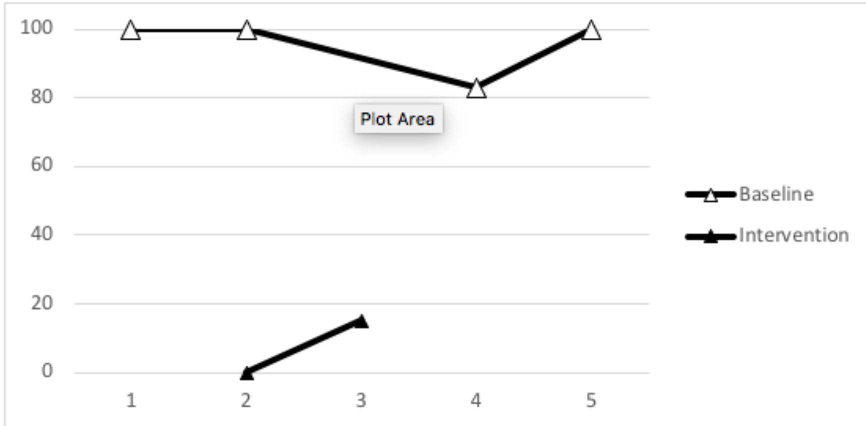

Figure 7.0.1. Erik's Percent Correct Intervals of Proximity in the ProCom Study.

For Fred, an 11-year-old with autism, the response to the intervention is similar to the baseline in that both data paths are low level and stable near 0% correct for most sessions. Since the intervention is the same or lower than baseline the treatment effect is weak at 38% NAP (3/8). See Figure 7.2, left. In the vrSocial study, Fred's vrSocial baseline proximity data path shows a low and variable level of correct proximity (white circles) and is contrasted by the highly variable proximity intervention data path that is increasing from 60% to 100% until the last session dips to 12% (black circle). This dramatic change in performance for proximity yields a strong treatment effect of 96% NAP (24/25). See Figure 7.2, right.

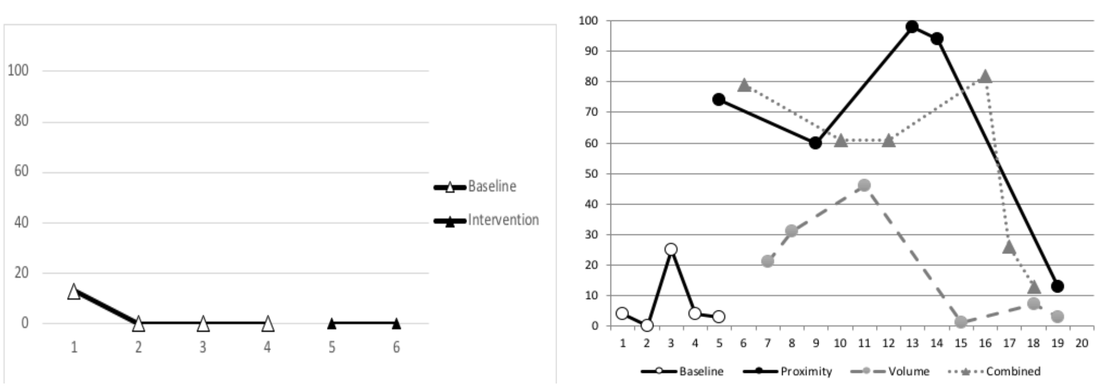

Figure 7.0.2. Fred's Percent Correct Proximity in the ProCom (left) and vrSocial (right).

Glen is a twelve-year-old boy with autism. His intervention data path reveals a possible learning effect from the initial exposure to the intervention. Here there is a low and stable baseline at 0% correct proximity for first baseline, then a jump to 100% in treatment, then a maintenance of that high and stable level in the return to baseline, suggesting that learning behavior occurred. This change is reflected in the medium treatment effect of 75%NAP, (6/8). See Figure 7.3, left. Glen's performance in baseline in vrSocial is variable due to one of the five sessions yielding a zero percent correct when the others were high (*i.e.,* 80-100% percent correct). In the proximity intervention, his performance remained high and stable. All sessions were above 90% correct (black circles) but with the strong baseline scores, the difference between these conditions is minimal, yielding a weak treatment effect 60% NAP, (15/25). See Figure 7.3 right.

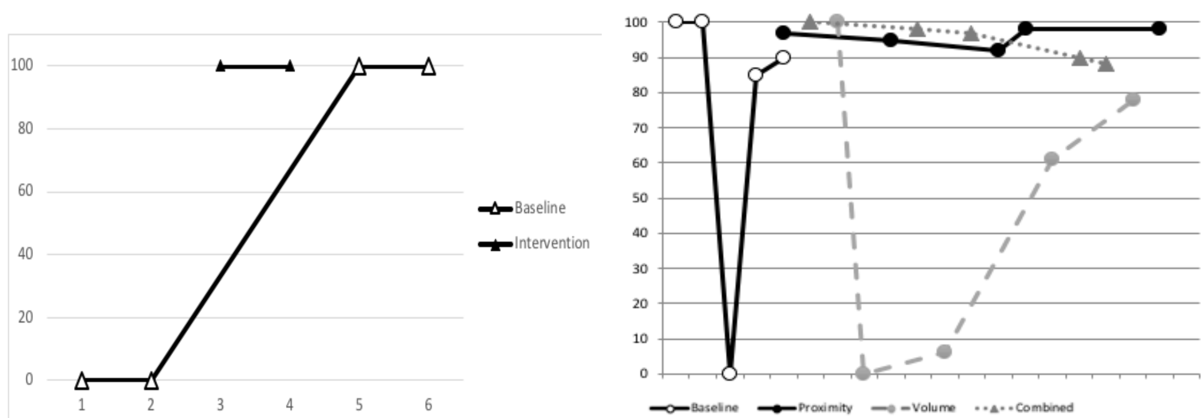

Figure 7.0.3. Glen's Percent Correct Proximity the ProCom (left) vrSocial (right) Studies.

Hanna is an 11-year-old girl with autism and down syndrome. Her data path for intervention and baseline show a pattern that indicates high variability in both conditions. The intervention data path (black triangle) starts off at 100% and drops to 0% while the baseline stays mostly at zero with one outlying session at 100%. Given the high change that occurred in both conditions, this session has a weak effect at 63% (10/16). See Figure

7.4. Reviewing the log data with research assistants, we reveal that the first session she stood on the farthest edge of the social zone and examined the phone, but came very close, into the intimate zone, which is standing less than 45 centimeters away from the other, with the same female research assistant in the following session.

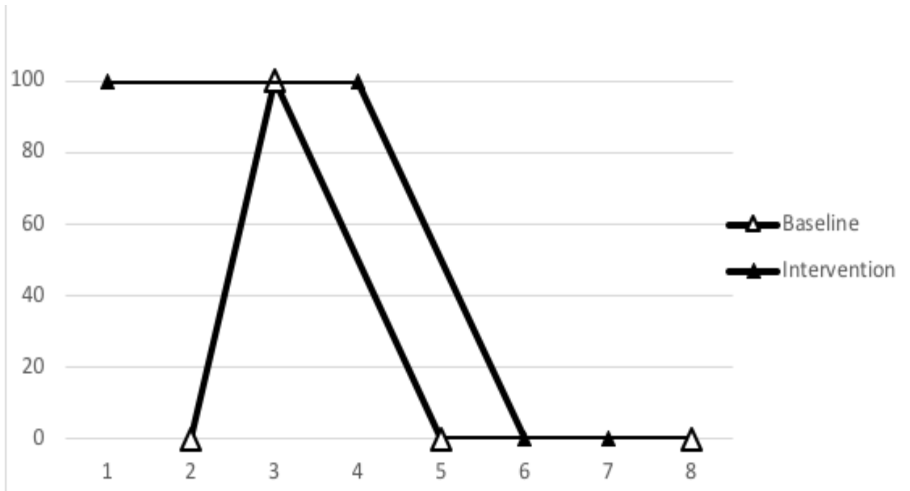

Figure 7.0.4. Hana's Percent Correct Intervals of Proximity in the ProCom Study.

Isaac is a fourteen-year-old boy with autism who did not respond to or attend to the phone and stood close to the research assistants in all trials, regardless of condition. He engaged with researchers by standing side by side with the researcher, and in one trial, shared his screen with the research assistant. The system was not calibrated for this type of stance, which would allow for closer proximity given one's eyes are not directly in line (Marshall et al., 2011). Had I included the side by side formation in our analysis, his position would have been correct rather than a zero for one of the treatment sessions. However, I only captured data related to face-to-face interactions, and consequently, his proximity was 0% correct for all sessions, resulting in a weak treatment effect of 50% NAP, (8/16). See Figure 7.5, left. In vrSocial, Isaac displays nearly perfect proximity in baseline (white circles) with variability in his volume (white squares), thus volume is the primary target for this case. In the treatment for proximity, Isaac's proximity intervention data path (black circles) is highly variable and at a lower rate than his baseline, as are the data paths for the other conditions, perhaps suggesting that he was exploring the system. This comparison yields a 0% NAP (0/25), a weak treatment effect but the focus for this participant is his response to the volume visualization. See Figure 7.5, right.

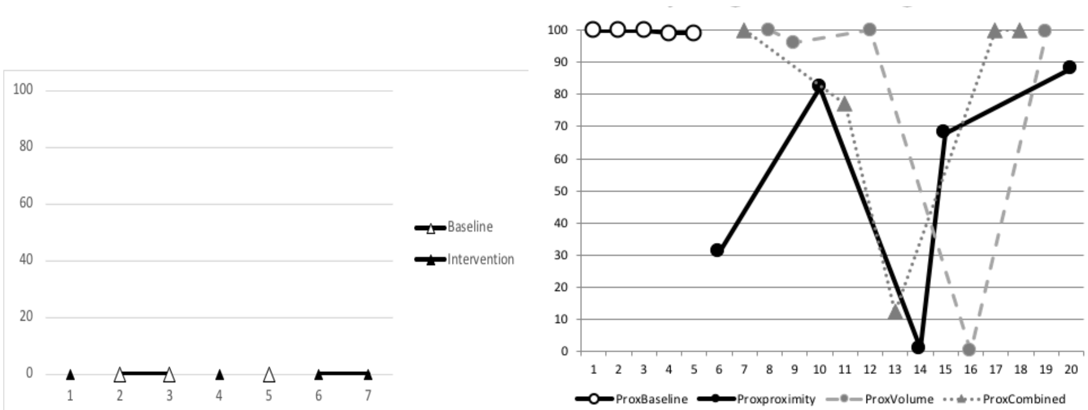

Figure 7.0.5. Isaac's Percent Correct Proximity in the ProCom (left) and vrSocial (right) Studies.

Kent is an 11-year-old boy with autism. His intervention path is highly variable, mostly high level with one outlying low session near the beginning of the study (black triangles). The lower level baseline is stable until a spike in the last session. This spike occurs after 3 treatment sessions and 3 baseline sessions which could have possibly supported learning the target skill during this study. The higher rates in the intervention condition resulted in 81% NAP (13/16), a medium treatment effect. See Figure 7.6, left. In vrSocial, Kent displayed extreme variability in the proximity baseline by fluctuating from 100% to 0% back to 100%. With the proximity visualizations, Kent's scores returned to a high and stable level (black circles). With the degree of overlapping data points between baseline and treatment, Kent's %NAP is weak at 58%, (14.5/25). See Figure 7.6, right.

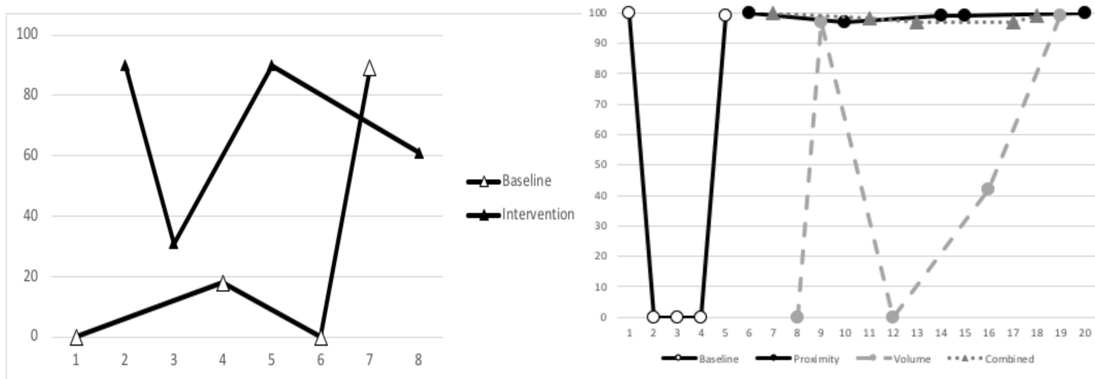

Figure 7.0.6. Kent's Percent Correct Proximity in the ProCom (left) and vrSocial (right) Studies.

Jen is Kent's sister and is an 8-year-old girl with autism. In the ProCom study, she demonstrated very high and stable rates of correct proximity in both baseline and intervention condition, resulting in very little differentiation between the two conditions, thus a weak effect at 34% NAP (5.5/16). See Figure 7.7, left. Jen displayed a decreasing trend in baseline for proximity with an increasingly stable high rate of correct proximity in the intervention sessions (black circles), resulting in a medium treatment effect of 66% NAP, (16.5/25). See Figure 7.7, right.

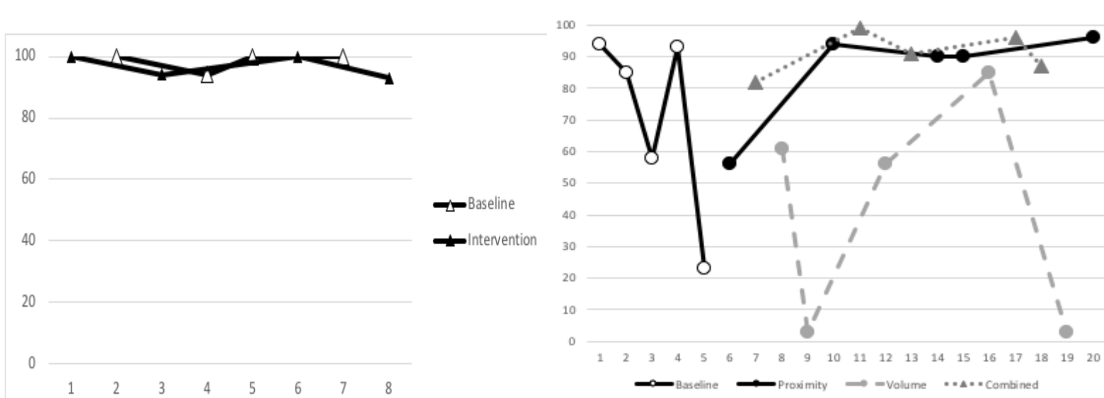

Figure 7.0.7. Jen's Percent Correct Proximity in ProCom (left) and in the vrSocial (right) Studies.

Mason is an 8-year-old boy with autism who demonstrated a perfect score of 100% in all sessions, regardless of condition. There is no room for improvement over the baseline. Since the scores were the same, the NAP is 50% (8/16), a weak effect. See Figure 7.8.

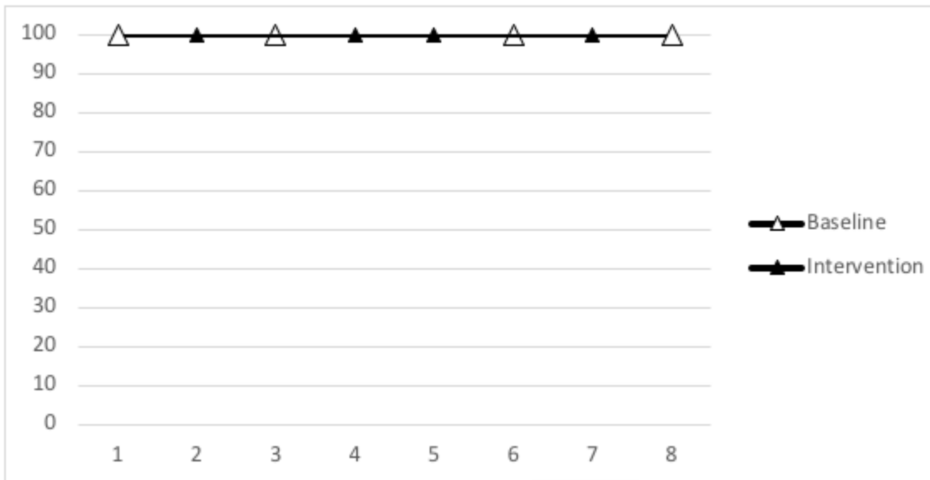

Figure 7.0.8. Mason's Percent Correct Intervals of Proximity in the ProCom Study.

Noah is an 8-year-old boy with autism. He demonstrated the same perfect score in the ProCom study (similar to Mason) for both intervention and baseline sessions, resulting in another weak effect of 50% NAP (8/16), see Figure 7.9, left. His vrSocial baseline level of proximity is a stable 0% with a dramatic increase to a high stable trend near 100%, a strong treatment effect of 100% NAP (25/25). See Figure 7.9, right.

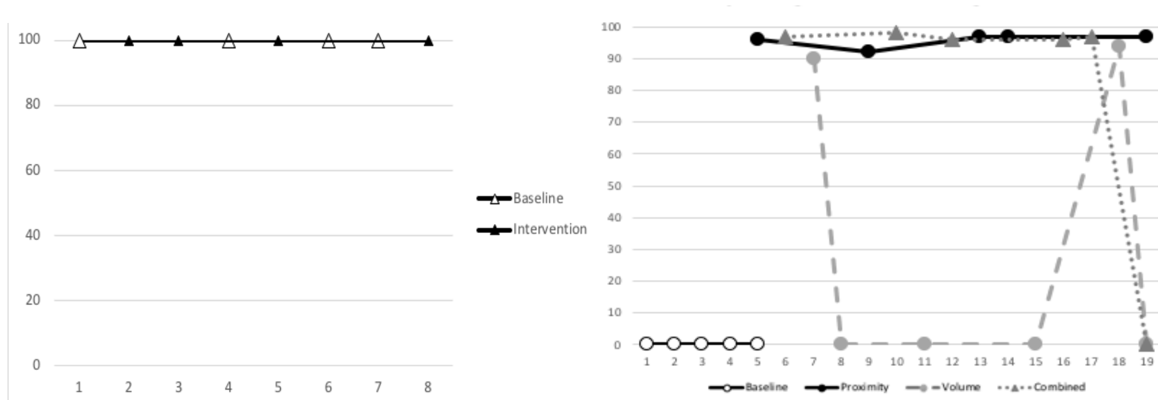

Figure 7.0.9. Noah's Percent Correct Proximity in the ProCom (left) and vrSocial (right) Studies.

Peter, a 7-year-old boy with autism and ADHD demonstrated a highly variable baseline for proximity in vrSocial with a score ranging between 0% and 90%, while his proximity intervention data is high and stable, resulting in a strong treatment effect of 100% NAP, (25/25). See Figure 7.10.

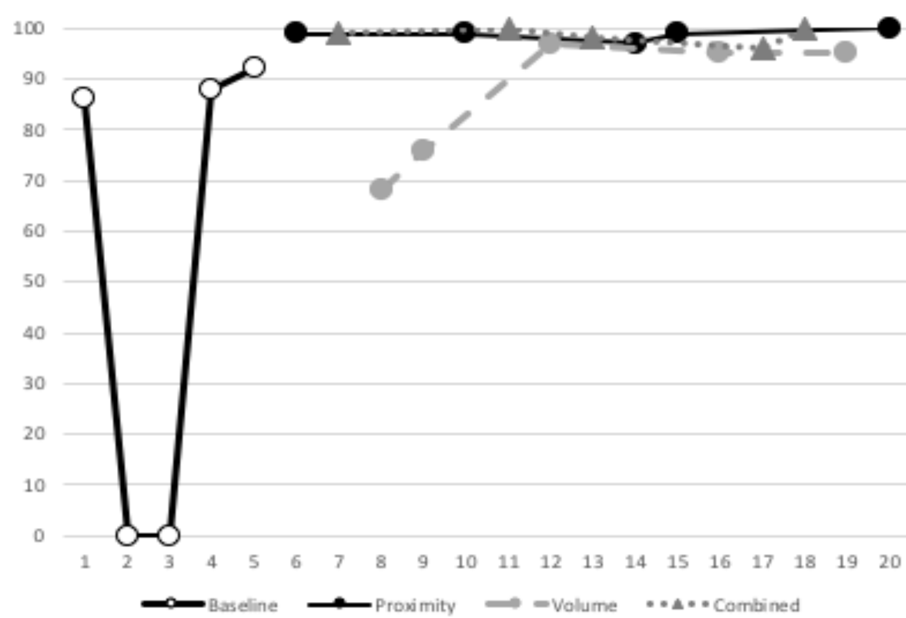

Figure 7.0.10. Peter's Percent Correct Proximity in the vrSocial Study.

Quinten, a 10-year-old boy with autism and Peter's older brother, demonstrated an increasing trend resulting in high scores in the proximity baseline in the vrSocial study. This high level became stable in the proximity intervention (black circles) resulting in little treatment effect at 40% NAP (10/25). See Figure 7.11.

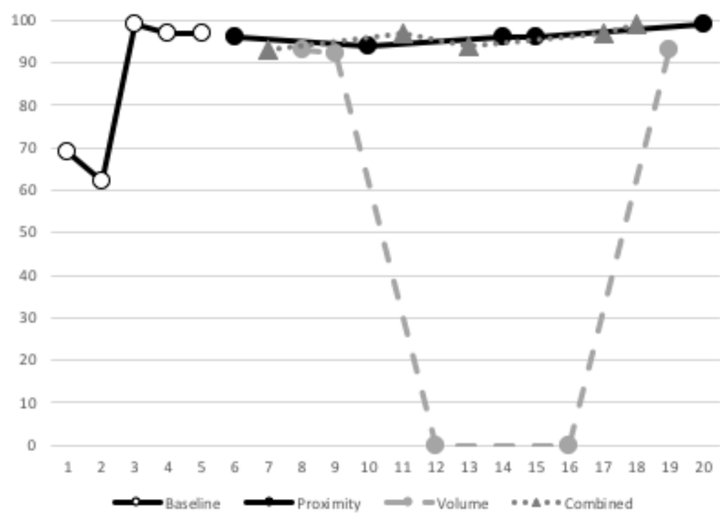

Figure 7.0.11. Quinten's Percent Correct Proximity in the vrSocial Study.

Roger is an 8-year-old boy with autism who participated in the vrSocial study. His proximity baseline data path (white circles) is highly variable: the data starts out at a high level then rapidly decreases to a low level of zero while the intervention path (black circles) is high and stable. Due to the initially high baseline scores, the treatment effect is weak (just below medium effect cut off of 65%) at 64% NAP (6/25). See Figure 7.12.

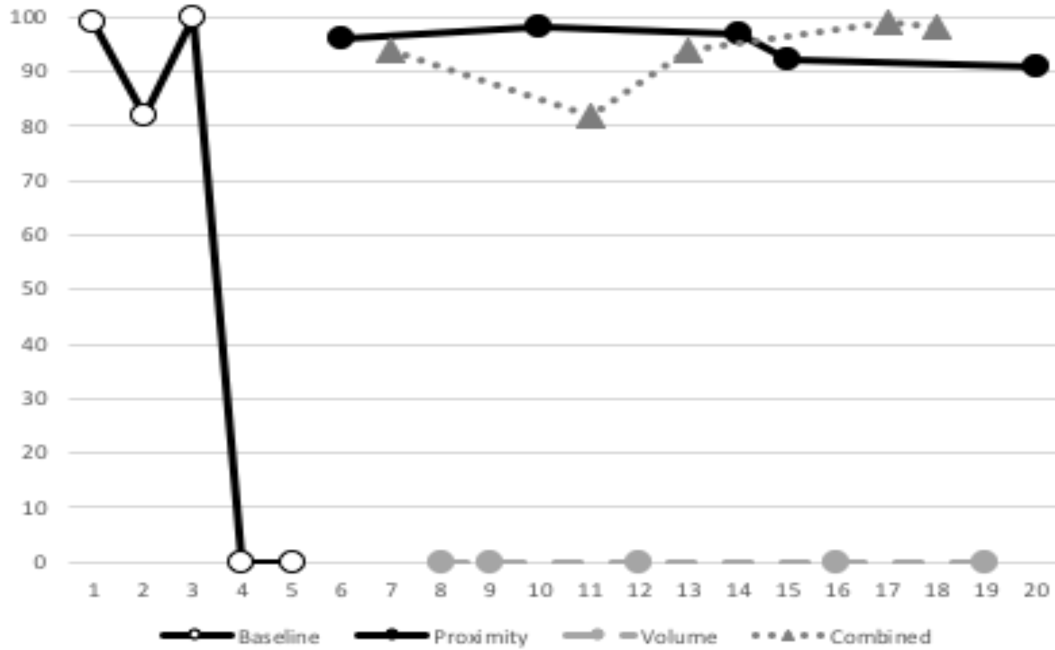

Figure 7.0.12. Roger's Percent Correct Proximity in the vrSocial Study.

Laura and Olivia are twin girls who volunteered for the ProCom study, but only one chose to participate in the ProCom study. The day they came in for the vrSocial study, they both chose to participate yet they were not able to follow the protocol to leave the headset and headphones on for one-minute trials, so no experimental data was collected for them. They were, however, invited to explore the system over the next two hours in which they each took turns wearing the headset and interacting with the research assistant as an avatar without the constraint of having to stay in the system for repeated one-minute trials. I have included their data in this work as they contributed qualitative data. Details of their experience appear in the Chapter 8.

Summary

The three studies in this work show a socially-significant portion of participants had an immediate positive response to visualizations. This is encouraging, as previous literature purports that by simply being in social proximity with others, social relationships are more likely to form. Those participants who displayed strong and medium effects appear to have been able to understand and implement the information provided in the visualization. For those who had a weak effect, other mediating variables may have attributed to the poor outcome. Factors that competed with the interventions were: lack of awareness of nonverbal communication difficulties; lack of understanding of interface; and lack of motivation to engage with the interface. Factors related to sensory sensitivities also provide insight into design recommendations and are presented at the end of this chapter.

In my exploration to understand the impact of visualizations for pitch, volume, and proximity across two augmentative reality platforms and one virtual reality platform, I found visualizations in AR and VR systems do have a positive impact on some users who demonstrate difficulties performing normative social behaviors. The experiments were conducted to determine behavior change that reaches clinical or social significance—defined by Baer, Wolf, and Risley as the "*extent to which changes in the target behavior result in noticeable changes in the reasons those behaviors were selected for change originally*" (Cooper et al., 2007). The targeted behaviors in this work--pitch, volume, and proximity--were selected because they are foundational dimensions of nonverbal communication. Given people with autism have difficulties with nonverbal communication, any improvement in these variables is deemed socially significant. These findings, of measured differences in variables between intervention and baseline conditions, providing evidence of the degree of effectiveness and speed with which these changes can be made, were observed in the samples.

Project & PD#	Pitch in AR	Volume in AR	Volume in VR	Proximity in AR	Proximity in VR
Aaron	Weak	strong			
Ben	Weak	weak			
Carson	medium	*weak			
Diane	medium	strong			
Erik				*weak	
Fred			weak	weak	strong
Glen			*weak	medium	weak
Hanna				weak	
Isaac			weak	weak	*weak
Jen			*weak	medium	weak
Kent			medium	*weak	medium
Laura			N/A	N/A	N/A
Mason				*weak	
Noah			*weak	*weak	strong
Olivia			N/A		N/A
Peter			weak		strong
Quinten			weak		weak
Roger			*medium		weak

Table 0.2. All Study Participants Results by Platform and Variable. * Participants that Achieved 90% Correct or Above in Baseline.

Overall, AR and VR systems each have potential for participants who demonstrate weakness in proximity and prosody. For the adults who participated in sayWAT, the volume condition was more successful. For the group of children who participated in both ProCom and vrSocial, proximity was improved for a few participants who demonstrated poor proximity in baseline. In vrSocial, proximity was improved in many while volume did not have a significant impact. In summary, the %NAP treatment effect results in Table 7.2 indicate that there are 14 weak cases, 6 medium effect cases, and 5 strong effect cases (11/25) culminating in 44% successful cases. Many cases were in the 80% in baseline, or so variable that effect size does not tell a complete story. In a clinical trial, these participants would not be screened into these types of studies. As pilot work without any technological comparisons, it was prudent to include everyone who was interested so that we can learn who might be a target for responses in bigger studies as well as how the participants and their parents felt about using technology to support social skill.

Combining Variables in VR

The motivation for including combination intervention conditions was to see if more information resulted in more or less change in target behaviors. The visual analysis of each participants' combination condition shows a similar pattern compared to the corresponding proximity and volume data. This finding suggests that participants responded to the nonverbal communication visualizations consistently in terms of the response in a single condition or, a combination condition. This could imply that multiple interventions could be employed at one time. Future work could explore the boundaries of how much information is enough or too much to be actionable. Other variables need to be explored as well because not every participant demonstrated improvement.

CHAPTER 8: FEASIBILITY RESULTS

In this chapter, I answer research question 2: What factors surrounding a technological social skills intervention impact its efficacy and acceptance? I discuss the themes that developed across the observations, surveys, and interviews regarding the factors that impacted the users' experience. In support of the encouraging qualitative results, the qualitative data provide insight into the *social significance* of using a technical social skill intervention. Participants discuss what it was like to wear an intervention and how a system could provide insight into their partner's nonverbal communication. In the studies that involved children, the parents and I observed how independently the participants used the system and what aspects of the system were easy to use or created barriers to use. Each of these themes is discussed below. Overall, participants reported that the systems were simple, and usually, enjoyable to use.

Overall Usability of a Wearable Intervention

A major concern of my design was that wearers not be distracted from their primary task of engaging in conversation. In each study, participants confirmed they saw the alerts and acknowledged the information was new, as well as in a few cases, asked for more information or instruction. Part of the point of these technologies is to create an awareness so that a change is possible. In sayWAT, Carson reported that the system *"was ok, I wouldn't say distracting, interesting seeing something just right there"* and the ease of use was echoed by Diane when she said *"[I] just let it go, I did fine I think, I really enjoyed it".* They commented they were able to blend its feedback into their interactions. Carson said about sayWAT, *"I could see the volume, it made sense. It was very natural, I just did what was natural in my normal voice, if I tried to go up or down it seemed unnatural...after getting* *adapted to it, the very low ones were my partner, then the larger ones was me, after figuring that out, it was much easier to do it."* The ability to comprehend volume more readily than pitch feedback likely explains the stronger demonstration of efficacy for volume.

In ProCom, some participants articulated their understanding of the ProCom interface (*i.e.,* Fred and Glen both mentioned that the colors changed as the person moves). Kent noted that the system "*tells you to stop, you can see,"* adding "*it started out a green and it stops being green and it went to red and I backed up.*" Noah said for him that ProCom "*answered questions about closeness and told him to back up a little bit.*" All the children stated that they liked the ProCom system, with a few caveats. For example, Glen said "*it was really cool but creepy how it knows where you are*." Comments referring to the system knowing where one is point to a concern for the user's privacy. An explicit explanation of what is recorded—timestamp, ID number, and a continuous log of centimeters from others—may have helped the participants to not worry about their privacy, although this knowledge does not account for how others might perceive such a system. Jen expresses this self-consciousness of not wanting to appear as if she is spying on others. Many of the AR interviews focused on how this system could be used outside the lab. Parents suggested making the system appear to be more like a clothing accessory. Customizing for a child's fashion preferences was mentioned frequently during test sessions. This request is consistent with literature regarding the potential for stigma associated with wearing assistive technologies (Profita, Albaghli, Findlater, Jaeger, & Kane, 2016; Shinohara & Wobbrock, 2011).

Rather than focus on appearance of the system, for the VR study, one mother challenged the value of using the system in life outside of the lab. Mason's mother wondered if the skills are transferrable, which could be a target for future work. This work did not target the generalizability of learning that occurs in the experimental studies to life outside of the lab. However, given the difference in participants comfort levels in VR compared to AR, one might infer the potential for transference. For example, after spending a combined three hours in the lab, Laura eventually put on the headset and explored the VR environment as well as engaged in greetings with the research assistant. At one point she approached his avatar and began reaching out to explore touching him. See Figure 8.1. This is especially interesting as in the AR study, she would not approach the research assistant and maintained a distance over 22 feet.

Figure 8.1. A Participant and Research Assistant Interacting during VR session (Left) and After the Session (Right).

Overall, the participants enjoyed the VR system. The mother of Glen states that she believes Glen "*was more immersed in Virtual Reality because he is also into video games.*" Comments like these suggest there is an acceptance for technically mediated social interactions. Evidence of video game culture and screens more broadly in society is changing what is considered “normal” in terms of interaction, and it is particularly empowering in terms of this population (Ringland, 2018).

Additionally, this familiarity with videogames seems to have supported the *ease of use* of the VR system. The mother of Quinten said:

> *“I love it. I mean, to work on so many social skills this way, it’s an incredible way of thinking about it all. I didn’t think about it that way, you’re always forcing one on one, face-to-face. For him, there is definitely a change. It’s totally different, his interactions. He doesn’t normally communicate when people come over, he barely will say hi to the adults.”*

The ease with which participants engaged in the interaction with the visualizations creates an accessible means for social engagement. The VR system was usable and enjoyable. Parents were surprised how comfortable their children felt in VR. Noah described his interactions in VR as “*easy peasy*” despite reportedly struggling in other social skills therapies.

Expressing Interest in Others

Although created for social situations, all three systems were designed to be tools for the individual, meaning the data is private for the wearer. A major challenge of delivering feedback based on audio data in the same physical space, however, is that the other speaker influences the information received. As described previously, in the volume condition in sayWAT, this is quite explicit. Carson described wanting more of such feedback and suggested that the feedback could be related to their conversational partner’s interest in their interaction:

> *If it could know a person’s interests due to the tone of their voice that might be interesting. If it can pick up if the person is bored, the person you are talking to, it would be pretty interesting, like allow the person speaking to shift gears to get to something they know.*

Carson's interest in exploring the potential of an augmented social interaction leave the questions about how one might adapt our design decisions to be flexible enough to provide more structure for interested users. In other works, researchers have grappled with some of these issues. For example, in the social emotional prosthetic (el Kaliouby et al., 2006) and *Superpower Glass* (Voss et al., 2016), these wearable systems for children with autism focus on providing the wearer with information about the other persons' affect. In MOSOCO, the system had an explicit button to automatically generate a partner's interests (Escobedo et al., 2012). In sayWAT, the alerts about a conversation partner's prosody *could* help the wearer to identify nonverbal behaviors or even emotions in their conversational partners. This type of exploration could prove to be useful in understanding the conversational partner's state as well as the impact of one's own prosody in the conversation, and ultimately the communication between them.

Ramping Up Through Co-Use

One way to support the uptake of wearable assistive technology is to consider "step up" versions of systems to support learning. Prior literature in personal informatics indicates three phases of use of personal systems: understanding the collected data, reflecting on it, and taking action (Li, Dey, & Forlizzi, 2010). This "stage-based" approach is complicated in wearable assistive technologies for children, because caregivers often initiate use of a system and are interested in behavior change. Meanwhile, the users may not be motivated to use the system or have an understanding of its purpose. For example, all but one parent still expressed interest in using ProCom in day-to-day activities. Jen and Kent's mother explained that she wants social proximity to be mastered:

I want them to know not to stand too close because it's annoying the person in front of you and they're going to be like 'back up'. But it's not something they are motivated to care about. They've never really been motivated to care, I care – but they don't. I don't want to have to constantly tell them, you know remind them. With (ProCom) they're still getting feedback – instead of having the person talking about it. Just them being able to learn it without me having to always tell them.

The mother of Fred also expressed her concern over her son's lack of awareness of social norms related to personal space:

I feel he doesn't know how close to get or how to close not to get. It's like an abstract idea for him… walking between spaces or Disneyland or anywhere you're trying to walk through a group, it's like he's not even aware that he walked in through them, that's how low his proximity compass is.

Likewise, the mother of Erik expressed the relief such a system would have been when her son was first learning this skill:

If we had a system like this, then maybe it would've been easier maybe, it would've been much more short-lived perhaps. Maybe we would be less stressed out because behaviors like that prevent us from going out to a lot of public places.

Therefore, designers could support an initial "ramp up" phase to assist parents in teaching their children to use the system. Learning to use wearable assistive technology could involve verbal, gestural, or physical prompting to teach a user how to check one's position in relation to others and reference the feedback from the system. Although children receive ongoing prompts from others in day-to-day life, the choice to respond or not to respond to the information on a dynamic screen is left up to the user. Users who depend on others, either conversation partners or parents, are engaged in a collaborative experience. Dependent users gain support from those who understand that the purpose of the technology is assistive (*i.e.,* parents, therapists, conversational partners) (Profita et al., 2016). Therefore, designing for assistance suggests designing in a way to make the support needed visible enough to enlist others to collaborate in achieving the social task when needed.

A collaborative approach could reduce the work the parents do to prepare their children to use a system due to sensory sensitivities. A ramp up mode could be designed to support the systematic de-sensitization parents use to support a child in adopting a new tool. Some mothers supported their children during the ProCom trials by intervening when their children became disengaged from the conversation or started playing with the system. When Erik disengaged with the conversation partner, his mother called the partner after the trial with suggestions of what he could say during the trial, such as, *"Ask him what his favorite dessert is."* These parent prompts were common for the few children who became distracted by the technology during the trials. These results confirm the idea that even a system explicitly built for a single user can and may be used socially and cooperatively. An open challenge then, in this particular case, is ensuring that the children feel autonomous and empowered enough to use the system alone while also comfortable enough to share it when they choose. Similarly, some parents wanted additional feedback about the child. As a different kind of collaboration, these shared data might enable collective reflection within families.

Once a system is comfortable and comprehensible, the motivation of the child to use the system becomes the primary goal. Supporting motivation of the primary user might involve building in extrinsic rewards (*i.e.,* point systems) thus supporting the parent and the child. I found that for some participants in the vrSocial project, the shared application of time taking provided a social motivation as success was dependent on the behavior of both partners. Alternatively, designers could add in a mode with extrinsic motivation to support independent use if desired.

Comfort through Reduced Sensory World

In seeing a subset of children in AR and VR platforms, the differences in the sensory issues the children experienced is a primary finding. For four participants in ProCom, the research team, and parents, needed to do additional work to ensure the child's comfort while using the system. For example, Laura's mother spent several minutes acclimating her daughter to wearing the system by describing its parts and actions and letting her observe her mother handling the system that makes a soft swishing noise when the sensors are turned on. Hanna and Isaac removed or turned off the ProCom system between trials. Erik put his fingers in his ears during the intervention trials after which his mother said:

> *I'm so proud of you because you tolerated that on your body. [then addressing researcher] Not too long ago he wouldn't have been able to do it.*

Erik's mother explains this is a fairly recent aspect of his development, that he can tolerate sounds, and a few months before he may not have been able to complete the study. These results indicate that wearables, while opening new possibilities, provide additional challenges to overcome for this population. In particular, researchers and designers must consider all of the potential additional sensory and attention challenges inherent to the device when creating it and when developing an intervention that uses it.

To address this sensory sensitivity barrier, the VR system was built to provide a different type of mediation. The mothers consistently described immersive VR as comfortable for their children compared to engagement in face-to-face, physical world interactions. The life-sized avatar and virtual environment seemed to remind the participants and their mothers of video games. VR looks and feels like a videogame. For example, the mother of Quinten said*:*

> *He just feels like he's looking at an iPad and that feels good. That makes him feel comfortable. Because it all comes down to eye contact, they don't feel comfortable. I know how much his iPad gives him calm. So, I think that he feels so relaxed talking like that (in VR) versus like face-to-face.*

Mothers reported that immersive VR appealed to their children's interests and therefore provides intrinsic motivation to engage with the technology. They also suggested the narrow range of sensory input in vrSocial allowed participants to feel safe and open to explore the environment and to interact with others.

Isaac's mother, who observed his sessions using each platform, explained that she saw VR as a much better tool for him. Isaac's mother states:

> *VR immersed him a lot more than AR, feedback was a lot simpler, that VR was more clear and obvious in its cues and that VR gives explicit directions, best scenario for a child.*

It may be the pervasive and visual nature of the cues in VR, that having the air around one's avatar be filtered to another color as a form of cue, seems to have more of an impact than a small icon of a person on a mobile phone that is to be referenced during a physical face-to-face interaction.

Parents describe their children as more comfortable, more responsive than in face-to-face interactions. This feeling was also expressed by the Mother of Fred who exclaims:

> *I kinda like the virtual reality better, I feel like it was more immersive. In augmentative, you had to pay attention to this (she gestures the phone in her hand) and not this, (she gestures where a person would stand). In VR, I think it would be easier to pay attention to what is around you.*

Parents described the VR experience as more interactive. This may be counterintuitive as the VR system is a virtual world, but for these children, this mediated experience allowed them to be more engaged. As the mother of Lauren and Olivia describes:

> *This was obviously way more interactive with them (than the AR system) they responded better, I mean Olivia was laughing and actually talking. I think last time I don't think we got her to do much. She was not interested at all. This one, being more like a game setting for her, was more interesting for her. It made her explore and it made her want to communicate with somebody.*

Parents seemed to just like this approach better. As Noah's mother confesses:

> *I like this one better, it just seemed he was more interested in this one. How he could tell if he was being too loud or standing too close, more visual I guess you could say.*

In VR, participants were able to escape the full sensory experience of physical face-to-face interaction but still allow for a rich social interaction. Parents recognized and commented on the unique opportunity to practice communication skills. Laura and Oliver's mother suggested:

> *Having something versatile like that, they were more willing to say things, they are more willing to interact with you. If you had a speech pathologist on the other side, getting them to say the things they wanted, it might draw them out.*

Despite this innate potential, however, as noted above, professionals like speech therapists, social skills instructors, and others are still essential to the experience to provide contextual, supportive and responsive communication.

VR provides a platform but cannot yet eliminate the key roles of human actors, and indeed may never be able to do so. Thus, an area of work might be in helping clinicians and clinical researchers to capitalize on the increased social engagement and talking exhibited within this platform. Many mothers described vrSocial as very visual, picking up on the primarily singular mode of input used. Mothers described this visual experience as comfortable and "more normal" to their children, such as for the mother of Peter and Quinten:

> *They are not taking in so much sensory, its more just visual. There wasn't crazy stuff going in their ears. It was just one person talking, so for Peter, he feels in control because of it. Most of it is the sensory issues, as you know, that's what it is with their behaviors and stuff.*

This sentiment of their children's preference for minimized sensory input was echoed by the mother of Laura and Olivia who described Olivia as living in her own world with vastly different sensory perceptions than those of the other people in her life:

> *I think they already live in their own kind of world, so to them this is more normal. I think she perceives the world as, literally, a whole different place. Maybe they don't have to rely so much on their physical senses too, maybe that overload is not as big of a problem. If they are zoned in this, they don't have to feel everything.*

The sensory experience of being in an immersive VR system is reduced as the sound one receives from the system comes through the earphones, and in the design of vrSocial, only the voice of the conversation partner. The visuals are minimized to contain a simplistic avatar, ground and sky with the dynamic visualization of proximity and prosody added in the intervention conditions. Perhaps the visual, proprioceptive, and potentially tactile sense of another standing near in virtual space is not as threatening as in physical space. No physical world touch can occur, no smells are transferred into the VR environment, nor are any facial expression or subtle body movements captured. In this way, the sensory experience of standing face-to-face is drastically reduced to auditory and visual perception.

This reduced-sensory experience view, shared by many of the parents I interviewed, is echoed in some ways by the kinds of messaging parents get from clinicians, therapists, and even researchers, that children with autism have such different sensory engagements that they may as well be in another "world." Given this view, VR becomes appealing as a way to reduce and control the kinds of issues a child with autism is experiencing, either for comfort and entertainment or explicitly as part of therapeutic training. By reducing specific triggers, such as facial expressions and close physical proximity, VR can simulate face-to-face interaction. The mother of Peter and Quinten expressed her thoughts:

> *I think it definitely brings him out more, it has taken a while (in this session) but now I am seeing it. I think that it's that visual idea, a computer versus face-to-face uncomfortableness.*

Parent reflections matched researcher observations that, at least in the controlled laboratory environment, children prefer computer-mediated interactions. Additionally, parent reports indicate that children are willing to take risks in the virtual environment that they may not take in physical spaces.

CHAPTER 9: DISCUSSION

In reflecting upon all the design and evaluation activities in this body of work, I synthesize my findings into three implications for design. The first is the call to shift from designing personal assistive technologies to be used solely but the user, to consider the need and desire to have human support with learning and using a new device. I refer to this as "ramping up for collective use." The second design implication adds support to other recent works which consider the stigmatization of using an assistive device and the concerns by the wearer of the invasion of privacy of interaction partners. The third implication is the concept of designing alternative media channels for people with neurodiversity.

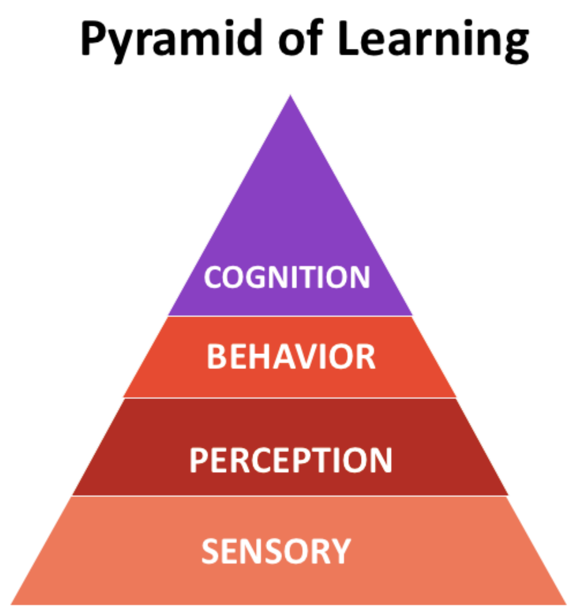

Figure 9.1. Simplified Illustration from Williams & Shellenberger's 1996 Pyramid of Learning.

The need for designing alternative sensory channels is supported by the current thinking about human development and learning. Figure 9.1 depicts a simplified learning pyramid inspired by (Williams & Shellenberger, 1996) the fields of education and occupational therapy. See Figure 9.1. In this simple version, four layers are presented that represent the hierarchy of systems involved in learning, starting with a foundation level at the bottom, the pyramid depicts the bottom level as sensory, then perception, then behavior, ending with cognition at the top.

From my empirical work, I have conceptualized four examples of how I modified the sensory information to support alternative communication modes. The four modes contribute to a new way of thinking about design of assistive technology for Neurodiversity—a Sensory Accommodation Framework.

Sensory Accommodation Framework

In my three project applications, I altered the sensory input of three systems to make the system's environment and interactions accessible. I suggest design implications for AR and immersive VR as an emerging assistive technology for settings for students with sensory sensitivities who otherwise are excluded from environments. The following design considerations contribute to scholarly, clinical, and educational knowledge about the design of, and potential for, immersive VR to serve as assistive technology for people with autism as well as the broader group of neurodiverse people. The need to customize the sensory modalities for children with autism has been explored previously for computer-generated visual and auditory feedback (Hailpern et al., 2009). This work goes beyond comparing two modalities to manipulating more modalities and their interaction. This work, as an extension of ability-based design (Wobbrock, Kane, Gajos, Harada, & Froehlich, 2011), made adaptions to support a variety of sensory abilities and challenges common to autism. Here I provide details of four generative ideas to support the development of sensory-friendly systems: channel augmentation, channel reduction, channel transformation, and channel switching.

Channel Augmentation

Nonverbal communication has been described as a hidden dimension of communication for people with autism (Myles et al., 2004a). The silent messages that are conveyed along with words are intended to clarify the meaning (Mehrabian, 1971) yet can confuse people who have difficulty interpreting this form of communication. The aim of augmenting a social interaction is to *add* information about nonverbal communication (*e.g.,* placing proximity rings on the floor or phone display). In doing so, a designer provides additional and alternative stimuli to be processed by the user. Channel augmentation adds to the existing information in an environment. Specifically, the secondary information is added to clarify, simplify, or highlight some aspect of the available information in an effort to be more accessible. In some cases, this augmentation may be an acceptable additional burden on the user and is not a distraction from the social interaction. Careful design of the interaction with the system considers how one's gestures may impact the social interaction (Damian et al., 2015b). For others however, having additional information to manage during a challenging activity could have ill effects, as mentioned in the previous chapter by parents whose children participated in both AR and VR studies of nonverbal communication. It could be the case that the alternative information is attended to by the wearer *instead of* attending to the social partner in which case the system augments with alternative information and filters out less desirable input, or therefore serving as an "involvement shield" (Humphreys, 2005). In the case of these experiments, it would have been seen as appropriate for a participant to be engaged to some degree with the novel system being studied. It was expected that the participants would reference the systems during the trials with conversation partners. The acceptability of referencing one's personal device during interactions has increased since smart phones have become ubiquitous as mobile phone use "has become a way to negotiate social relations in public spaces" (Humphreys, 2005). Given this emerging social practice, using a tool during an interaction to augment that interaction should be seen as socially-desirable behavior.

Channel Reduction

In this work, I reason that if sensory integration is a challenge for people with autism, then reducing the number of sensory modalities or channels delivering sensory input should be helpful if the relevant information is preserved. Thus, for people with sensory integration difficulties, their energy can be redirected at efficiently taking in new information rather than simply tolerating the multiple sensory experiences occurring around them. These discomforts can be worked around by reducing the shear amount of information through filtering out "rich media" (Daft & Lengel, 1986). Rich media contains multiple sources of information such as face-to-face interactions. Face-to-face interactions include: tone of voice, facial expression, eye contact, body language, and more. By reducing the overall sensory load, users have more opportunity to engage with others without sensory distractions. Neurologists have determined that people with a variety of neurodiverse conditions interpret sensory modalities differently (Bogdashina, 2016; Little et al., 2017; Robertson & Baron-Cohen, 2017).

Examples of reducing the overall sensory experiences in my VR project are: the use of minimal background environments, the static body of the avatar (*i.e.,* only whole-body movements such as moving back and forth are possible), minimal use of colors and textures, the only sound is the audio form the other person's headset, and no haptic feedback. I included only objects or people that are part of the task at hand to reduce distraction while supporting attention to the conversation.

Channel Transformation

By filtering sensory information to resemble "lean media"-- media with a limited amount of information (Daft & Lengel, 1986), the amount of information is reduced so that the salient details are illuminated--thus eliminating the struggle to separate the global from the local details. For example, to support the user's attention to important details, I provide visual cues such as a red circle. Additionally, I highlight the meaningful information—standing too close to the other and the need to step back-- by obscuring the view of the conversation partner with colored filters. The majority of the stimuli in the virtual environment is visual, with the visualizations of nonverbal communication appearing as graphics. I chose to use a graphic data visualization (*i.e.,* combination of symbols, icons, and text to convey a message) because of the visual perceptual strengths affiliated with autism, such as "superior detection or discrimination thresholds for static stimuli" (Robertson & Baron-Cohen, 2017). Although the graphics I built were not static, they were persistent in the virtual environment, creating a continual presence.

Channel Switching

By leveraging the strategies employed by people with autism, designers can leverage the strength of some channels and avoid weak channels or using multiple channels. For example, vrSocial conveys ephemeral information—such as volume, space, and temporal processing—through visualization. Some of the information conveyed through these transient modalities supports an understanding of the context or global environment. As people with autism often prioritize local information over global, these momentary messages can be lost. Much of the nonverbal communication repertoire is made up of global information that is conveyed through all channels. Specifically tone of voice and facial expressions are considered global information, and are often perceived in parallel, requiring a user to see and hear these global messages at the same time. By switching to a single channel, visual, and organizing the information in persistent graphic displays, this nonverbal communication can be captured and preserved for the user to perceive. This focus on detailed-focused preference leverages the "superior detection or discrimination thresholds" found to be characteristic of autism (Robertson & Baron-Cohen, 2017) .

Conclusion

AR and VR systems can provide social interaction support for people with autism. AR provides support in physical face to face interactions, thus providing a tool that can be used for training or as a prosthesis for interesting nonverbal communication. Of the two platforms, VR offers the ability to control the sensory load in the system, adapting it to meet the sensory needs of the individual. VR may be preferable for those looking for a prosthetic over a training tool, as it allows for customized interactions, such that individuals can attend classrooms with their own individualized input settings or other kinds of experiences without sharing a sensory space. The flexibility of controlling the sensory environment opens opportunities to be more inclusive. By designing a space that is tailored to individual needs (*e.g.,* ADHD, autism, sensory processing disorder, post-traumatic stress disorder, etc.), more people could participate in virtual face-to-face interactions and other cultural experiences.

The decision to target behavior change through a *training tool* or provide access to social information through as *prosthetic tool* may be based on how comfortable the user is when using the system during a social interaction. This work suggests that before behavior change is an appropriate target for a user, they should feel comfortable using the system and be able to discern the information provided.

Functional prototypes do not have the capability to make this determination, so a human--the user, caregiver, therapist, or other stakeholder-should be advised to ensure the information is being received before the expectation of action and eventual learning to perform socially normative behaviors. In human to human intervention, the therapist is constantly, consciously or not, making decisions on how to respond in the moment based on several environmental factors. This judgement has not been targeted as a function of most technological systems for people with autism. Because of the dependency of knowing if the user is comfortable (in terms of sensory overload), comprehending (in terms of making sense of a technical system's output), and willing (social-emotionally) and able (physically) to take action, systems should be wary of targeting behavior change for neurodiverse people. Therefore, the first goal of these systems should be to make people comfortable while using the system, and then assuring access to the alternative information.

These components constitute an *assistive technology* for people with sensory challenges. My future work will begin with designing at the foundation level (sensory perception) and then I will examine the impact on social interaction when these first two factors (comfort and access) have been met. If these goals are not met, then my future work will be targeted at working around that challenge and providing alternative routes. Alternatively, if these goals of comfort and access are met, then I could explore any number of potential next steps. I would determine the next phase by checking in with users to learn about what they want to do next with these systems. Potential responses could be that the users and stakeholders want to now target personal behavior change, thus moving from an assistive technology to an educational or training technology; they may want to address more collaboration in systems to share the burden as well as provide insight into other's perspective; some may want to engage in social movements of acceptance, and some may want to engage in critical design. For example, a new system could be designed to provide neurotypical users with information portrayed from a neurodiverse perspective and provide prompts and cues for the neurotypical to change their behavior. This type of reverse-mainstream design could support autism advocacy by using technology to suggest that neurotypical users accept diverse behavior and accommodate, as needed, such as "move back" or "speak softer." Designing in the socially-expected way does not always serve the user, Haimson describes the necessity to not always make every social media application connected to another (Haimson, February 2018). Future design could incorporate any combination of these goals as each aim to support inclusion.

AFTERWORD

When I started my PhD, after completing a master's degree in counseling psychology 20 years before, I made an assumption, as perhaps many clinicians would do; the assumption that technology was capable of doing what humans do. What I did not expect was how much work humans do to mediate a social interaction. As a behavior analysist, I had implemented thousands of behavioral procedures and gave credit to the procedure rather than split its worth with the human who was the implementer-the human instrument. There are subtleties to our interactions that we may not even be aware of, so now I ask how a system could execute a basic protocol, such as praising a target behavior, without having these human abilities. Humans are complicated and how much of that complexity can we put into technology is still emerging. It is an open question about how far we can go in terms of expecting machines to do peoples' work. But, we can expect machines to do machines work. And humans to do the human work of deciphering the subtleties of interaction. Since these may be invisible to the expert or researcher, we might consider developing technical intervention heuristics.

Lessons learned:

1. Tech should do what tech is good at—and it should be something humans can't do, such as create realtime visualizations of social feedback—then humans can do the discerning if a person comprehended the information and wants to take action.

2. We need a set of intervention heuristics to assess for the tacit aspects of human interactions--the human instrument- that may be invisible to a research team.

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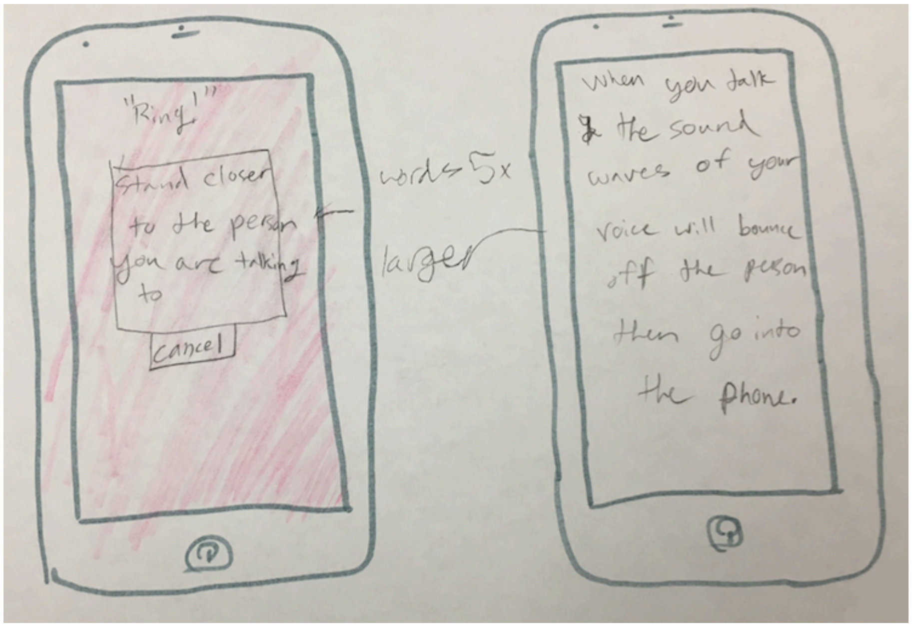
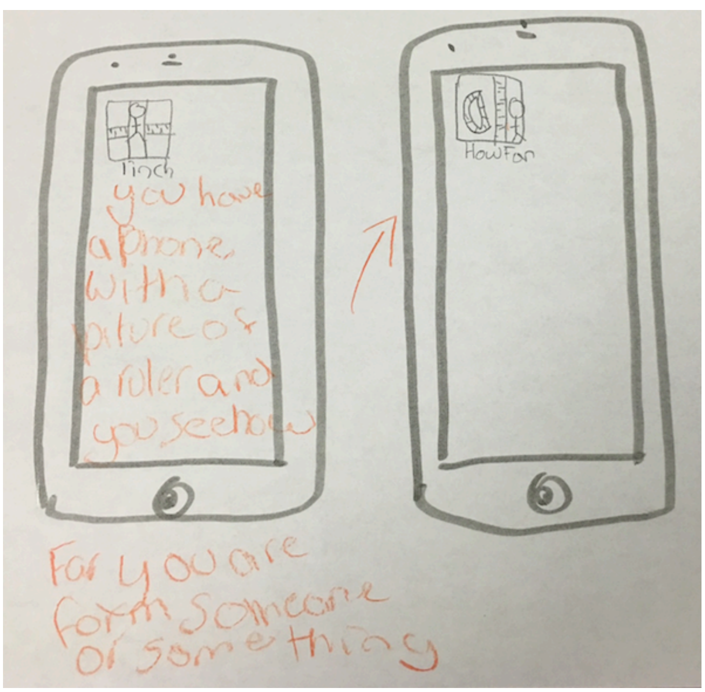
APPENDIX

All designs form the ProCom Parallel design activity. 1-5 by children, 6-11 by adults.

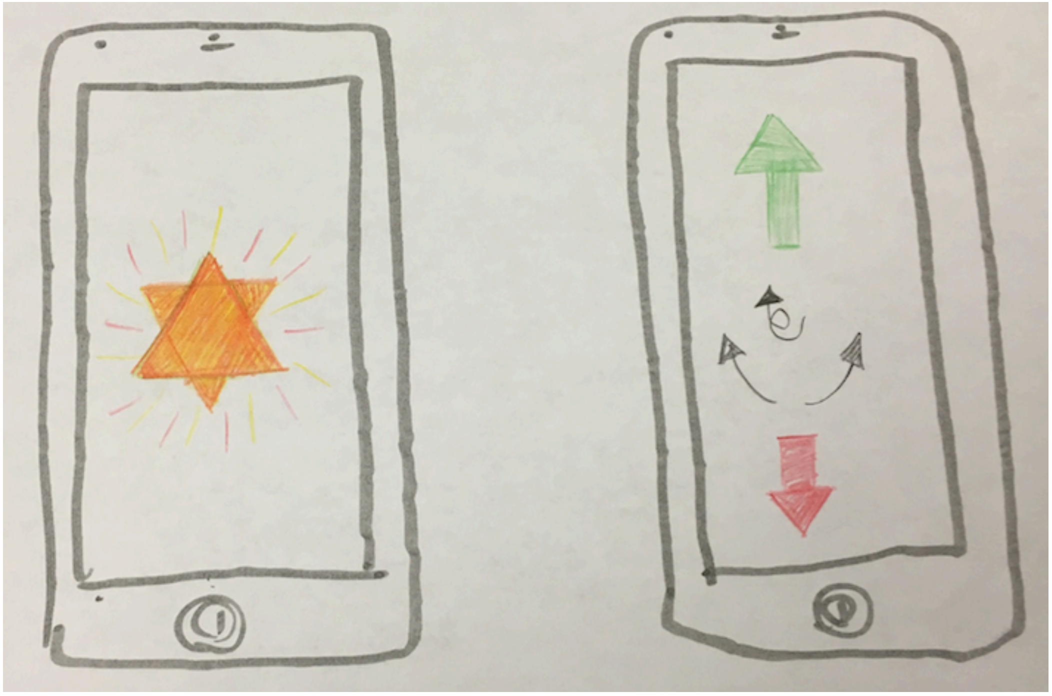
By children:

1.

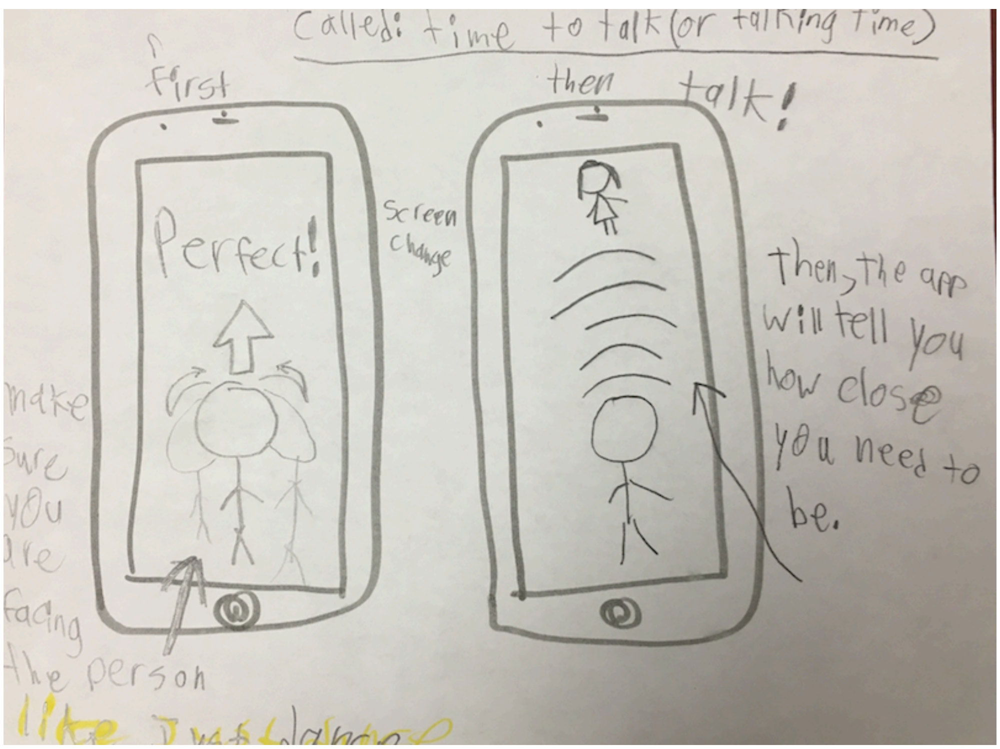




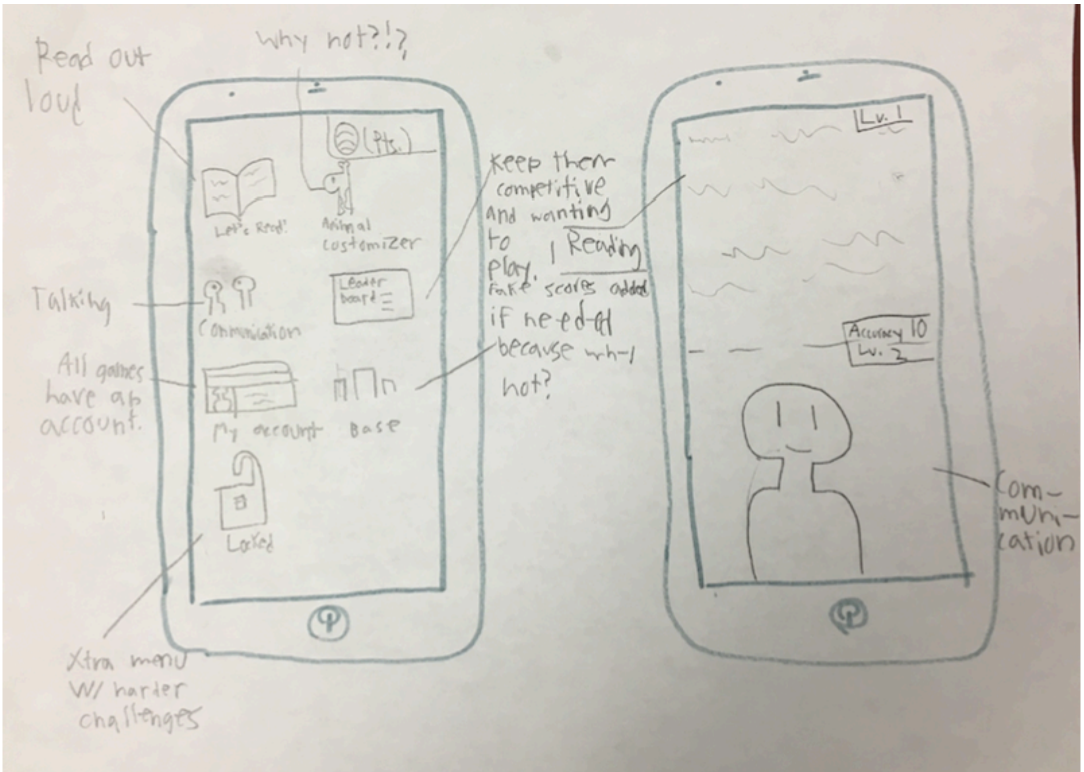
2.



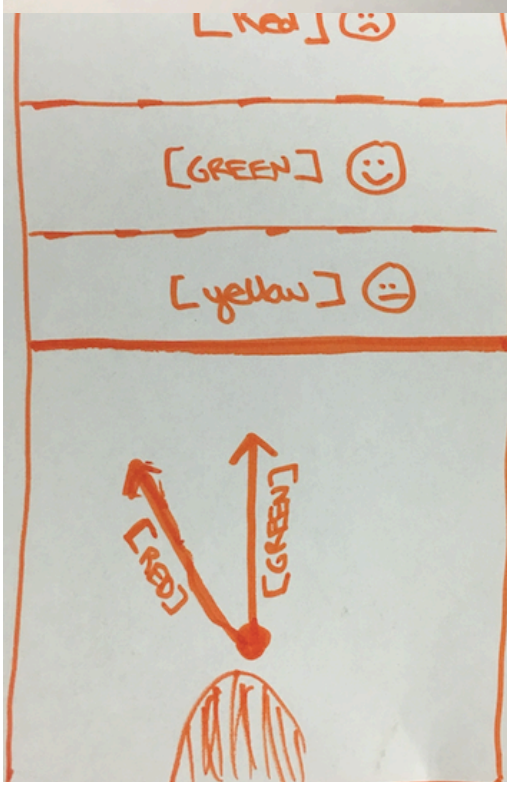
3.


Called: time to talk (or talking time)
First
then
talk!
Perfect!
Screen change
Then, the app will tell you how close you need to be.
make sure you are facing the person

4.


Read out loud
Why not?!?
(Pts.)
Let's Read!
Animal customizer
Keep them competitive and wanting to play.
Reading
Fake scores added if needed because why not?
Talking
Communication
Leader board
All games have an account.
My account
Base
Locked
Xtra menu W/ harder challenges
Lv. 1
Accuracy 10
Lv. 2
Com-munication

5.

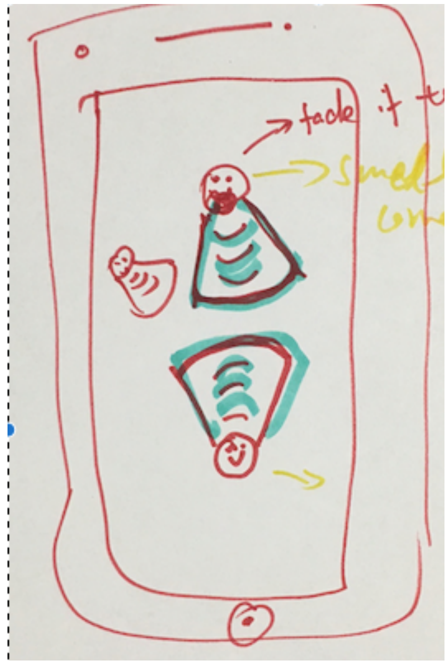

[GREEN]
[yellow]
[RED]
[GREEN]

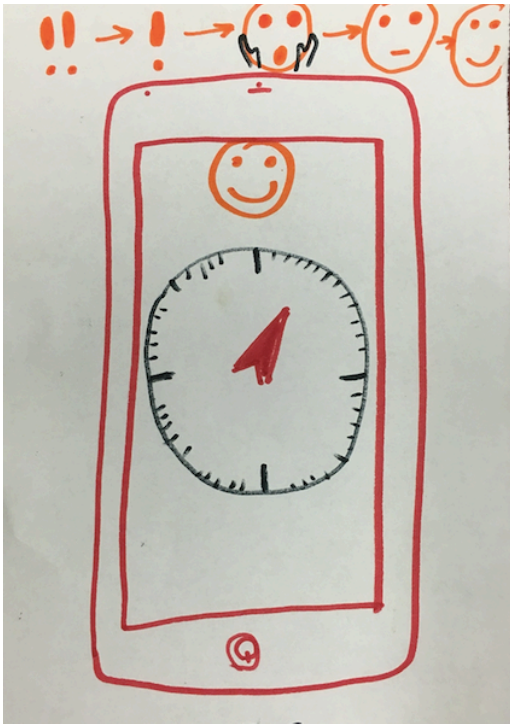
6.

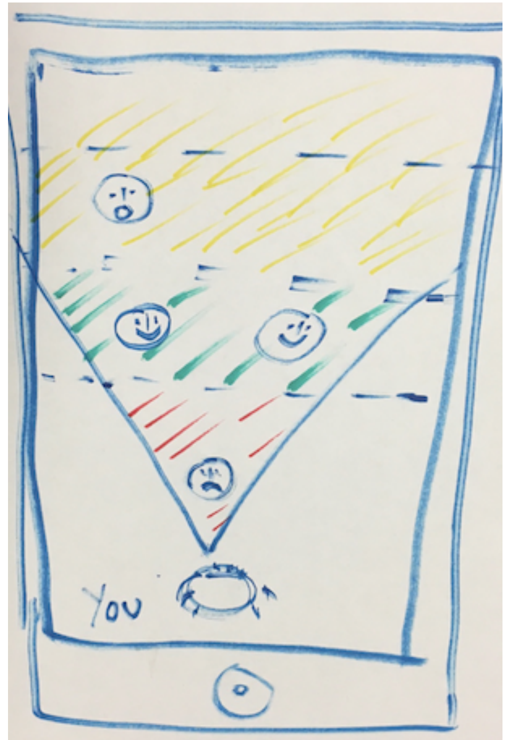

BACK UP!

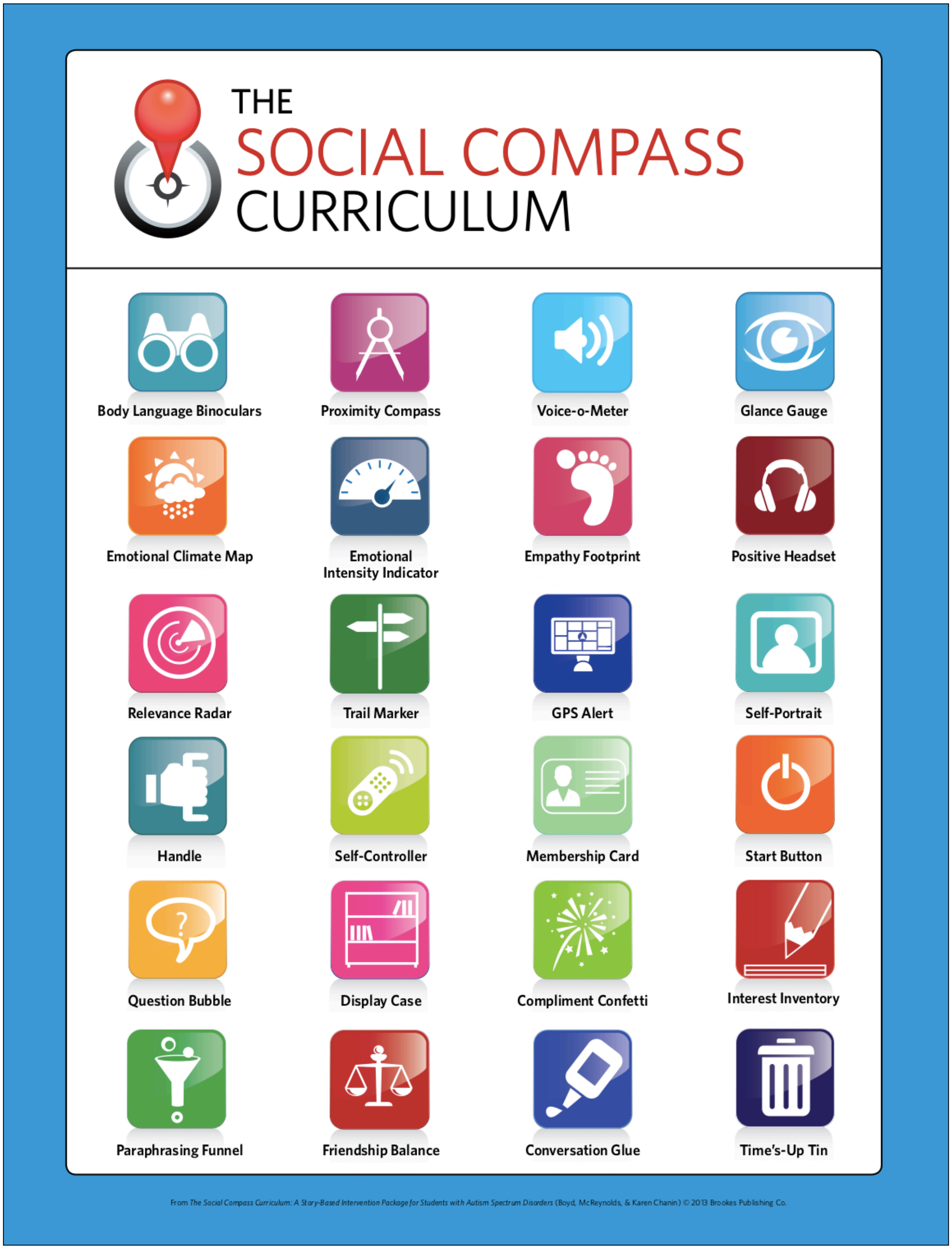
7.

8. 

9. 

10. 

11. 



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