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Interactive Technologies for Autism

Julie A. Kientz
Matthew S. Goodwin
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Synthesis Lectures on Assistive, Rehabilitative, and Health-Preserving Technologies

Ronald M. Baecker, *Series Editor*

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Editor

Ronald M. Baecher, *University of Toronto*

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ABSTRACT

Development, deployment, and evaluation of interactive technologies for individuals with autism[1] have been rapidly increasing over the last decade. There is great promise for the use of these types of technologies to enrich interventions, facilitate communication, and support data collection. Emerging technologies in this area also have the potential to enhance assessment and diagnosis of individuals with autism, to understand the nature of autism, and to help researchers conduct basic and applied research. This book provides an in-depth review of the historical and state-of-the-art use of technology by and for individuals with autism. The intention is to give readers a comprehensive background in order to understand what has been done and what promises and challenges lie ahead. By providing a classification scheme and general review, this book can also help technology designers and researchers better understand what technologies have been successful, what problems remain open, and where innovations can further address challenges and opportunities for individuals with autism and the variety of stakeholders connected to them.

KEYWORDS

autism, autism spectrum disorders, interactive technologies, technology, computing, human-computer interaction, desktop, web, Internet, video, multimedia, mobile, smartphones, tablets, shared active surfaces, tabletop computing, virtual reality, augmented reality, sensors, wearable computing, robots, robotics, natural user interfaces, natural input, pen input, voice input, gestures, speech, tangible computing, tactile computing, eye tracking

[1] For consistency throughout this book, we will be using person-first terminology, that is, we will refer to "individuals with autism," as opposed to "autistic individuals." There are valid opinions for both forms of expression (see http://autisticadvocacy.org/identity-first-language/ for a discussion of the topic), and we do not mean to side with any particular position in choosing this wording. In addition, we will not use the word "disorder" when referring to individuals with autism. Though that is the strict wording used for the psychiatric diagnosis, we do side with those who feel the use of the word "disorder" encourages an inappropriate negative connotation to the condition.

Dedication

To Maya and Shwetak—J.A.K.

To Sage, Sophia, and Emmeline—M.S.G.

To Warner, William, and Steve—G.R.H.

To Aidan, Blaise, Mary Catherine, Meghan, Sara, and Richard—G.D.A.

Contents

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Foreword

This book is a product of pioneering research that the authors, Julie Kientz, Matthew Goodwin, Gillian Hayes, and Gregory Abowd, have conducted—some together in different combinations and some separately—at various research universities such as Georgia Institute of Technology, Massachusetts Institute of Technology, Northeastern University, University of Washington, and University of California, Irvine. The book's immediate impact is two-fold: (1) to demonstrate that interactive technologies are used not only "for," but also "with" and "by" individuals with autism, and thus to acknowledge their agency, autonomy, and creativity; and (2) to demonstrate that interactive technologies are interactive not only in a dyadic user-technology sense, but also that their use mediates interactions within social networks that include individuals with autism as well as other "stakeholders" in their well-being and participation (i.e., family members, peers, teachers, and practitioners).

The authors' comprehensive review of interactive technologies that have been, and are being created and used, takes stock of the state of technology for autism directed at three areas: enriching interventions, facilitating communication, and supporting data collection. This book expects a significant intellectual investment from its audience. The presentation of content is appropriately complex and does not talk down to the readers. Readers interested in benefiting from this volume will have to inhabit the intricate conceptual universe that the authors have built. In addition to being an invaluable resource for individuals with autism and their families, this book will be useful for researchers and practitioners coming into this very important field.

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CHAPTER 1

Introduction

The use of interactive technologies for individuals with autism has grown dramatically over the last decade. One of the primary motivations for this is the observation that individuals with autism appear to have increased interest in and frequently use interactive technologies when they are made accessible. (Mazurek et al., 2012). As reviewed in the following pages, a number of stakeholders are capitalizing on and exploiting this attraction to support and enhance clinical goals for screening and diagnosis, educational goals for intervention monitoring, as well as other basic and applied research efforts. The purpose of this book is to provide a brief introduction to autism and then review historical and state-of-the-art use of technology by and for this population. Our intention is to help readers understand some basics of autism, and then provide a broad review of the research literature that demonstrates the role technology has served. We expect this book can be useful to new researchers to the area of autism and technology, as well as more experienced researchers who are looking to identify new potential areas of focus. We also expect this may be useful to teachers, parents, caregivers, and individuals with autism who want to know more about the research surrounding interactive technology use for autism. We aim to identify problems that still need to be solved and suggest promising avenues for further development and evaluation, all in service of advancing science, technology, and quality living for individuals with autism. We also hope to encourage more research in this space, as there are many interactive technologies that are being used for autism that show much promise, but have not yet been scientifically validated.

1.1 INTRODUCTION TO AUTISM

Autism was first described as a syndrome by Leo Kanner, a child psychiatrist at John Hopkins University (Kanner, 1943). In his seminal work, Kanner characterized 11 children who shared a fundamental inability to relate to other people, a failure to use language to convey meaning, and an almost obsessive desire to maintain sameness. Kanner also noted that anxiety played a prominent role in the clinical presentation of autism; the children he observed often displayed intense fears of common objects. Bettelheim (1967) suggested autism was the result of inadequate nurturing by emotionally cold, rejecting parents, a theory that prevailed until the late 1960s and did a great deal of harm to many families. Rimland (1964) and Rutter (1970) provided persuasive arguments that autism had an organic etiology; the most influential of their findings being that approximately 25% of children with autism developed seizures in adolescence. It is now abundantly clear that autism is a complex neurodevelopmental condition with underlying organic genetic and neurological differences, and is not caused by parenting deficiencies or other social factors. Autism occurs across all socioeconomic levels, in all cultures, and in all racial and ethnic groups (Dyches, Wilder, & Obiakor, 2001).

There is no specific biomarker, laboratory test, or behavioral assessment procedure to identify autism; it is defined exclusively by past and present behavior determined from developmental history interviews (e.g., Autism Diagnostic Interview), parent reporting on current behavior (e.g., Modified Checklist for Autism in Toddlers), and structured and semi-structured tasks that involve social interaction between an examiner and a child (e.g., Autism Diagnostic Observation Schedule). Autism is a spectrum condition covering a wide range of ability levels and severities, ranging from more severely affected to high functioning (often referred to as high-functioning autism or HFA). Despite this heterogeneity, all individuals on the autism spectrum are characterized by qualitative (i.e., abnormal and not merely delayed development) impairments in social-communication and restricted and repetitive interests, activities, and behavior (see DSM-5, American Psychiatric Association, 2013). We note that the DSM-IV (American Psychiatric Association, 2000) included Asperger's Syndrome as part of Autism Spectrum Disorders. The new DSM-V, introduced in 2013, has removed that sub-classification. A number of the articles reviewed in this book were designed for or tested with individuals with Asperger's Syndrome as defined by the DSM-IV. The DSM-IV diagnosis also classified other disorders as Autism Spectrum Disorders, such as Childhood Disintegrative Disorder, Rett's Disorder, and Pervasive Developmental Disorders-Not Otherwise Specified, which have also been removed from the DSM-V criteria. There has been some amount of controversy surrounding the new diagnostic criteria, and not everyone agrees.

Autism is more common in males than females, with a ratio of 4:1 widely reported across samples (e.g., Fombonne, 2002). Many individuals with autism, but not all, also have moderate to severe mental retardation (Fombonne, 1999);[2] suffer from seizures, with onset most often occurring during either the preschool or adolescent years (Volkmar & Nelson, 1990); and experience co-occuring neurodevelopmental conditions, for example, Tourette syndrome (Sverd, Montero, & Gurevich, 1993) and attention deficit hyperactivity disorder (ADHD) (Ghaziuddin, Tsai, & Ghaziuddin, 1992).

Early research suggested that autism was relatively rare, occurring at a rate of four to six affected individuals per 10,000 (Lotter, 1967; Wing & Gould, 1979). In the mid-1980s, diagnostic criteria broadened, and rates of 10 per 10,000 were found in total population screenings (Bryson, Clark, & Smith, 1988). More recent studies that focus on preschool children utilize standardized diagnostic measures of established reliability and validity, employ active ascertainment techniques, and yield prevalence estimates of 60–70 per 10,000—translating into approximately 1 in 150 across the spectrum of autism (Baird et al., 2001; Bertrand et al., 2001; Chakrabarti & Fombonne, 2001). At the time of writing, current estimates from the Centers for Disease Control and Prevention (CDC) suggest a rate of 1 in 88 children (Baio, 2012). However, a more recent study reported that

[2] For a caveat to these estimates, see Mottron et al. (2006).

1 in 50 students in U.S. schools are currently receiving services related to autism (Blumberg et al., 2013), although no independent replications have confirmed this prevalence estimate. Regardless of the true rate of autism, more than 2 million people in the U.S. are currently believed to carry the diagnosis.

This apparent increase has led to dramatic claims, particularly in the lay media, for an "epidemic" of autism. However, according to reviews by Wing and Potter (2002), Rutter (2005), and Gernsbacher and colleagues (2005), there are several possible reasons for the observed increase in autism rates, including: (1) changes in diagnostic practice; (2) increasing awareness among parents, professionals, and the general public of the existence of autism; (3) development of specialist services; (4) differences in methods used in studies; and (5) possible true increase in numbers.

Individuals with autism display difficulties across the entire range of developmental domains. The unfolding and maturation of these basic competencies are affected to a greater or lesser degree in autism, depending on a child's pattern of dysfunctions, extent of impairment, and level of support. Autism is almost always a chronic condition; however, the functioning of individuals is not static. Just as other children and adolescents do, individuals with autism continue to grow, learn, and develop over the course of their lives. While there is great variability across the autism spectrum, and individual differences make it difficult to generalize across the condition, some general patterns of development can be offered as children with autism move from infancy through adolescence and beyond. Unfortunately, very little research has been conducted, and thus little is known, about the ways autism manifests in adulthood and how best to support this older segment of the autism population.

Autism typically manifests quite differently across people who share the same diagnostic label. Moreover, autism may even present itself differently in the same person across settings and over time. This extreme heterogeneity among individuals with autism has led to the common colloquial saying, "If you've seen one child with autism, you've seen one child with autism." However, there are some commonalities in how the condition manifests, which we describe in the subsequent sections.

1.1.1 INFANT DEVELOPMENT

Infancy is a period of dynamic growth and change. During this time, early symptoms of autism are found to cluster around impairments in early emerging social interaction skills, including attentional functioning, preverbal communication, exploration and play, motor imitation, and attachment.

One of the important aspects of attention is the ability to identify and focus on salient elements or features in the environment for further processing (James, 1950). In the first year of life, infants with autism are found to visually orient less frequently to people as compared to typical and developmentally delayed controls (Osterling, Dawson, & Munson, 2002). This selective bias is found to persist in the second year and beyond (Dawson, Meltzoff, Osterling, Rinaldi, & Brown, 1998). More recent findings suggest this pattern of attention in the first year of life may serve as an effective diagnostic criterion for autism (Klin, Lin, Gorrindo, Ramsay & Jones, 2009).

In the first nine months of typical development, and before the development of speech, infants are able to effectively communicate their needs by a variety of means, including reaching for a desired object or fussing or crying. These communicative attempts are usually directed at the goal itself and not at the person that might be instrumental in attaining the goal. At about nine months, infants begin to direct their communicative attempts toward adults by, for instance, making eye contact while reaching for a distant toy. Along with this change, infants begin to substitute early emerging physical gestures (e.g., an open-hand reach) with conventional gestures such as pointing or showing. Emergence of these behaviors at the end of the first year of life marks the beginnings of intentional communication—communication in which a child is aware that his or her behavior affects a listener (Bates, 1979).

Preverbal children with autism are found to communicate less frequently (Stone, Ousley, Yoder, Hogan, & Hepburn, 1997) and use less complex combinations of communicative nonverbal behaviors (Stone et al., 1997). Specifically, two-year-old children with autism are less likely to use eye contact or conventional gestures, such as distal and proximal pointing and showing gestures. They are more likely to manipulate a person's hand using hand-over-hand gestures and are less likely to pair their communicative gestures with eye contact and vocalizations compared to developmentally typical peers (Stone et al., 1997). A disproportionately high number of the communicative behaviors observed in young children with autism are also concerned with requesting objects or actions; they are not aimed at directing another's attention to an object or event to initiate joint attention (Baron-Cohen, 1989; Bruner, 1975; Mundy & Sigman, 1989). Compared to typically developing peers, most children with autism also develop language later, and their language development is marked by the presence of unusual features (Tager-Flusberg, Lord, & Paul, 2005). For instance, pre-verbal children with autism often show abnormal patterns of sound production, including defects in well-formed syllables and overproduction of atypical vocalizations such as growling, tongue clicking, and trills (Wetherby, Yonclas, & Bryan, 1989).

Deficits in functional and symbolic play in relation to other cognitive skills have also been well documented in preschool children with autism (Sigman & Ruskin, 1999). While play skills continue to develop in the preschool period and can be enhanced through prompts, scaffolding, and modeling, children with autism continue to engage in little spontaneous functional and pretend play (Lewis & Boucher, 1988). Motor imitation and emulation also play an important role in the emergence of both symbolic and social-cognitive skills (Tomasello, Kruger, & Ratner, 1993). Studies on imitation in preschool children with autism consistently report deficits in this area (e.g., Rogers, 1999). There has been some speculation that attachment, the affective bond between a child and a parental figure (Ainsworth, Blehar, Waters, & Wall, 1978), is deficient in infants with autism, but there is little evidence of a syndrome-specific attachment deficit in infants with autism

(Capps, Sigman, & Mundy, 1994). There are additional areas of life that are impacted by autism in significant ways. We discuss these further in later chapters when we describe the reasons behind why some technologies were designed the way they were.

1.1.2 EARLY CHILDHOOD AND SCHOOL-AGE CHILDREN

The developmental characteristics of autism in infancy persist over time, and in school-age children can manifest in specific cognitive, behavioral, communication, and social profiles.

For the child with autism, elementary school years bring challenges associated with changing expectations that accompany increasing physical and behavioral maturity. During the period from ages 6 to 12, the child with autism faces transitions to new learning environments, contact with new peers and adults, and departure from familiar places and routines. These changes can affect many domains of functioning, as the child is required to adapt to more complex and demanding social environments, to learn more sophisticated skills, to communicate at a higher level, and to process more information. Such experiences, which are common to all school-age children, can be particularly challenging for those with autism, who not only have developmental delays in multiple domains, but also have difficulty adjusting to changes in their environments.

Although there is considerable heterogeneity among children with autism, some generalizations can be made. For example, Wing and colleagues have described three subtypes of social behavior, *aloof*, *passive*, and *active-but-odd*, that capture many of the manifestations of autism seen in the school-age child (Wing & Attwood, 1987; Wing & Gould, 1979).

The *aloof* profile is most likely to be described as "classically autistic." These children do not seek, and may actively avoid, contact with others and may become very distressed if forced to do so. Despite having verbal abilities, they do not initiate communication, and much of their time may be occupied with stereotyped or other repetitive interests. These children with autism are noted for their unresponsiveness and failure to initiate interactions with both peers and adults. They often do not play with other children or demonstrate interest in friendships (Rutter, 1974). Impairments in their ability to use eye gaze and gesture appropriately in social situations lead to frequent failures to communicate. Aloof children with autism may also be sufficiently unresponsive making it very difficult to direct and maintain their attention. They may seem deaf at times, even though they are not. Tantruming is common in these children, particularly when their routine is disrupted or by other circumstances they cannot control. While individuals with these characteristics are most often seen in the preschool age group, some continue in this manner into later childhood, adolescence, and adulthood. Older individuals with this profile are most likely to have severe mental retardation (Seltzer, Shattuck, Abbeduto, & Greenberg, 2004).

The *passive* group includes children who do not actively avoid social contact with others, but who nevertheless lack the spontaneous and intuitive grasp of social interaction achieved in normally developing children. They may accept social approaches of others, but often do not have skills to respond appropriately. Their communication and play behaviors can be rigid and sometimes stereotyped. These individuals tend to function at a somewhat higher developmental level than those in the aloof group, with more language and fewer motor stereotypies. Although passive children with autism can be easier to engage and support than those who are aloof, they still require considerable help relating to peers in the classroom or other situations. Some children with autism who start out displaying the aloof pattern of behavior later have a better fit with the passive group. Thus, presentation as aloof versus passive may depend to some extent on the child's developmental level, and a transition from one category to the other may reflect maturation as well as accumulation of social experiences.

The *active-but-odd* children are those who are usually described as having higher-functioning autism. They actively seek contact with others, but the form and quality of their social approaches are atypical and often inappropriate. These more able children with autism experience difficulty relating socially to peers, even though they may have considerable language skills and may be interested in communicating with others. Characteristics of this group are behaviors such as repetitive questioning, inappropriate touching, conversation focused exclusively on the child's own narrow interests, and odd facial expressions, postures, and gestures. Their social behavior and communication seem to reflect a view of the social world that is literal and concrete, and they can show limited awareness of the feelings, thoughts, and motives of others.

1.1.3 ADOLESCENCE

The clinical presentation of adolescents with autism has not yet been studied as extensively as younger children with autism. Very few studies have examined whether contextual variables such as parental socio-emotional functioning, place of residence, and educational or intervention history predict later outcomes. However, the limited research suggests that adolescents with autism can improve markedly, experience deterioration in functioning, or continue a stable maturational course (Seltzer et al., 2004). A key variable mediating these developmental trajectories appears to be intellectual ability. Individuals with autism and mental retardation (also referred to as intellectual disability and defined by an IQ of less than 70, though it is often difficult for IQ to be measured in individuals with autism) have significantly greater difficulties in terms of education, work, living situation, and general independence than those with autism and average intelligence (Howlin et al., 2004). Many parents also report that their intellectually disabled adolescent with autism exhibits significant behavior problems, including resistance to change, compulsions, unacceptable sexual behavior, tantrums, aggression, and self-injurious behavior (DeMyer, 1979). For higher functioning adolescents with autism, academic performance can be at or above grade level, however, organizational and social expectations (e.g., keeping track of multiple assignments and long-term projects; moving quickly between classes; avoiding social taboos) can be overwhelming (Klin & Volkmar, 2000). For higher functioning individuals, adolescence may also be a time of heightened loneliness, anxiety, and depression as they recognize the profound nature of their difficulties, their differences from others, and their limited opportunities (Green, Gilchrist, Burton, & Cox, 2000).

1.1.4 THE ROLE OF SOCIAL ENVIRONMENT

A transactional model of development recognizes the individual as an active participant in the developmental process who, through continued and varied interactions with the environment, comes to adapt, learn, and develop (Bronfenbrener, 1979). In addition to the individual-level characteristics of autism described above, there are also factors relating to the family and school environment that contribute to developmental outcomes in this population. The following briefly reviews the roles that families and schools play in autism.

Questions about interactions between family context and the developmental trajectory of autism are relatively understudied. Studies in autism have focused primarily on child variables and child outcomes or on the stress of life for parents. Family variables, considered to be critical to general early intervention research (such as socioeconomic status, stress, supports available, and parents' involvement in a child's development), have not been well addressed in outcome studies of children with autism (Gresham & MacMillan, 1997). However, there are a few studies showing that family involvement in intervention is a strong predictor of outcome in children with autism (Dawson & Osterling, 1997; Dunlap, 1999; Lord & McGee, 2001; Rogers, 1998). Conversely, borrowing from the broader developmental literature, negative family factors including limited financial resources, lack of appropriate services, and insufficient support systems most likely produce unfavorable prognoses in children with autism. Environmental risk factors such as lack of services and negative attitudes toward disabilities probably also negatively influence the development of a child with autism. However, as mentioned previously, there is very little systematic investigation of these factors in autism.

Research also suggests that children with autism can improve a great deal when provided with school-based interventions that utilize a structured environment and intensive early behavioral, language, and social skills training (Rogers, 2000; Smith, Groen, & Wynn, 2000). Structure helps students with autism by making elements of the learning environment clearer and more predictable (Olley, 2005). Individualized interventions and education goals that are developmentally appropriate have also been shown to address this population's abilities and impairments and facilitate development (Schreibman & Ingersoll, 2005).

1.1.5 ADDITIONAL CHALLENGES WITH AUTISM

Research evidence in the behavioral, educational, and social sciences indicates that early diagnosis and intervention can be essential to achieving greater independence. Thus, caregivers can be in a race against time to find interventions that work for their child. However, many interventions may or may not work for any particular child, and these interventions are often applied simultaneously. Interventions commonly take the form of pharmacology, special diets, occupational therapy and sensory integration, behavioral therapies such as applied behavior analysis or functional behavior analysis, and symptom-specific support such as speech or language therapy.

The difficulty obtaining an early diagnosis, inherent heterogeneity in clinical presentation, and lack of a complete evidence-based research on the effectiveness of interventions all present significant challenges to those who support individuals with autism. While the condition has been known in the literature since the 1940s, we are increasingly learning how complex a condition autism is and how its etiology is at best a complex combination of genetic predisposition and environmental hazards. Despite our incomplete knowledge, there is still a lot we do understand about the challenges of autism in everyday life, and hence a lot that can be done to address them.

1.2 COMPUTER USE BY INDIVIDUALS WITH AUTISM

It is widely accepted that computing applications in multiple domains are largely successful when used by individuals with autism. A number of reasons have been put forth. The earliest articles we are aware of that discuss the use of computers and why they are promising for individuals with autism is that of Colby and colleagues (Colby, 1973; Colby & Smith, 1971). Another early work was the use of a microprocessor-based system for training individuals with autism using prompting and data collection (Rathkey et al., 1979). Panyan (1984) suggested that computer use in autism could increase learning rates, ability to work independently, creativity, and attention and social behaviors.

More recently, Silver and Oakes (2001) outlined several factors that may help explain the particular affinity for computers observed in individuals with autism. First, individuals with autism often have difficulty filtering sensory information that is not salient to their daily interactions (Rutter & Schopler, 1987). Computer screens allow information to be abstracted or limited to only relevant information, thereby supporting the filtering process. Second, many individuals with autism are often confused by unpredictability, social nuance, and rapid changes present in the non-computerized physical world. Computers are much more predictable than humans and do not require social interactions. Additionally, computational interactions can be repeated indefinitely until the individual achieves mastery. Third, computers can provide routines that are explicit, have clear expectations, and deliver consistent rewards or consequences for responses, which can encourage engagement with educational and assistive technologies by allowing an individual to make choices and take control over their pace of learning. Fourth, content can be selected and matched to an individual's cognitive ability and made relevant to their current environment, and photos can be used to help generalize to the real world. Finally, learning experiences can be broken down into small and logical steps and progress at a rate necessary for conditioned reinforcement. The data collected by computers can also be useful for assessing progress in learning.

In general, due to the individualistic nature of the autism experience, computer-based interventions can be tailored to an individual's needs or even special interests (Morris et al., 2010), which can potentially enhance learning and maintain interest over time. Because of these perceived benefits of using computers, they have become an integral part of a number of interventions and educational programs. They have also become a good way of supplementing face-to-face therapies that are time, cost, and/or other–resource prohibitive.

A number of approaches to designing interactive technologies for individuals with autism have been proposed. Lahm (1996) conducted a study assessing software features and what engages individuals with autism in the classroom and found that technology with higher interaction requirements and those that use animation, sound, and voice were more likely to captivate attention. Several papers discuss the experience of using participatory design with children with special needs (Frauenberger et al., 2011; Frauenberger et al., 2012) and more specifically children (Millen et al., 2011) and adolescents with autism (Madsen et al., 2009). Kaufman and colleagues (2011) describe their experience with iterative design for advancing the science of autism, and Porayska-Pomsta and colleagues (2012) discuss an interdisciplinary approach to technology design for individuals with autism. Finally, Putnam and Chong (2007) conducted a survey with parents of individuals with autism to understand what needs they have in computing software and found that social skills, academic skills, and organization skills were the most important areas for interactive technologies.

1.3 OTHER REVIEW ARTICLES

This book is not the first to review the space of autism and technology. In our literature review, we encountered a number of summary articles, ranging from systematic rand meta-analytic eviews (e.g., Ramdoss et al., 2011; Grynszpan et al., 2013) to discussion or thought pieces about the future of technology in support of autism (e.g., Goldsmith & LeBlanc, 2004). We also encountered many articles that sought to review specific types of technologies for use with individuals with autism, such as robotics (e.g., Feil-Seifer & Matarić, 2009), virtual reality (e.g., Parsons & Mitchell, 2002), tabletops (e.g., Piper et al., 2006), video instruction (e.g., Ayres & Langone, 2005), pervasive computing (e.g., Kientz et al., 2007), speech output (e.g., Schlosser & Blischak, 2001), and computer-mediated communication (e.g., Burke et al., 2010). In addition, we encountered a number of articles that describe the use of technologies for specific purposes, such as communication (e.g., Mirenda, 2001), functional skills instruction (e.g., Ayres & Langone, 2005), and social skills (e.g., Reed et al., 2011; Wainer & Ingersoll, 2011). There have also been review articles that discuss the role of technology in supporting family and caregivers of individuals with autism (e.g., Oberleitner et al., 2006; Solomon, 2012).

In this book, we make no attempt to include every article written on the subject of technology and autism. Indeed, over the course of writing this review many more relevant articles came to our attention, a testament to the promise and interest in this rapidly growing area. Thus, we focus here on providing a classification scheme from which to overview the general space that is beneficial to those seeking a basic introduction to the area, while providing enough detail to foster future research and allow current researchers to position their work among existing literature. We encourage readers to characterize their own work using our provided classification scheme, discussed in Chapter 2.

Another important note is that our review does not include various models of disability that one might bring to bear on the discussion (Mankoff et al., 2010). The medical model most often invoked—sometimes unintentionally—in the work we review focuses on physical and functional limitations a person might exhibit, and thereby looks to augment, assist, or adjust for these deficiencies. Other approaches include a social model that focuses on condition management and independent living, rather than "fixing" a person with a disability (Zola, 1983), as well as post-modern approaches that privilege each unique individual's lived experience (Pinder, 1996). In the current review, we also largely leave the kind of critique of technologies that one might invoke based on these different models to the side in favor of a broader summarization of technological approaches. However, for those interested, we recommend other work focused on describing the relationship between assistive technologies and disability studies (Mankoff et al., 2010), as well as consideration of neurodiversity in human-computer interaction research (Dalton, 2013).

1.4 STRUCTURE OF THIS REVIEW

The structure of this review is as follows. We first begin with a discussion of our method for identifying published papers included in this review and provide a description of the classification scheme we developed for organizing different technologies according to platform, domain, goal, target end user, setting, publication venue, empirical support, and technological maturity. The next eight chapters constitute the core of our review and are based on the eight components of interactive technology platforms we identified, including personal computers and use of the Web, mobile devices, shared active surfaces, virtual reality, sensor and wearable technologies, robotics, and natural user interfaces. In each core review chapter we clearly define the technology platform, review technologies that use the platform, and provide a discussion of challenges and future directions for research using that platform. We conclude the book with some overall discussion points and thoughts for the future of interactive technologies for autism.

CHAPTER 2

Methods and Classification Scheme

In this chapter, we provide a description of the methods we used to identify and analyze interactive technology research included in this review. Through a high-level analysis of the existing literature, we developed a classification scheme to help categorize each technology approach. Several frameworks could be developed around the same body of literature, and in fact, we experimented with multiple approaches while drafting this content. Ultimately, we settled on an approach that is both descriptive and explanatory, while supporting the potential for exploration and innovation going forward.

2.1 METHODS

This section is intended to provide an overview of the use of interactive technologies by and for individuals with autism for researchers new to the area, who may already be experts in a variety of social, medical, and computer science fields, or who may be new to research altogether. Given the rapid growth rate in this field, we did not set out to conduct a comprehensive review of the literature. Rather, with a focus on being as inclusive as possible, we set out to understand both the research and design spaces of this important and growing field. Notably, there are a wide variety of relevant commercial products in this space as well. Given our focus on research and the near impossibility of conducting any type of comprehensive review of commercially available products, we limit our discussion of commercial products but do include them when particularly relevant. Thus, we did not have specific inclusion and exclusion criteria for works included in this review. Others have conducted systematic reviews and meta-analyses of the autism and technology literature that we defer to for this level of analysis (Ramdoss et al., 2011; Grynszpan et al., 2013).

In gathering papers to include in this review, we conducted searchers on the ACM Digital Library, IEEE Xplore, PubMed, ERIC, and PsychInfo. We also searched abstracts of the International Meeting for Autism Research (IMFAR) from the last five years on Google Scholar to identify published papers from those projects. Keywords included "Autism," "Asperger," "PDD-NOS," "Technology," "Computer," "Robot," "Sensor," "Virtual Reality," and "Mobile." We then searched citations of the resulting articles for additional papers to include. From the resulting papers, we narrowed down the resulting list to those that fit our definition of interactive technologies and included the most recent articles for each application identified. We included technologies that ranged from demos to fully functional or publicly available technologies and those that have been used by or specifically designed for individuals with autism and their caregivers. We did not include technologies that had the potential to be used for autism but had not yet been applied to this domain. We note that there may be additional and related search terms beyond those identified, and while we tried to be as inclusive as possible, the search we conducted was not intended to be systematic.

Our review and classification is based on technologies described specifically *in the papers we identified*, as opposed to hypothetical or extrapolated uses, such as those mentioned in a critical review intro or discussed in conclusion/future directions section, or based on what we know from outside knowledge or future work. We focused our search on those technologies that originated from the research community or have a basis in research-validated intervention techniques. This ended up excluding a number of applications from popular media, such as games for children with autism found in the Apple App Store[3] or on Google Play.[4] These marketplaces are rich with different applications, but in general, they are beyond the scope of this book unless they have been studied in the scientific literature.

2.2 CLASSIFICATION SCHEME

To organize the papers, we conducted bottom-up coding of different aspects of twenty influential papers across a broad spectrum in the area of technology and autism to determine a set of characteristics that define their use, listed in Figure 2.1. To refine the codes further we individually applied these codes to a larger set of papers, and then met to discuss the application of the codes and finalize the set. Once there was strong agreement amongst the authors, we categorized the codes and wrote definitions to develop a classification scheme to help organize existing literature and projects relating to interactive technologies for autism and to help identify areas for future work. The final scheme consists of eight different dimensions along which projects can be categorized. Within each dimension, we determined several labels within that dimension that could describe the work.Below we list the eight dimensions, along with associated labels within those dimensions and their operational definitions. For each technology, it is possible that several labels exist within each dimension, such as a technology being designed for both the web and mobile, or one that is used by both individuals with autism and their family members.

2.2.1 INTERACTIVE TECHNOLOGY PLATFORM

This section describes the primary platforms, form factors, or delivery mechanisms used by the technology or application.

- *Personal Computers and the Web:* Includes applications that use a traditional keyboard, mouse, and monitor, and Internet-based applications that are primarily designed for ac-

[3] http://www.apple.com/osx/apps/app-store.html
[4] http://play.google.com/store

cess via a computer-based web browser. This can also include laptop-based technologies, but the primary differentiator is those that are intended to be stationary and not mobile.

- *Video & Multimedia*: Includes the capture, storage, and/or access of a combination of text, audio, still images, animation, video, or interactivity content forms. Also includes interactive videos, DVDs, or other multimedia.
- *Mobile Devices*: Includes applications delivered on mobile phones, PDAs, tablets, or other mobile devices intended for personal use. Can be used in multiple environments or anywhere the user goes.
- *Shared Active Surface*: Includes applications that are intended for multiple users in a co-located, mostly synchronous interaction, such as large displays, tabletop computers, electronic whiteboards, etc.
- *Virtual & Augmented Reality*: Includes the use of virtual reality, augmented reality, virtual worlds, and virtual avatars.
- *Sensor-Based & Wearable*: Includes the use of sensors (e.g., accelerometers, heart rate, microphones, etc.), both in the environment and on the body, or computer vision to collect data or provide input.
- *Robotics*: Includes physical instantiations of digital interactions. Includes both humanoid or anthropomorphic robots and general digital devices that carry out physical tasks. Includes both autonomous robots and those operated remotely by humans.
- *Natural Input*: Includes the use of input devices beyond traditional mice and keyboards, such as pens, gestures, speech, eye-tracking, multi-touch interaction, etc. Also required interaction with a system rather than just providing passive input.

2.2.2 DOMAIN

This category refers to the focus area relevant to autism that the technology targets, such as helping with acquisition of certain skills or addressing certain challenges.

- *Social/Emotional Skills*: Includes applications or projects that focus on emotion recognition, pro-social behaviors, nuances, and figures of speech.
- *Language/Communication*: Includes applications or projects that focus on learning vocabulary, language acquisition skills, reading, spoken language for communicative purposes, semantics, syntax, morphology, or prosody.

- *Restrictive/Repetitive Behaviors*: Includes applications that focus on repetitive or circumscribed behaviors, interests, or play. May include both high-level cognitive behaviors and low-level behaviors, such as manipulation of body or objects.
- *Academic Skills*: Includes applications that focus on skills traditionally taught in educational institutions, including math, science, letters, shapes, colors, etc. Language skills would be an academic skill, but because they are often a primary focus for other applications, we included them in their own category.
- *Life/Vocational Skills*: Includes skills that allow individuals with autism to function in home, work, or everyday life. Includes skills such as clothing, toileting, meal times, time management, transportation, safety, scheduling, and workplace skills.
- *Sensory/Physiological Responding/Motor Skills*: Includes applications that focus on an individual's sensory or physiological responding, such as perception, activation, recovery, or regulation. Also includes applications that focus on an individual's movement, including fine motor, gross motor, motor fluency, posture, and gestures.

2.2.3 GOAL

This category refers to the primary goal of the technology itself. Some technologies related to autism are intended to screen or diagnose, whereas others are intended for interventions.

- *Functional Assessment*: Includes applications or projects focused on the collection and review of data over time to assess an individual's learning, capability, or level of functioning. The data collected is intended for end users and/or people caring directly for individuals with autism.
- *Diagnosis/Screening*: Includes applications that assess the risk of an autism diagnosis in the general population, or that assist in helping make or understand the severity of an autism diagnosis.
- *Intervention/Education*: Includes applications that attempt to improve or produce a specific outcome in an individual with autism. May focus on teaching new skills, maintaining or practicing skills, or changing behaviors.
- *Scientific Assessment*: Includes applications or projects that use technology in the collection and analysis of data by researchers to understand more about autism and its features or characteristics.

- *Parent/Clinical Training*: Includes applications that provide support for caregivers, educators, clinicians, and other professionals to further their own learning and education or improve skills.

2.2.4 TARGET END USER

This category focuses on the person or persons who actually interact with the technology itself and are considered the primary users. It does not include secondary stakeholders or those who may benefit from the technology but do not actually interact with or use it.

- *Person with Autism*: Includes both children and adults with autism. Diagnosis can be anywhere on the autism spectrum and include both "high" and "low" functioning individuals.

- *Family/Caregiver*: Includes anyone who cares for or supports an individual with autism. May include parents, siblings, other family, friends, volunteers, group home staff, etc.

- *Peer*: Can be an adult or child who is a peer to individuals with autism. Includes both neurotypical individuals as well as those with autism or other cognitive disorders.

- *Clinician/Therapist*: A paid professional who works with individuals with autism. May include medical professionals, doctors, occupational therapists, physical therapists, speech therapists, applied behavior therapists, or other allied health professionals.

- *Researcher*: Anyone intending to collect data or conduct studies about individuals with autism and publish something generalizable about obtained data.

- *Educator*: Includes those who teach or are otherwise involved in the education of students with autism in schools (public or private), including teachers, administrators, school staff, etc.

2.2.5 SETTING

The care of individuals with autism takes place in a number of different settings. This category refers to the settings or locations in which the technology is intended for use.

- *Home*: A person with autism and/or their family's home or personal living space.

- *School*: A public or private place for educating individuals with autism. Includes both schools that specialize in autism education as well as general, inclusive classrooms. Could be at all levels from preschool through post-secondary education.

- *Research Lab*: Technology is intended for use in a research laboratory under careful observation or for controlled settings.
- *Clinic*: A place of professional practice that is not intended for education, such as a doctor's office, therapist's office, or a specialty service provider.
- *Community*: Technology is intended for use while the user is freely moving in public places like parks, stores, restaurants, etc.

2.2.6 PUBLICATION VENUE

Technology for autism is inherently interdisciplinary, and these disciplines have large variations in expertise and research approaches. This category describes the field from which the research publication originated.

- *Autism-Specific*: Journals or publication venues specifically relating to understanding autism. Examples: *Autism*, *International Meeting for Autism Research* (IMFAR), *Journal of Autism and Developmental Disorders* (JADD), *Focus on Autism*. There is a conference series specific to autism and technology, *International Conference on Innovative Technologies for Autism Spectrum Disorders*,[5] first held in 2012.
- *Social/Behavioral Science*: Journals or publication venues from areas in Psychology, Human Development, or Sociology. Examples: Journal of Consulting and Clinical Psychology, Child Development, Behavior Research Methods.
- *Computing*: Journals, conference publications, and other publication venues relating to the fields of computing, computer science, or human-computer interaction. Often included in the ACM or IEEE digital libraries. Examples: CHI, UbiComp, CSCW, ToCHI, PUC, ASSETS.
- *Education*: Journal articles or publications focusing on education or special education. Often included in the ERIC digital library. Examples: *American Journal on Intellectual and Developmental Disabilities*, *Mental Retardation*, *Journal of Mental Health Research in Intellectual Disabilities*.
- *Medical*: Journal articles or publications from the medical field, including health informatics. Often included in the PubMed digital library. Examples: *JAMA*, *JAMIA*, *AMIA*.

[5] http://www.itasd.org/

2.2.7 EMPIRICAL SUPPORT

Many technologies that have been designed for individuals with autism are experimental and may not be scientifically proven yet. To help readers distinguish between these types of technologies, this category describes the type of study that has been completed with the technology in terms of its feasibility, usability, acceptability, efficacy, and effectiveness. We note that in the field of human-computer interaction, smaller N studies are common due to the cumbersome nature of doing rigorous evaluations of novel and often non-robust technology prototypes, and thus feasibility studies are more common. However, the impetus for better experimentation is growing, and we hope to encourage more activity in this space. In addition, we note that the three levels within this classification are fairly broad. Within a given category, there may be varying levels of quality in terms of study design, number of participants, and level of control.

- *Descriptive*: Study design seeks to observe natural behaviors without affecting them in any way. Common approaches include observational methods (e.g., ethnography), case study methods, and survey methods.

- *Correlational/Quasi-Experimental*: Study design involves comparing groups, without any random pre-selection processes, on the same variable(s) to assess group similarities/differences and/or determine the degree to which variables tend to co-occur or are related to each other. They are similar to experimental study designs but lack random assignment of study participants. Common approaches include nonequivalent groups design, regression-discontinuity design, retrospective designs, and prospective designs.

- *Experimental*: Study designs seek to determine whether a program or intervention had the intended causal effect on study participants. There are three key components of an experimental study design: (1) pre-post test design, (2) a treatment group and a control group, and (3) random assignment of study participants. Common approaches include randomized controlled trials, Solomon four-group design, within subject design, repeated measures design, and counterbalanced measures design.

2.2.8 TECHNOLOGY MATURITY

This category describes the maturity of the technology used with individuals with autism and its readiness for use or distribution by the general public.

- *Design Concept/Non-Functional Prototype*: The technology is not yet functional. It may be an idea expressed as a sketch, storyboard, interface mockup, etc. May also include non-functional but interactive prototypes such as paper prototypes, Wizard-of-Oz prototypes, video prototypes, etc.

- *Functional Prototype*: A functional prototype has been developed and interacted with the intended users for the target purposes. It has been built for use by the developers to answer specific questions, but may require assistance with setup, use, or maintenance.

- *Publicly Available*: The technology is mature enough that it can be used without assistance from the developers or research team. This might be a commercial product, software that is open source, or applications available for download on websites or on mobile marketplaces.

As an example of how we applied the classification, Abaris (Kientz et al., 2005; Kientz et al., 2006), an application that uses digital pens, speech recognition, and video recording for supporting therapists conducting discrete trial training therapy, would be categorized as:

- **Interactive Technology Platform** *of Personal Computers and Web, Video & Multi-media,* and *Natural Input*

- **Domains** of *Academic Skills* and *Language/Communication Skills*

- **Goals** of *Functional Assessment* and *Intervention/Education*

- **Target End Users** of *Clinician/Therapist* and *Educators*

- **Settings** of *Home* and *School*

- **Publication Venue** of *Computing*

- **Empirical Support** of *Correlational or Quasi-Experimental Study Designs*

- **Maturity** of *Functional Prototype*

Figure 2.1 includes 20 papers on technologies reviewed for this book and their associated coding within the classification scheme as a demonstration of the coding scheme. We chose the 20 papers based on their diversity across specific areas within the classification as a way of defining, refining, and testing our scheme's components.

In the subsequent chapters, we used this scheme to describe the different types of interactive technologies. As has been used by other systematic review articles (e.g., Grynszpan et al., 2013), we organize different sections of this review by the *primary technology platform* of the application. This includes Personal Computers & Web, Video & Multimedia, Mobile Devices, Shared Active Surfaces, Virtual & Augmented Reality, Sensor-Based & Wearable, Robotics, and Natural Input. Some applications and technologies might use more than one platform (such as both mobile devices and a shared active surface). We discuss those as part of each chapter and co-reference where appropriate.

Within each chapter, we have included a section that discusses exemplary technology platforms from among the 20 technologies used to develop the classification scheme. We describe how these technologies fit within the rest of the scheme beyond the technology platform and then provide a discussion of the overall trends we saw for the given platform. We also discuss opportunities for future work and identify areas that may be of interest to new researchers.

We note that this review provides a snapshot of the current landscape of interactive technologies for autism, and that technology is always evolving and changing, as is our knowledge about autism. We expect that there will be many new technologies identified beyond those discussed in this review. To keep the community up-to-date, we have started a public, shared Mendeley.com group called "Interactive Technologies for Autism" that contains all of the references cited in this review.[6] We welcome the community to add additional references, comment on existing ones, and add tags to references to classify them in our scheme. We also believe the classification scheme may evolve as technologies evolve, and we welcome a discussion of this through the Mendeley group.

[6] http://www.mendeley.com/groups/3745371/interactive-technologies-for-autism/

	Paper	Whalen et al., 2010	Westeyn et al., 2012	Wallace et al., 2010	van Santen et al., 2010	Tartaro et al., 2008	Piper et al., 2006	Klin et al., 2002	Kientz et al., 2009	Kientz et al., 2005	Hong et al., 2012	Hirano et al., 2010	Hayes et al., 2008	Hailpern et al., 2009	Goodwin et al., 2006	Feil-Seifer et al., 2009	Escobedo et al., 2012	el Kaliouby et al., 2006	Dziobek et al., 2006	Bauminger et al., 2007	Albinali et al., 2009
Interactive Technology Platform	Personal Computers & Web	◆							◆	◆	◆		◆								
	Video & Multimedia		◆						◆	◆			◆			◆			◆		
	Mobile Devices											◆					◆	◆			
	Shared Active Surface						◆					◆								◆	
	Virtual & Augmented Reality			◆		◆					◆						◆				
	Sensor-Based & Wearable		◆		◆										◆	◆		◆			◆
	Robotics															◆					
	Natural User Interfaces				◆			◆		◆				◆							
Domain	Social/Emotional Skills		◆	◆		◆	◆	◆	◆		◆	◆	◆			◆	◆	◆	◆	◆	
	Language/Communication	◆			◆	◆			◆	◆				◆				◆			
	Restrictive/Repetitive Behaviors		◆										◆	◆							◆
	Academic Skills	◆								◆		◆	◆								
	Life/Vocational Skills									◆	◆	◆									
	Sensory/Physiological/Motor														◆						
Goal	Functional Assessment												◆								
	Diagnosis/Screening		◆		◆			◆	◆							◆					
	Intervention/Education	◆					◆			◆	◆	◆	◆	◆		◆	◆	◆		◆	
	Scientific Assessment		◆	◆	◆	◆		◆							◆	◆			◆		◆
	Parent/Clinical Training									◆											
Target End User	Person with Autism	◆	◆	◆		◆	◆				◆	◆		◆	◆	◆	◆	◆	◆	◆	◆
	Family/Caregiver	◆	◆						◆		◆										
	Peer										◆	◆					◆	◆		◆	
	Clinician/Therapist					◆	◆		◆	◆				◆		◆					
	Researcher		◆	◆	◆	◆		◆							◆	◆			◆		◆
	Educator	◆					◆			◆		◆	◆							◆	
Setting	Home		◆						◆	◆	◆										
	School	◆	◆				◆			◆		◆	◆				◆			◆	◆
	Research Lab		◆	◆	◆	◆		◆						◆	◆	◆			◆		◆
	Clinic								◆	◆											
	Community																	◆			
Publication Venue	Autism-Specific	◆		◆	◆										◆				◆		
	Social/Behavioral Science																				
	Computing		◆				◆		◆	◆	◆	◆	◆	◆		◆	◆	◆		◆	◆
	Education					◆															
	Medical							◆													
Empirical Support	Descriptive		◆	◆							◆							◆			
	Correlational/Quasi-Experimental						◆		◆	◆		◆	◆	◆			◆				◆
	Experimental	◆			◆	◆		◆							◆	◆			◆	◆	
Tech. Maturity	Concept/Non-Functional Prototype																	◆			
	Functional Prototype		◆	◆	◆	◆	◆		◆	◆	◆	◆	◆	◆		◆	◆		◆	◆	◆
	Publicly Available	◆						◆							◆						

Figure 2.1: Coding of 20 papers used to define, refine, and test our classification scheme.

CHAPTER 3

Personal Computers and the Web

We begin our review with the class of applications that has had the longest and broadest history of use with individuals on the autism spectrum: applications intended for use on a desktop or on the web. The experience of using these applications usually requires an individual to sit at a screen and use a keyboard and/or mouse to interact with specially designed software in a primarily stationary and seated position.

3.1 OVERVIEW

The first personal computers were made available to the general public in the late 1970s and early 1980s, with platforms such as the Apple II, TRS-80, and Commodore 64. The Internet and the World Wide Web (or the Web) became popular a little over a decade later with the invention of the first web browser, Mozilla, in 1992 and the launch of Netscape in 1994. Coincidentally, the rising popularity of computers and the Internet followed a similar timeline with that of the rise of awareness and diagnostic rates of autism. Thus, it is somehow fitting that computers have become so popular with individuals with autism, though we are certainly not suggesting this is causal.

For the purposes of this review, personal computers and the Web as a platform includes applications that use a traditional keyboard, mouse, and monitor, and Internet-based applications that are primarily designed for access via a computer-based Web browser. They can also include laptop-based technologies, but the primary differentiator is those that are intended to be used while stationary and not while mobile.

Applications designed for traditional personal computers and the Web have some particular advantages for their use by individuals with autism. For one, the popularity and prevalence of desktop computers and laptops still make them the most common way of distributing technological interventions to large-scale audiences. Their relative affordability also allows them to reach the largest audiences of any of the interventions described in this book, though the other platforms are gaining ground on the desktop computer. Many schools have desktop computers in the classroom, and efforts like One Laptop Per Child[7] are pushing the penetration of computing in developed nations. Thus, traditional computers are appropriate for many educational settings where other systems—such as mobile phones—may not be allowed, affordable, or practical (Cramer & Hayes, 2010). Because computers, particularly desktops, tend to be in fixed locations, they are less likely to be lost, stolen, or broken, and it also means that individuals have a stable place and environment where they can do their work. The systems have also been around for a significant amount of time

[7] http://one.laptop.org/

and thus have a long history of devices and software that can be run on different platforms, and often comprise more powerful systems that can run more data-intensive and processing-heavy programs without having to worry about battery life or network connectivity. Use of the Web has a unique advantage of being able to be accessed from almost any computer, including many mobile devices. They can also allow for instant updates without requiring users to install upgrades. Finally, for the most part, Web applications do not depend on any minimum system requirements.

On the other hand, desktop-based systems requiring users to be in a fixed location necessarily limit their flexibility to fit into everyday activities. Even laptops, that are arguably more mobile than desktops, typically require a certain amount of space within which to operate and can include cumbersome peripheral devices. In addition, many applications built for traditional computers require the use of a mouse, keyboard, or both, which may have a steeper learning curve for individuals with autism, especially those who are non-verbal or who have motor impairments. Traditional personal computers also may not be able to take advantage of some of the more interactive, real-world technologies described in other sections, which may make generalization of skills learned on a computer more difficult than it might be with other technologies. Despite these limitations, these applications still have a large amount of promise, which we describe in the next section.

3.2 DESKTOP AND WEB TECHNOLOGIES FOR AUTISM

In general, we group technologies in this section based on the following three categories: 1) specialized software or websites designed specifically for individuals with autism; 2) general purpose software, websites, or other technology applications specifically used by individuals with autism; and 3) studies comparing computer-based tasks to other types of interactions.

3.2.1 SPECIALIZED SOFTWARE AND WEBSITES FOR INDIVIDUALS WITH AUTISM

A number of researchers have designed, built, and studied the use of specially designed software for individuals with autism and their caregivers. These applications address a wide variety of areas from education to screening to communication.

One of the earliest examples of specialized educational software for autism is DT Trainer[8] by Accelerations Educational Software. DT Trainer is a computer-aided instruction program that uses components of applied behavior analysis, a popular intervention for individuals on the autism spectrum (Lovaas, 1987). This was one of the first commercially available and low-cost systems to support discrete trial training in school systems. A more research-based application in this space is TeachTown (Whalen et al., 2006), based on a variant of discrete trial training, called Pivotal Response Training (Koegel et al., 1999). TeachTown has been subject to rigorous validation for

[8] http://www.dttrainer.com

efficacy (Whalen et al., 2010). Researchers using TeachTown conducted a between-subjects study across 47 classrooms in the Los Angeles School District and determined that those who used the software across the three-month period showed more improvement on cognitive and language outcomes than those in the control group.

KidTalk (Cheng et al., 2002) is another program that provides a means of conducting online therapy for individuals with high-functioning autism and Asperger's Syndrome. KidTalk consists of scripts for interaction and provides different rewards for progress and engaging in socially appropriate behavior. It also provides therapists with tools for group therapy and feedback. KidTalk has been tested for feasibility with a number of small groups and shows promising results, but has not been released as a commercial product.

Teaching facial processing and emotion recognition skills to individuals with autism using software has been a common thread of work in this space. Tanaka and colleagues (2003) have developed a framework for studying facial processing defects in individuals with autism they call Let's Face It! This system is made up of a series of mini games designed to teach facial processing, including finding a face in a scene, matching faces with similar expressions, creating a face with different emotional components, and following eye gaze of a face on the screen (see Figure 3.1, left). Bölte and colleagues (2002) designed and evaluated a system (see Figure 3.1, right) with 10 individuals with autism to teach recognition of facial affect, based on concepts related to Theory of Mind (Baron-Cohen et al., 1985). They found the system produced improvement in detection of facial affect, but cautioned against generalization of their findings.

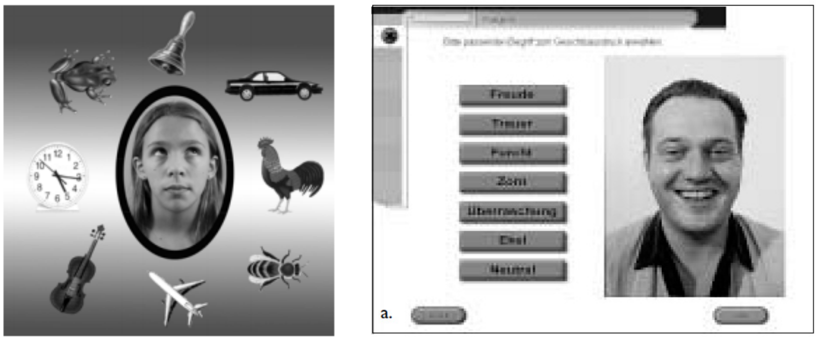

Figure 3.1: (A) Left: "The Eyes Have It" mini game as part of Let's Face It! (Tanaka et al., 2003) and (B) Right: a tool for teaching facial affect recognition (Bölte et al., 2002).

The Mind Reading software application (Baron-Cohen et al., 2004) (see Figure 3.2) was designed to teach individuals with autism to read and understand emotions by using strength areas typical of their target user population to address reading emotions. Several studies have identified that individuals with autism have improved emotional response scores after using this software after a set period of time (Golan & Baron-Cohen, 2006; LaCava et al., 2007; LaCava et al., 2010). FaceSay, another software application that uses realistic avatar assistants in an interactive, structured environment (Hopkins et al., 2011), was used to teach both lower functioning children and higher functioning children with autism social skills. Their randomized controlled trial study showed that higher functioning children improved in facial recognition, emotion recognition, and social interactions while lower functioning children improved in emotion recognition and social interactions, making it a promising application. A similar research prototype, called Facial Expression Wonderland, has similar goals for teaching facial expressions to children with autism (Tseng & Do, 2010). The system has not yet been evaluated rigorously at the time of this writing, however Ould Mohamed and colleagues (2006) developed a method for assessing attention analysis in the use of software by combining gaze direction and face orientation. This type of analysis could be used to evaluate all the systems mentioned above.

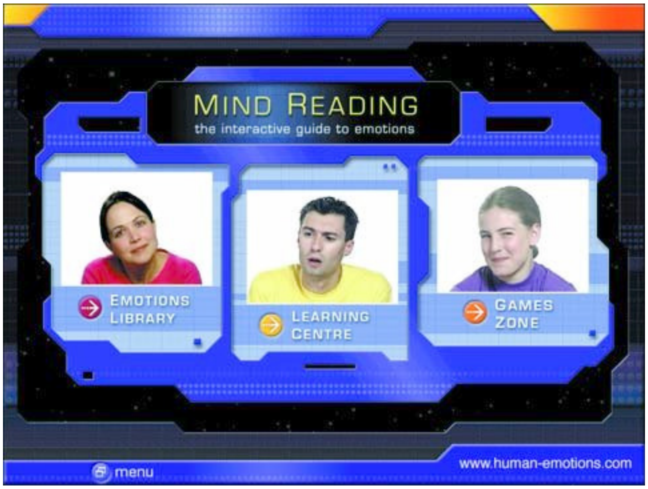

Figure 3.2: Mind Reading (Baron-Cohen et al., 2004).

Other desktop and web-based software has been designed to improve communication skills of individuals with autism. Hetzroni and Tannous (2004) developed an application based on daily life activities like play, food, and hygiene to teach specific functions of communication. Specific outcome measures included factors related to echolalia, relevant and irrelevant speech, and communication intentions—all of which showed improvement after using their system. The authors claim that their software also generalized learning to the natural classroom environment. Da Silva and colleagues (2011) developed a software application for improving communication skills, called TROCAS. TROCAS (see Figure 3.3) supports photos, audio, videos, a message board, an online digital book library, and connection to a story tool. The design of the system was specifically built to allow individuals with autism to specify communication preferences and present them in a format that would allow for the best user experience. Preliminary tests of the use of TROCAS by three children across 12 weeks showed some improvement in communication competencies.

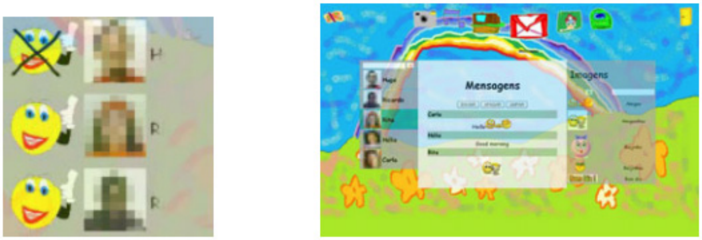

Figure 3.3: TROCAS system (Lucas da Silva et al., 2011).

In addition to software designed specifically for use by individuals with autism, websites and software have been designed for caregivers of affected individuals. For example, the Autism Support Network[9] and TalkAutism[10] are online portals for parents and caregivers to find resources, obtain peer support, ask advice of experts, and seek advocates. Baby Steps (Kientz, 2012; Kientz et al., 2009) is a software application designed for parents of young children to help track developmental progress and help detect autism (among other developmental delays) earlier (see Figure 3.4). The system is a stand-alone application that asks parents to track milestone questions along with sentimental memories of a child's younger years. Baby Steps was evaluated with eight families for a three-month period of time and findings suggested that certain features allowed for timelier tracking of milestones and improved communication with pediatricians.

9 http://www.autismsupportnetwork.com/
10 http://behaviorimaging.com/talkautism/

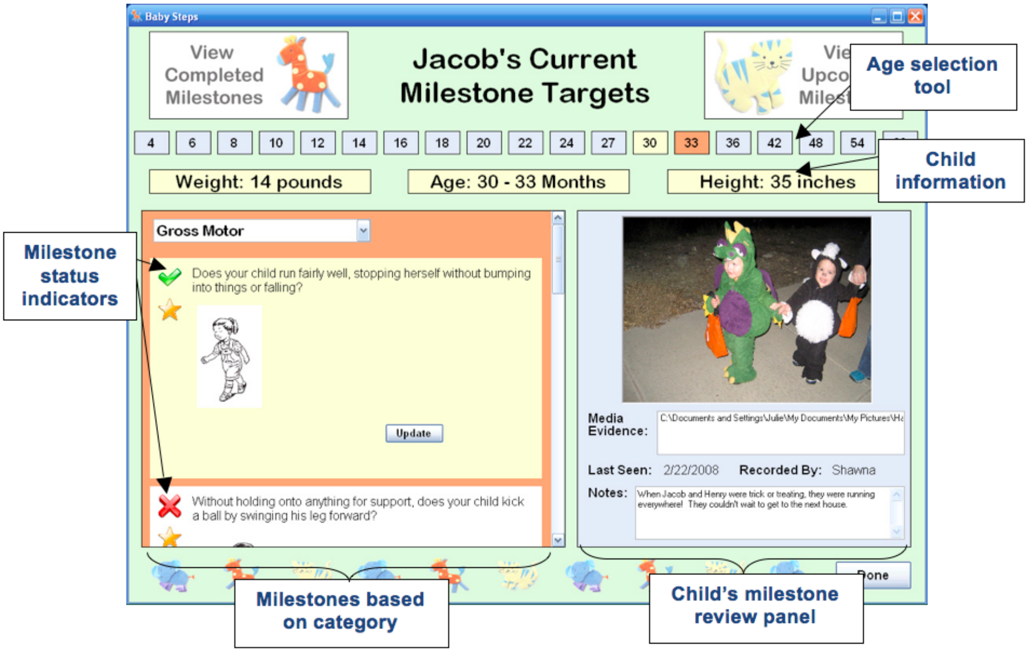

Figure 3.4: Baby Steps system for tracking developmental milestones in young children (Kientz et al., 2009).

3.2.2 MAINSTREAM SOFTWARE AND WEBSITE USE BY INDIVIDUALS WITH AUTISM

In addition to the numerous systems specially designed for individuals with autism, there have also been uses and adoption of more general-purpose software or websites by those experiencing autism. These include tools for computer-mediated communication as well as educational technology.

People with autism use a variety of tools for communicating. For example, Burke and colleagues (2010) conducted a qualitative study on how computer-mediated communication (CMC) tools are used for social purposes by individuals on the autism spectrum. Their study examined uses of cell phones, text messaging, email, instant messaging, social networking sites, online dating sites, and discussion forums. Their analysis revealed that many individuals with autism, despite social connectedness being an area of deficiency as part of their diagnosis, are able to use CMC tools to connect with others and develop successful relationships. However, their findings indicate that people with autism may still have issues relating to trust, disclosure, inflexible thinking, and perspective taking, making it harder for them to maintain relationships.

Benford and Standen (2011) studied the feasibility of using email to facilitate interviews with 23 high-functioning adults with autism, as opposed to in-person interviews. In their paper, they discuss epistemological, methodological, and practical issues of doing research in this way, and found that it can provide a viable means of conducting research with a population that is often difficult to reach, and one that allows them to have greater control over what they say and how they say it.

Educational games and software designed for use by students in general have also been used in a number of studies with individuals with autism. For example, Lewis and colleagues (2005) used The Learning Company's Clue Finders game as a tool for assessing how children worked on computers in social interactions and influence acceptance by peers in classroom interactions. Pixwriter allows writing along with pictures in a split screen format to teach students with autism to write using a computer (Pennington et al., 2012). Early learning reading software called Headsprout helps teach word lists and text reading skills (Whitcomb et al., 2011). Our experience in working with educators in the field of autism suggests that there are many uses of mainstream software applications by individuals with autism beyond these specific examples. However, one challenge is that there are often difficulties in finding age and skill appropriate software for a given classroom and for a given individual.

Beyond tools specifically developed for education and then repurposed for use by people with autism, there have also been investigations of tools developed for general use. Several researchers have used an older tool called Bubble Dialogue (Cunningham et al., 1992), developed in 1992 as a means of using a HyperCard-based technique as a constructivist education tool that uses a comic strip model with speech bubbles to teach communication skills (see Figure 3.5). This tool has been used successfully by a number of individuals with autism across several different projects. For example, Dillon and Jean (2012) determined children with autism could use Bubble Dialogue in their process of imaginative storytelling. Glenwright and Agbayewa (2012) used the tool to help higher functioning children and adolescents to comprehend verbal irony through computer-mediated communication. Similarly, Rajendran and colleagues (2005) used the tool to explore how individuals with Asperger's Syndrome can use CMC tools to respond to non-literal language and inappropriate requests made through technology. Although Bubble Dialogue is over 20 years old, recent studies still find that it is a useful tool for understanding computer-based interaction skills that may generalize to other types of CMC applications.

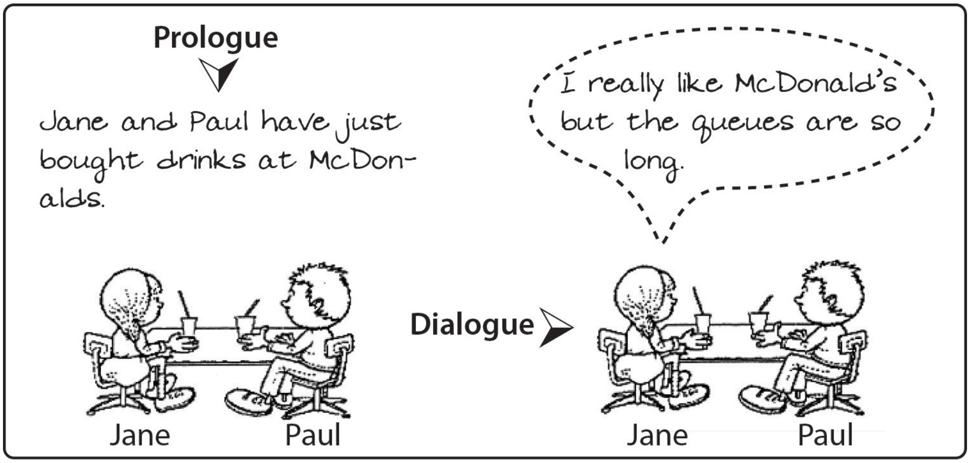

Figure 3.5: Bubble Dialogue application (Cunningham et al., 1992).

Google SketchUp is a 3D modeling tool that researchers have identified as a useful and attractive way for engaging the visual-spatial skills of individuals with autism. Wright and colleagues (2011) conducted a qualitative study of Google SketchUp in seven boys with high-functioning autism and found that it promoted intergenerational communication between parents and grandparents.

Beyond individuals in Burke and colleagues' study mentioned previously (Burke et al., 2010), there have been some popular examples of individuals with autism using computer-mediated communication. For example, there is a popular website, WrongPlanet.net, which serves as a blog, discussion forum, and chatroom for individuals with autism and their families, and the popular virtual world, Second Life, has a number of worlds dedicated for people with autism. There have also been uses of blogs and YouTube videos of individuals with autism. One YouTube video, "In My Language" by Amanda Baggs, was used to explain how she experiences the world, and has been viewed over 1 million times here.[11] There are likely many more uses of mainstream software and websites beyond those mentioned, but in our literature search, we did not identify many research studies exploring them. The number of websites, blogs, social networks, and mainstream software applications are voluminous. We believe there is certainly room for additional research to explore which tools are the most useful, why, and how they can be improved and made even more useful for individuals with autism.

[11] http://www.youtube.com/watch?v=JnylM1hI2jc

3.2.3 COMPARISON OF COMPUTER-BASED TASKS WITH OTHER TYPES OF INTERACTIONS

Perhaps some of the earliest uses of computer-based applications for individuals with autism are those involving simple computer-based substitution for tasks typically accomplished without the use of digital technologies. The reason for these types of comparisons is the conjecture that including humans or physical components in educational tasks can provide too much stimulation for individuals with autism to concentrate, and thus they may have better performance on a computer. There is also motivation to move certain interventions to the computer, as it can be expensive for one-on-one individualized interventions with a human being, and thus a child with autism could receive more therapy in a given week if some of it was conducted via computer.

There are mixed results in studies that compare the use of technology versus in-person interaction. For example, nearly 30 years ago, Plienis and Anthony (1985) conducted a study that looked at the performance and behavior of individuals with learning and behavioral problems (including autism) when they engage in a two-choice discrimination task. They found no differences in task performance between the computer and adult delivering instruction, but they did observe more behavioral difficulties when they engaged in the task with an adult. About 10 years later, Chen and Bernard-Optiz (1993) compared computer-aided instruction with teacher-based instruction. They found computers to be more interesting and motivating, eliciting better behavior during computer use. A more recent study by Moore and Calvert (2000) specifically compared a computer-based application and a behavioral program with a teacher for teaching vocabulary tasks. They found the children with autism to be more attentive, motivated, and able to learn more vocabulary with the computer program. Taken together, it appears there is promise in computerizing tasks traditionally performed by a teacher or therapist for individuals with autism.

Another study tested three different types of instruction for teaching non-verbal reading skills to three different students, one of whom had autism (Coleman-Martin et al., 2005). The three cases included teacher-only instruction, teacher plus computer, and computer-only instruction (using Microsoft PowerPoint™) and found that all three students met criteria equally well across conditions. An additional look at reading skills (Williams et al., 2002) compared an interactive and engaging book-based experience with a scanned and digitally enhanced (with sound files, interactive elements, etc.) through a multimedia authoring tool called Illuminatis. After ten weeks, they found that children with autism spent more time on the computer task and five out of the eight children tested acquired new words. More recently, Barrow and Hannah (2012) conducted an exploratory study looking at computer-assisted interviewing as a means of gathering input and feedback from individuals with autism. They reflect on their experiences compared to traditional interviewing techniques and conclude that it is a viable tool for communication.

Researchers have also explored how individuals with autism compare to typically developing peers during computer-based tasks. For example, Bernard-Opitz and colleagues (2001) compared the use of a computer program to teach social problem solving by eight matched pairs of individuals with autism and typically developing peers. They found that children in both groups could be taught problem-solving skills through software, although the individuals with autism learned at a slower rate and produced fewer results.

Other research has compared the use of computer instruction for not just individuals with autism, but also their therapists. For example, Granpeesheh and colleagues (2010) studied the use of an eLearning tool for conducting training for applied behavior analysis therapy compared to traditional one-on-one, in-person instruction. They found similar results in knowledge acquisition for both methods, but that in-person instruction resulted in slightly better scores. However, they conclude that eLearning strategies can be useful when resources are not available for in-person instruction. Another study compared inexperienced teachers conducting therapy when given a computer-assisted instructional task versus one-on-one instruction and found that teachers had 90-100% accuracy in the computer-based task compared to only 60% in the one-on-one instructional task (Kodak et al., 2011). This demonstrates that there is promise in using computers not only for individuals with autism, but also their therapists and teachers.

Finally, other research has shown that computer-based activity schedules are successful in teaching individuals with autism a variety of new skills through the use of videos, sounds, and images (Stromer et al., 2006). These activity schedules have been created using standard prompts as well as Microsoft PowerPoint (Rehfeldt et al., 2004).

3.3 CLASSIFICATION APPLIED TO PERSONAL COMPUTERS AND THE WEB

In Figure 2.1, we tagged two of our twenty representative articles as using desktop and web as a technology platform. These included Baby Steps (Kientz et al., 2009) and TeachTown (Whalen et al., 2010). Here we describe how these both fit into the classification scheme defined in Chapter 2 and discuss overall trends we observed for technologies making use of personal computers and web-based platforms.

Baby Steps (Kientz et al., 2009): The Baby Steps software application was classified as *personal computers & web* because it is a standalone application for Windows-based computers as well as *video & multimedia* because it allows parents to upload videos and photos of their children's developmental progress. We classified it as tracking both *social/emotional* skills and *language/communication* skills since those are the prominent areas of concern. The goal of the system is to aid with *diagnosis/screening*, and the target users are parents and pediatricians, so we categorized the target end users as *family/caregiver* and *clinician/therapist*. The primary settings are at a parent's *home* and a pediatrician's *clinic*. The research was published at the CHI conference, which is primarily a *computing* venue. Kientz et al.'s study consisted of a small controlled pilot study, so we consider it to be *correlational/quasi-experimental*, and Baby Steps is currently at the stage of a *functional prototype*.

TeachTown (Whalen et al., 2010): We categorized TeachTown as a *personal computer and web* platform because it consists of a series of educational software applications that are designed for personal computers. The skills it teaches are primarily *language/communication* and *academic skills*. The goal of TeachTown is as an *educational intervention*, however, it is designed for use in both *school* and *home* settings, and thus its target end users are the *person with autism*, their *families/caregivers*, and their *educators*. Whalen et al. published their efficacy study of TeachTown in the journal *Autism*, which is an *autism-specific* publication venue. The TeachTown study in this paper was conducted as a randomized controlled trial, and thus we consider it to be *experimental*. TeachTown is currently *publicly available* via their website.[12]

In general, personal computers and web platforms had some of the largest variety in terms of publication venues, since many of the research studies were rigorous evaluations of software, rather than aiming to create a more technically novel system, as many contributions in the computing publication venue strive to do. We saw more publicly available software in this category, as many technologies were easier to distribute via the web and did not require specialized hardware beyond widely available personal computers. The domains and goals for these applications were quite varied, as many software and web applications exist. However, we did notice that educator target end users and school settings seemed very prominent in this category, perhaps due to the widespread availability of traditional personal computers in classrooms. Finally, we saw a higher proportion of experimental studies of technologies in this platform, which may be a result of seeing a higher prevalence of publications in domains outside of computing, where experimental studies are more of the norm.

3.4 FUTURE DIRECTIONS

In general, despite the surge in growth among other technology platforms discussed in future chapters in this volume, growth in this space has been less pronounced. However, there is still much promise surrounding the potential for desktop, laptop, web, and social media technologies. Computers are likely to be present in school settings for decades to come, because budgets often do not allow for adoption of newer technologies at a fast rate. In addition, websites and social media can often be used on multiple platforms, including shared active surfaces (Chapter 5) and mobile devices (Chapter 4). We anticipate seeing increased use of Web-based applications, as they can run on many devices, do not rely on computers being configured in a certain way, and are easier to update. In addition, some of the limitations of Web-based applications, such as access to specific

[12] http://web.teachtown.com/

interactive components, have been addressed as Web browsers and technologies have advanced. The advent of responsive design (Marcotte, 2011) also allows Web designers and developers to make one website that functions on a variety of devices (desktop, tablet, smartphone, etc.) using a single source code—a distinct advantage over previous Web design activities.

More studies are needed to understand the long-term impacts of technology use in people with autism, just as such studies are needed for the general population. A recently published study by Finkenauer and colleagues (2011) consisted of a longitudinal study of the use of the Internet by those with autistic traits compared to neurotypical individuals. They found that while the number of hours was not different between the two groups, those with autistic traits were more likely to compulsively use the Internet. Likewise, a study by Burke and colleagues (2010) found that individuals with autism often had difficulty with trust, disclosure, inflexible thinking, and perspective taking on the Internet. As with any type of tool, the trade-offs should be considered and the individuality of the person using it should be taken into account before it can be recommended for broad use.

CHAPTER 4

Video and Multimedia

In this chapter, we describe the use of multimedia (e.g., image, video, audio, and combinations thereof) to support teaching and assessment of individuals with autism. Notably, the title of this chapter is "Video and Multimedia" to highlight the particularly prominent place video holds in the space of technologies for autism. However, this work includes the capture, storage, and/or access of a combination of text, audio, still images, animation, video, or interactivity content forms. It also includes interactive videos, DVDs, or other multimedia. We particularly highlight ways in which video is a mode for both collection and delivery of information. Our classification scheme defines "Video and Multimedia" as: "*Includes the capture, storage, and/or access of a combination of text, audio, still images, animation, video, or interactivity content forms. Also includes interactive videos, DVDs, or other multimedia.*"

4.1 OVERVIEW

Given that autism is largely characterized, diagnosed, and monitored behaviorally, and that so many individuals with autism are thought to be visual learners (Quill, 1997), multimedia—particularly images and video—is an appealing mechanism for collecting, analyzing, and delivering vast amounts of information. Baskett (1996) showed that having video conversations with another individual reduced anxiety, and thus video technology can serve as a useful intermediary. This approach is not without its challenges of course, including technical as well as social, practical, and legal concerns. However, even with these challenges, the affordances, opportunities, and potential for video in support of individuals with autism is so strong that a large number of research projects have focused on its use. Before we describe those projects in depth, we first begin with some basic definitions and background on video.

Most dictionaries define video as relating to the recording or playing of "moving visual images" with multimedia expanding this use of video to include references to computer text. We focus on using these relatively broad considerations of video and multimedia as a platform for diagnosing, monitoring, instructing, and supporting individuals with autism. However, we recognize that such a broad definition will necessarily require that we not include every possible research project nor commercial product in existence.

Much work has been done to capitalize on the visual processing strengths observed in individuals with autism in terms of instruction and reduction of problem behavior. At the same time, with no specific genotype or physiological phenotype for autism, researchers and clinicians rely on behavioral phenotyping for diagnosis and monitoring. It has been argued that video and multimedia records can become essential parts of this process through what some reference as "behavior imaging" (Narayanan & Georgiou, 2013), an analogy to medical imaging that refers to the capture and recording of behavioral data.

The concept of multimedia is changing, as elements like games and immersive environments become more plentiful. For those platforms, however, we direct readers to Chapters 6 and 7 in this same book. In this space, we focus on multimedia as including video, text, still images, animations, and audio. Given the broad nature of video and multimedia, there are many ways in which one might categorize projects in this space. In our review, however, we break them into two major areas: instructional aids and tools for recording and assessment.

4.2 INSTRUCTIONAL AIDS

In both regular and special education classrooms, video has long been used to teach a variety of concepts, whether through watching a science demonstration or learning appropriate social skills. We describe video-based instruction separately from the broader category of multimedia, which may include video but does not have to and may include other media elements. Finally, we close with a discussion of tools to support authoring of these instructional media, a continued challenge for those wishing to use them.

4.2.1 VIDEO MODELING AND IMAGE-BASED INSTRUCTION

Some learning theories argue that observing behaviors and attempting to replicate or model them account for much of the natural acquisition of skills (Shipley-Benamou et al., 2002). For individuals with autism, application of these approaches more directly, through video modeling and video-based instruction, can assist in learning and retaining positive behaviors (See Figure 4.1 for an example). Several articles have reviewed in-depth the area of video modeling for autism (Ayres & Langone, 2005; McCoy & Hermansen, 2007; Bellini & Akullian, 2007; Delano, 2007), and the summary of salient points follows.

Video modeling, a type of video-based training, typically involves watching recorded videos of others or oneself performing a behavior correctly or positively. The former, peer modeling, focuses on observing people similar to oneself (in physical characteristics, age, group, ethnicity, etc.), whereas the latter, self-modeling, encourages watching oneself complete a task successfully. It can also be helpful to view the world as though one is experiencing it, a so-called "first person shooter" perspective (Shipley-Benamou et al., 2002).

Video modeling traditionally focuses on only watching those videos in which the person performs the activity correctly. However, recording and watching videos of oneself performing the same activity over time opens up opportunities for self-evaluation and visual progression of personal growth over time. Likewise, using video to learn and practice skills enables delivery of positive feedback and presentation of concepts and instruction in engaging ways (Goldsmith & LeBlanc, 2004).

Finally, the use of video training, both video modeling and other kinds of instruction, appears to be effective, at least in part, because it directs focus to relevant stimuli by requiring the viewer to look at a small spatial area and listen to accompanying language (Shipley-Benamou et al., 2002).

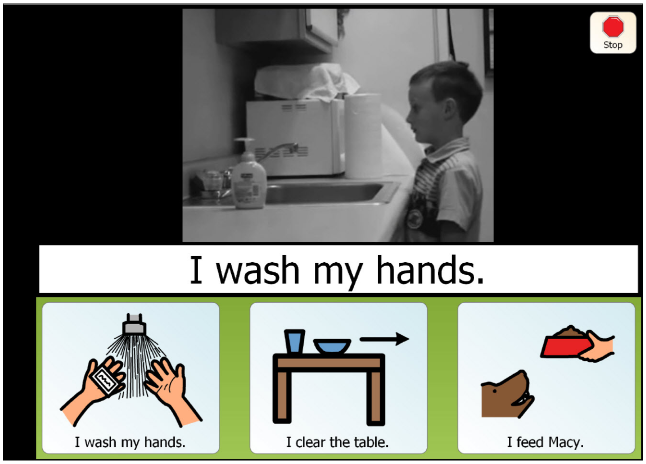

Figure 4.1: Video-based modeling feature from Boardmaker Studio software.[13]

The availability of relatively low-cost mechanisms for recording and replaying videos has enabled research to be done on the effectiveness of video-based instruction for individuals with autism for more than two decades. Ayres and Langone (2005) reviewed much of this literature, concluding that more detailed studies would be required to describe the specific mechanisms by which video-based instruction works, but generally speaking find that parents, educators, and other caregivers can effectively use video for instruction. Video-based instruction has been shown to successfully teach a variety of skills, including developmental, life and transition, as well as speech and language and even academic skills. In what follows, we briefly overview some of the work in these three areas demonstrating the ways in which video-based instruction can and should be used with individuals with autism, as well as open questions still to be explored.

Video modeling appears to improve in-vivo instruction when teaching developmental skills and enhancing generalization of those skills outside the academic instructional environment. Additionally, classroom management issues, such as reducing disruptive behavior during transition time, have been shown to benefit from video priming (Schreibman, et al., 2000). However, evidence for this improvement is still somewhat scarce and needs replication. One study, comparing video modeling with in-vivo modeling, focused on five students with autism who all experienced a baseline condition of prompted responses, rewards, and other best practices followed by either video modeling or in-vivo modeling of a specific task (Charlop-Christy, et al., 2000). In this study, students

[13] http://www.mayer-johnson.com/autism-article3

all performed their tasks independently after the same or fewer minutes with video modeling than in-vivo and showed at least some evidence of generalization. In another study, the focus was only on one preschooler with autism, but a multiple baseline design enabled the researchers to suggest that video modeling supported generalization of skills mastered in the academic environment only (in this case, preschool songs and other age appropriate instructional aids) (Kleeberger & Mirenda, 2010). One challenge to the study of developmental skills in general, but in particular in response to a technological intervention like video modeling, is the choice of tasks and the preparation of materials—videos—to support those tasks. These tasks should be similarly difficult across participants but also of specific need for the child being tested, which makes it virtually impossible to establish a fully controlled and consistent study. In the two papers highlighted above, something closer to a case study model was employed for analysis even though in one of the studies the tasks were randomly assigned to the in-vivo or video modeling conditions for comparison (Charlop-Christy, et al., 2000). New technological approaches, such as crowdsourcing videos, which has been done when writing social stories (Boujarwah, et al., 2012) might allow for much larger studies with a greater breadth of participants and tasks.

Tightly related to concerns about teaching developmental skills are teaching life skills, which are key to transitioning to independent living. Researchers and clinicians alike have long used static picture-based prompting to teach a variety of life skills in autism, but a direct comparison of picture and video-based prompting indicates that video prompting may be more effective as well as less expensive to implement and deliver than picture-based approaches (van Laarhoven et al., 2010). Various approaches to video-based instruction for life skills have been tried and shown to be successful, including standard observational or training videos as well as more specific video modeling approaches. These tools are rarely used in isolation, however. For example, a video instructional package for teaching grocery shopping skills was found to be effective for three children with autism but included on-site prompting and reinforcement in addition to video training (Alcantara, 1994). Likewise, an image-based tool for teaching photography skills to adults with developmental disabilities showed that video prompting could be an effective instructional strategy, allowing for both generalization and skill maintenance over time (Edrisinha et al., 2011). The advent of new mobile technologies that are commonly used and less stigmatizing than special purpose assistive technologies has enabled the use of video modeling in general education (Cihak et al., 2009) and community-based environments (Nikopoulos et al., 2008). Similar to teaching developmental skills, however, a major limitation to teaching life skills through video—and subsequently conducting research about its efficacy—is the creation of large libraries of instructional videos. A variety of computational approaches, including programmatically changing backgrounds, actors (or at least skin and hair color), and other elements of videos may enable larger corpuses of realistic life skills videos to be produced that can facilitate larger trials to assess the efficacy of these approaches. Although limited in scope, some research has attempted to demonstrate video modeling as a tool for reduction of inappropriate behaviors, rather than just an increase in appropriate behaviors. In one study of three children with autism using a multiple-baseline-across-subjects design, video modeling was shown to be effective at reducing problem behaviors for children with lower baseline levels of disruptive behavior (Nikopoulos et al., 2008).

Given the prominence of instructional concerns around speech, language, conversation, and social skills for individuals with autism in general, it is unsurprising that video-based instruction has evaluated these issues as well. In fact, a review published a few years ago provides a nice overview of this literature (Shukla-Mehta et al., 2009). A variety of programs have been developed to enhance speech and language skills in individuals with autism, many of them taking advantage of the affordances of video and multimedia. For example, in a study of 20 children with autism and mixed intellectual disabilities and nine teachers using a specially developed multimedia program, an overall increase in verbal expression was found. Those with low language also showed an increase in verbal expressiveness, while those with high language showed an increase in enjoyment (Sherer et al., 2001), indicating that while the effects may be slightly different between groups, such programs can be used across the spectrum of verbal capabilities in individuals with autism.

Although video modeling and video-based instruction have not been used extensively to teach academic skills to children with autism, the limited available research is promising. Fourth through sixth grade students with learning disabilities showed statistically higher word acquisition scores when exposed to a video instruction program than their peers who received no video instruction (Xin & Reith, 2001). In another, more limited study involving only one child with autism, the student watched a variety of video models including a teacher writing the word and play acting a word's meaning, eventually learning to spell enough novel words to match her general school placement (Kinney, et al., 2003).

Video and multimedia have also been shown to support teaching social language skills to individuals with autism (Maione & Mirenda, 2006). In some cases (e.g., Sansosti & Powell-Smith, 2008), traditional tools like social stories (Gray, 2003) are augmented by video and other media. In other cases, video modeling, in its more traditional form of scripted videos to be watched before an interaction, is shown to be effective in teaching social skills. For example, one study of two children with autism who watched videos prior to interacting demonstrated that they made more appropriate play comments when engaging in play sessions with their siblings (Taylor et al., 1999). As another example, the VidCoach system supports learning an important transition-related social skill, job interviewing (Ulgado 2013). However, at the time of this writing, results of empirical testing of this system have not been published.

While promising, the effects of multimedia training are not dramatically better than those observed in conventional therapist-instructed training. Additionally, a therapist can respond in situ to the particular needs and proclivities of each student, whereas customization might be required for the video-based tools to provide this same level of support (Wong & Tam, 2001). This customization may include changing elements in the video to match the context of activity for that student, such as outdoor classrooms in California and Florida as opposed to enclosed school hallways in other areas, or the context of the students themselves, such as ethnicity, gender, or even height of the students. These customizations require substantial content generation and can be challenging. Other customizations, however, can be accomplished technologically. For example, one study showed that although students with autism performed worse than their neurotypical peers on video-based emotional and facial recognition, their performance improved in relationship to the speed (slowness in this case) of the video (Tardif et al., 2007).

4.2.2 INTERACTIVE MULTIMEDIA

Both researchers and practitioners have begun to expand traditional visual supports using multimedia (Hayes et al., 2010) (see Figure 4.2), often coincidentally and opportunistically (Stromer et al., 2006). For example, Stromer and colleagues' (2006) review notes that the expansion of activity schedules (an exemplary visual support) through computing technologies enables learners to develop new skills through audio, video, images, and coordinated text. These effects were present on sometimes elaborate but often fairly simple computerized visual supports, leading to the conclusion that interactive multimedia simultaneously presents opportunities for teaching generative and functional skills and provides a framework for understanding acquisition of these skills.

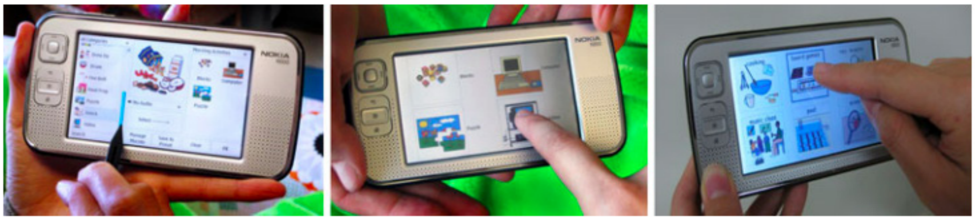

Figure 4.2: Interactive visual supports (Hayes et al., 2010).

Just as with video-based instruction, interactive multimedia has been used to support a variety of therapeutic and instructional interventions, including play (Dauphin et al., 2004) and other social skills (Hagiwara, 1999; Kimball et al., 2004), activities of daily living (Rangel & Tentori, 2011), and academic skills like reading (Heimann et al., 1995) in individuals with autism. Although many of these projects primarily include a mix of video and activity schedules (e.g., Kimball et al., 2004), other modalities are also used. For example, photographs as part of a computer-based instructional module were shown to be helpful in teaching 11 children with autism or Asperger's Syndrome to recognize and predict emotions after using the program for five hours spread across ten sessions in two weeks (Silver & Oakes, 2001). As another mix-media example, the Mind Reading DVD uses silent films of faces, video recording, and written examples of situations that evoke particular emotions to teach emotions and mental states (Golan & Baron-Cohen, 2006). As one final example, text, speech, and images were combined to make a set of games that target specific communication disorders. In a study of ten adolescents with high-functioning autism and ten neurotypical adolescents, the researchers found that richer multimedia interfaces were more challenging for students with autism, indicating that perhaps there is a limit after which additional multimedia becomes more of a hindrance than a help for this population (Grynszpan et al., 2008).

4.2.3 MULTIMEDIA AUTHORING TOOLS

Many multimedia approaches rely on teachers or other caregivers and educators to become adept not only at creating engaging and informative lessons, but in doing so through technology. Fear or even a simple lack of technical skills can prevent this kind of innovation. However, only limited work has investigated how to author these materials more easily.

Higgins and Boone (1996) present a set of software guidelines based on their research on two multimedia authoring systems: HyperStudio and Digital Chisel. Although both of these systems are now nearly twenty years old, the concepts of how to invoke certain lessons within these paradigms may still be useful to both educators and researchers seeking to create such materials. Their very pragmatic instructions, such as buying as many computers as can be afforded, likely hold true today in most settings. Likewise, their suggestion of drawing out the lesson as it would appear in the software program is a useful technique for both software developers and lesson planners.

More recently, advanced computational techniques have been explored to make authoring these materials simpler and more efficient. For example, both Artificial Intelligence (Riedl et al., 2009) and crowdsourcing (Boujarwah, 2012; Boujarwah et al., 2012) (see Figure 4.3) have been demonstrated in limited trials to enable the production of large quantities of high quality social stories. Some researchers have explored how to enable students with autism themselves to create and use their own multimedia skills in developing social skills training materials (Cumming et al., 2010). Future work is required to test materials derived from these approaches in use, but the promise of—and need for—large quantities of freely available teaching materials for social skills makes it likely that the work will continue.

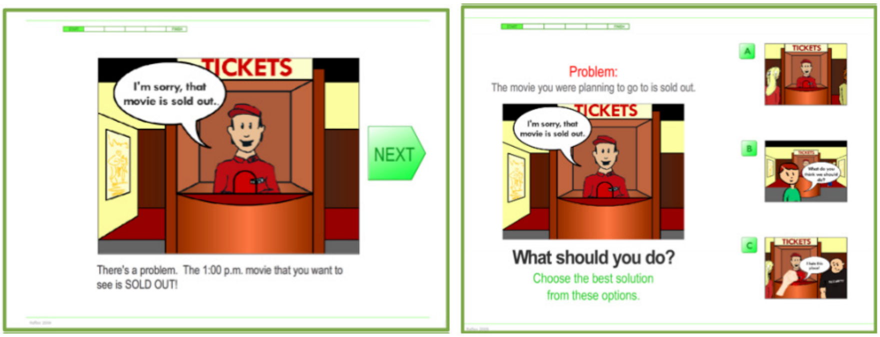

Figure 4.3: Crowdsourcing-generated instructional models (Boujarwah et al., 2012).

4.3 DIAGNOSIS, MONITORING, AND ASSESSMENT

Although the bulk of work on video and multimedia for autism has service focused on using multimedia tools as output, or instructional materials, researchers and providers alike have become increasingly interested in using them as input to clinical and care processes. Video can be used as standardized assessment tools, in addition to questionnaires and behavioral measures already in place. It can also be used to capture and document activities in support of diagnostic or monitoring efforts. In this section, we describe some of the research efforts focused on using video for assessment and record keeping.

4.3.1 ASSESSMENT OF INTERACTIONS VIA VIDEO

Just as showing videos can be useful for instruction, asking questions about what was discerned from video can be useful for assessment. For example, the MASC toolkit includes a short video that participants watch followed by a set of questions to be answered that reference actors' mental states (Dziobek et al., 2006). In a study involving 39 participants, researchers found MASC to discriminate individuals with autism from controls. Likewise, Golan et al. (2006) demonstrated with a similar sample size that adults with autism performed significantly lower than controls on questions describing mental states of actors in social scenes from feature films.

A wide variety of tools already exist for video annotation, such as Elan[14] and Anvil.[15] Additionally, researchers have explored specific issues related to video coding as part of assessment and scientific work. A common trend in technology research, particularly early stage, is to video record the use of technologies in a laboratory setting. Hailpern et al. developed the A-cubed method for coding such videos in an attempt to provide some standardization across reporting of their usage. They include audio and vocalization elements, physical interactions, as well as specific details about

[14] http://tla.mpi.nl/tools/tla-tools/elan/
[15] http://www.anvil-software.org/

responding to interactive systems. Their coding scheme provides high reliability in their experiments but requires intensive engagement with videos (between 20 to 40 minutes of work for each coder per minute of video) (Hailpern et al., 2008).

4.3.2 VIDEO CAPTURE

Manually recording data, whether using pen and paper or digital tools, can distract record-keepers from their primary activity of interest. Thus, to support the need for extensive documentation of a wide variety of behavioral phenomena, researchers have investigated the application of capture and access technologies (Truong et al., 2001) to the recording of educational, behavioral, and health data about and for individuals with autism (Hayes et al., 2004; Kientz et al., 2007). Truong and Hayes note four core benefits of using automatic capture technologies, including video recording:

1. Large quantities of rich data can be captured without the need for distracting human intervention.

2. These data can be automatically categorized and tagged, allowing for easier retrieval in the future.

3. People do not have to predict which data will be useful prior to an event, as in manual recording, and instead can determine importance after the event.

4. Automatic tracking of the provenance of data alongside collection of more data from different perspectives can reduce errors and selectivity in records.

Given these benefits and the greater emphasis on use of technology in classrooms and homes in support of autism more broadly, it is perhaps unsurprising that researchers have recently dedicated significant attention to the creation and evaluation of capture and access technologies in this space. In fact, use of these technologies has spawned a new approach to autism diagnosis and monitoring, called Behavior Imaging (Naranyan & Georgiou, 2013), which involves a collection of tools and techniques that allow researchers, educators, clinicians, families, and individuals with autism to understand and act upon observable human behaviors.

Hayes and colleagues (2004) describe a qualitative field study exploring the use of three early stage prototype systems for capturing video about children with autism: The Walden Monitor, CareLog, and Abaris. In this work, they describe social, practical, and technological considerations that are key for the design of capture applications in this space:

1. People must be able to record and analyze data iteratively as part of a diagnosis, intervention, and monitoring cycle.

2. Rich data generated by video are particularly important for disorders in which there are limited physiological indicators of progress but numerous behavioral indicators.

3. The task of keeping records must be able to fade into the background through the use of these technologies allowing caregivers and individuals with autism to concentrate on their primary tasks.

4. Designers must ensure that appropriate controls are in place to establish security and privacy of video data, which is by default identifiable.

5. The financial resources required to deploy and use capture and access technologies must be appropriate given the benefits they provide.

6. Because people will almost certainly continue to need manually recorded data alongside automatically captured data, capture and access systems should enable easy and usable integration of these data.

7. The system architecture should provide modular and distributed capabilities for video recording and other capture devices, storage of data, and interfaces for accessing the data, an issue that has become even more salient with the growth of cloud computing.

8. The system must support a variety of levels of views into and mining of captured data, an issue that brings to mind many of the challenges of "big data" currently being explored by other researchers.

After extensive redesign of these applications (see Figure 4.4), additional evaluation (Hayes et al., 2008; Kientz, 2012; Kientz et al., 2005; Kientz et al., 2007), and the creation of new prototype systems, this same group revisited these issues three years later (Kientz et al., 2007), noting some key design considerations: understanding the domain, making changes unnoticeable, simplifying interfaces, and allowing for customization. However, they also note continued design challenges, including the difficulty incorporating children with disabilities into the design process, limitations of currently available sensing technologies, and ethical and privacy considerations inherent to capturing large quantities of high quality data.

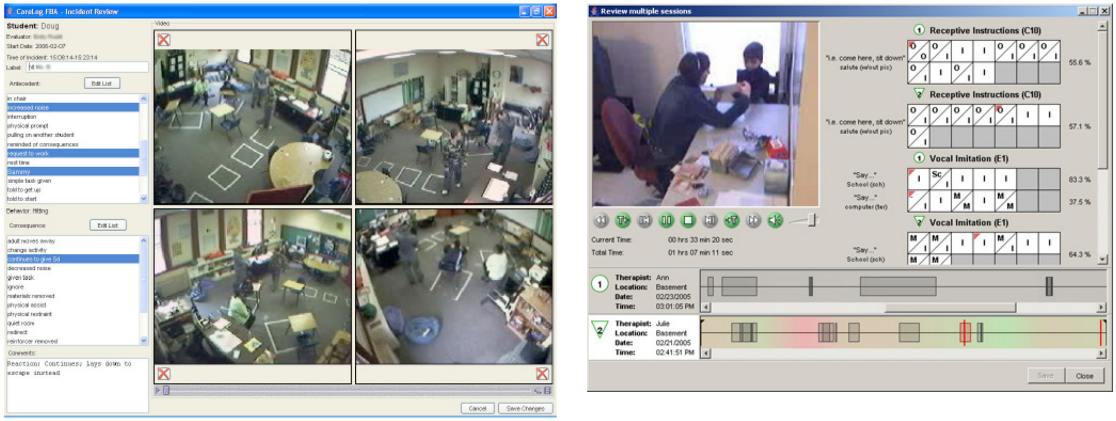

Figure 4.4: (A) Left: CareLog functional behavioral assessment application (Hayes et al., 2008) and (B) Right: Abaris capture tool for applied behavior analysis therapy (Kientz et al., 2005; Kientz et al., 2006).

Building on this early work, several research projects have continued to explore the use of video capture for a variety of challenges relevant to individuals with autism. For example, CareLog focuses on the capture of video data for behavioral assessment in classrooms (Hayes et al., 2008) and has inspired a commercial product, BICapture. As another example, Kientz and colleagues developed multiple systems for recording video evidence pertaining to childhood development (Kientz & Abowd, 2009; Kientz et al., 2009). In this work, they describe some of the challenges of recording appropriate "moments of interest" for the complicated task of assessing whether a child may be at risk for a developmental disability. One of the major research questions in this space continues to be how well parents can be trained to collect these research "specimens" at home (Nazneen et al., 2011). Nazneen and colleagues explicitly examined this issue for behavioral problems, finding that parents can be trained in this area, which supports the conclusion made by Kientz and colleagues. In this section, we have largely described video capture technologies that are focused on the recording of video data from the environment and direct readers to Chapter 8 on wearable recording and sensing for additional technologies focused on recording video on the body.

4.4 CLASSIFICATION APPLIED TO VIDEO AND MULTIMEDIA

In Figure 2.1, we tagged four of our twenty representative articles as using video and multimedia as a technology platform. These included the MASC toolkit (Dziobek et al., 2006) and CareLog (Hayes et al., 2008). Here we describe how each of these fit into the classification scheme defined in Chapter 2, as well as discuss overall trends we observed for technologies making use of natural user interface platforms.

The MASC Toolkit (Dziobek et al., 2006): The Movie for the Assessment of Social Cognition (MASC) is a research tool for assessing "mind-reading" capabilities. We categorized this work's interactive technology platform as *video and multimedia* due to its substantial reliance on live action videos as a key component of the instrument. This project targets *social and emotional skills* by showing short videos and asking the individual with autism to answer questions about actors' mental states. The goal of this work was primarily to assess "mindreading abilities in individuals with Asperger syndrome," so this was categorized as *scientific assessment*. The target end users for this work include the *persons with autism* themselves, who are tested, as well as a researcher who would be collecting the data about the assessment. MASC was developed to be used in a *research lab* and has been used by other researchers, for example, to test the effects of medication (e.g., Heinrichs and Domes, 2008) or to to compare social cognition with healthy controls (e.g., Pöttgen et al., 2013). The publication venue for this project was in the *Journal of Autism and Developmental Disorders*, which is an *autism-specific* venue. Finally, the studies conducted were *experimental*, and the MASC toolkit at the time of the writing of this paper had reached the maturity of a *functional prototype*, not yet available for public use. Given that other researchers have used MASC, it is now somewhat publicly available. The tool is available in multiple languages, but most of the research citations of the work has either involved German researchers using the German language version or English-language researchers citing it as a motivation for the creation of their own video-based mindreading assessments.

CareLog (Hayes et al., 2008): The CareLog project was categorized as using both *video and multimedia* as well as personal computers and the web. The system relies on multiple audio and video feeds to collect data and a desktop or laptop computer to store and view both the audio and video data and the meta-data that users associate with them. The assessment function performed by CareLog, Functional Behavioral Assessment, is used to monitor *social/emotional skills, restrictive/repetitive behavior*, and *academic skills*. In this paper, teachers were the primary users and gathered data about and assessed progress on all of these skills across student participants. The goal of functional behavior assessment, and thus CareLog, is for *functional assessment* in service of *intervention/education*. One could easily imagine CareLog being used additionally for *parent/clinical training* and other goals; however, in this particular paper, the placement of the study in schools limited the goals that were evaluated. Thus, we did not include other goals in our coding. CareLog was developed for use and evaluated in the *school* setting, with follow-on work expanding it to other settings. The work was published originally at the CHI conference, which is a computing publication venue. The research study was a *correlational or quasi-experimental* design, and the maturity of CareLog is a *functional prototype* that is not yet available to the public. However, commercial work building on CareLog is available to the public as described earlier in this chapter.

In general, video has been used by parents, therapists, community members, and individuals with autism for decades. Long before computing researchers discovered autism as a salient and important research domain, autism researchers, providers, and educators were making use of advanced (for the time) video and multimedia technologies in the form of films, tapes, and so on. As multimedia has become cheaper and easier to both create and to consume, research projects and practical applications in this space have grown accordingly. At the same time, researchers in computing have long been interested in video and multimedia in terms of production, consumption and analysis, and applications. Thus, the recent intersection of these two areas has resulted in an enormous amount of research in both behavioral/social science venues and those in computing specific conferences and journals.

Given the wide variety of people engaging in this kind of work, it is perhaps not surprising that there is also a wide range of maturity in the technologies represented. Researchers whose primary focus lies in autism, education, psychology, and other related fields tend to use commercially or at least publicly available robust technologies and conduct experimental research. Computing specialists, on the other hand, tend to publish work centered on *conceptual* or *functional prototypes*, most of which are not yet publicly available and may never be.

Video and multimedia when used for instruction is primarily targeted at the person with autism or the training of non-professional caregivers. The recording of video and other types of media, however, can be used for a variety of purposes, including but not limited to assessment of professional providers, assessment of the individual with autism, and collection of epidemiological and population level data.

The domains and goals that can be supported through video and multimedia are substantial and diverse. In our review, there were papers that fit every category of each of these sections in our categorization, and no particular category dominated.

4.5 FUTURE DIRECTIONS

The research conducted thus far around the use of video and multimedia in support of individuals with autism and their care networks covers a wide breadth of areas. Broadly speaking, this body of work indicates that multimedia can be effective both for instruction and for documentation and review. We expect work to continue in this space, both as the research projects mature and as commercial products become more prolific and robust.

Multimedia is becoming increasingly commonplace online, in educational software, and in our everyday lives. For children with and without autism, there is no doubt that there will continue to be a proliferation of tools and content to support learning through video and other media elements. Importantly, however, large-scale empirical trials are still largely missing from this space. Ask almost any teacher or parent whether multimedia tools can support learning, particularly when accompanied by face-to-face and other instruction, and you are likely to get a resoundingly positive response. However, these claims should be validated, and perhaps more importantly, the specific mechanisms for the positive results seen in practice must be better understood.

In terms of technological advances in this space, improved video editing, crowdsourcing, and social sharing tools are all likely to enable the creation, collection, and distribution of media more easily. These advances should support teachers and parents in matching appropriate content to their students and children. Likewise, as software for playing multimedia elements improves, it should become possible to speed up or slow down content, pan and zoom to relevant elements for students with low vision, and generally customize the viewing experience depending on the needs of specific students. Likewise, these platforms should allow for greater collaboration and communication among professionals and parents, as individuals within a care network can collect and share relevant diagnostic and monitoring videos and other media.

CHAPTER 5

Mobile Technologies

5.1 OVERVIEW

Mobile technologies include applications delivered on mobile phones, PDAs, tablets, or other mobile devices intended for personal use. Although the lines between types and sizes of devices are continually being blurred, we distinguish mobile devices from those embedded in the environment (as reviewed in Chapter 8) or those primarily considered to be a desktop or laptop computer (as reviewed in Chapter 3). However, we note that in coding the literature according to our categorization, many papers described systems that made use of mobile devices as well as other platforms simultaneously. Mobile devices can be used in multiple environments or anywhere the user goes. Mobile and ubiquitous computing technologies have the potential to address many of the needs of the growing population of individuals with autism, their parents, and professional providers. Several commercial and research products exist to document progress for a variety of health concerns on smartphones and other mobile devices, as well as for teaching specific skills. Likewise, sensor-based and context-aware systems have become increasingly powerful ways to automatically assess and document behavior as well as provide interventions customizable to the situation at hand.

Key to the vision of ubiquitous computing—the third generation of computing, following the first generation of the mainframe and second generation of the personal computer—is the idea that interfaces can blend into the background as part of everyday use (Weiser, 1991). Powerful mobile technologies like tablets, phones, and personal music players are now part of the everyday technology landscape (Bell & Dourish, 2006) and, unlike many other assistive technologies, people *want* to carry them as they are useful and non-stigmatizing (Parette & Scherer, 2004). Additionally, the long battery life, lightweight, and vast utility of these devices make them an appealing anytime/anywhere platform for a variety of interventions and supports.

As computational systems grow both smaller and more powerful, it will become increasingly important and relevant for these mobile tools to be integrated into best practice interventions. In autism, we have witnessed an evolution from low-tech strategies of the 1980s to custom high-tech strategies to multi-purpose hardware filled with "apps" that we see today (Shane et al, 2012). One look at the Google Play Marketplace or the iTunes App Store (Figure 5.1) and a user will quickly become overwhelmed by the thousands of "apps for autism" and thousands more mobile apps not labeled explicitly for autism but potentially useful. This explosion of interest in the mobile space has brought about innovative designs that address a wide variety of issues, and there are even some indexing services emerging, such as Wynsum Arts iAM search platform for the App Store (www.

wynsumarts.com). However, the evidence base for the efficacy of these tools remains somewhat sparse. Likewise, detecting complex contextual information related to nuanced behavior is challenging, as is the secure archiving, transmission, and visualization of the data they collect. Few research projects have examined clinical or educational efficacy and the technological challenges of making robust, secure platforms. Finally, most of the research and commercial applications in this space target preschool and school-age children, with limited interest in the adult population. In part, this trend can be related to the overall emphasis on research for early intervention, and in part, the ability for older individuals to make use of non-autism–specific applications. In this chapter, we describe projects that make scholarly advances in these realms.

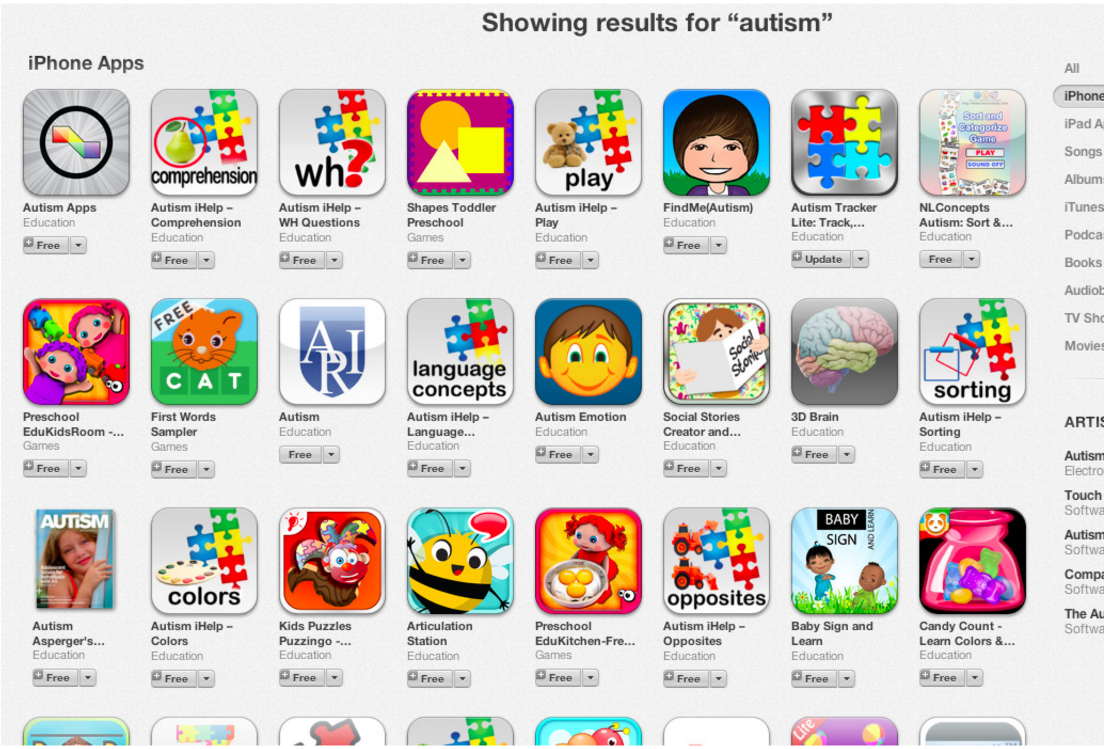

Figure 5.1: Apple App Store results for "autism" in iPhone apps (July 2013).

5.2 CURRENT TRENDS IN MOBILE DEVICES AND SOFTWARE

Assistive technologies have long been mobile, low-tech solutions that remain popular due to their ability to be used anytime, anywhere, at a low cost and without any concern for power or other technical infrastructure. However, over the last two decades, the use of high-tech technologies for autism has advanced dramatically across a variety of domain areas. In this section, we overview the ways in which mobile technologies have been used to collect data for and about people with autism, to support augmentative and alternative communication, and to empower individuals with autism to learn new skills and conduct a variety of tasks.

5.2.1 AUGMENTATIVE AND ALTERNATIVE COMMUNICATION

Even before the use of smartphones, tablets, and PDAs, assistive technologies for augmentative and alternative communication (AAC) were mobile. Devices like DyanaVox as well as more low-tech solutions predate the use of multi-purpose interactive technologies, and have been demonstrated to provide substantial benefits to their users (Sigafoos & Drasgow, 2001). Likewise, Foley and Staples (2003) demonstrated that Boardmaker could be used to create communication displays for use in a supported employment environment and McNaughton and Chapple (2013) more generally described evidence-based AAC strategies in the workplace. Chapple (2011) provides a compelling review of the history of AAC and alternate access over a twenty-year time period. Shane and colleagues (2012) offer a framework for describing AAC technology that goes beyond communication at its basic level and includes such concepts as "effortless everyday communicative exchange" as well as language instruction and video modeling. These works are incredibly useful reading for anyone interested in this space, as are books overviewing the subject (e.g., Jones, 2004).

Figure 5.2: The GoTalk is a commonly used speech generation device that predates the use of general purpose mobile devices for similar purposes. Photo credit CC Flickr user bknittle.

Speech generation devices (SGD, see example in Figure 5.2) or voice output communication aids (VOCA) are some of the most commonly used and researched mobile AACs (Schlosser & Blischak, 2001). These devices allow users to choose text or picture-based communication, which the device then translates into voice output. Although these devices tend to produce either speech or print feedback, the relative benefits of each depend greatly on the individual user and context of use (Blischak & Schlosser, 2003). In particular, in naturalistic learning environments, the utility of these devices may depend on specific attributes of the technologies within the tasks for both children and teaching staff (Schepis et al., 1998). As such, new software solutions available on multi-purpose devices provide potential for more of this customized communication, often at a lower price than dedicated AAC devices of the past. Popular applications, such as MyTalk[16] and ProLoquo2Go,[17] can be used as a primary AAC device, while other applications can augment more traditional paper-based and single device solutions. Researchers have also explored development of software-based AAC for smartphones, tablets, and other multi-purpose AAC devices (e.g., de Leo & Leroy, 2008; Hayes et al., 2010). The continual and rapid development of commercial products in this space, however, has limited the need for development of research systems. It has not, however, limited the need for empirical testing of these commercial systems, much of which is still lacking.

5.2.2 EDUCATIONAL TECHNOLOGY AND EVERYDAY SUPPORT

Even though a large quantity of the commercially available applications and software tested in research for mobile devices tends to focus on AAC, other uses of these technologies have also been of interest to researchers and practitioners in recent years. In particular, mobile devices have been shown as effective platforms for learning and engagement in educational tasks. For example, the vSked project focused on the use of a collection of mobile devices working in conjunction with a large touchscreen at the front of a classroom to support AAC, a token rewards system, and instructional aides (Cramer et al., 2011;Hirano et al., 2010).

Although mobile devices are useful in the classroom, both as AAC devices and beyond, learning does not just take place in classroom settings. In fact, generalization to settings outside those in which instruction is initially provided is a huge challenge for education in general, and for autism in particular. Thus, some researchers have explored how one might design technologies to support the kind of real-life practice required to generalize learning, particularly around non-academic topics, such as life skills (Tentori & Hayes, 2010). In limited cases, these technologies have also been evaluated in a variety of community and educational settings. For example, through the Technology in the Workplace program, students in workplace transition programs develop skills and confidence in the use of mobile technologies to reduce barriers to employment (Hayes et al., 2013). That program primarily used off-the-shelf technologies. However, the researchers did de-

[16] http://www.mytalk1071.com/
[17] http://www.orin.com/access/Proloquo2Go/

velop two mobile tools for use with individuals on the autism spectrum, which have not yet been evaluated: HygieneHelper (Hayes & Hosaflook, 2013, see Figure 5.3) and VidCoach (Ulgado et al., 2013, see Figure 5.4), the latter of which is also discussed in Chapter 4 related to video modeling. In other cases, custom technology developed specifically for generalization of skills has been evaluated, such as MOSOCO (Escobedo, et al., 2012). In that project, a custom augmented reality system prompted students to practice social skills used in the classroom. In the limited deployment, researchers saw improvements in both quantity and quality of socialization for three students with autism as well as nine neurotypical peers who used the prototype over a three-week period. Hourcade and colleagues (Hourcade et al., 2013) also examined the use of tablet applications to encourage social interaction for students with autism. What is promising in these projects is that the form factor, though mobile in both cases, can be different as well as the underlying technological approach—augmented reality in the former and interactive touchscreen in the latter—with similar positive results. This is particularly important for examining social skills, which could be hampered by too much engagement with technology. Instead, what we see in the research is positive engagement with other people *around* the technology, not just positive engagement *through* the technology.

Figure 5.3: The HygieneHelper homescreen displays a message each day sharing additional educational tips or motivational messages.

Figure 5.4: VidCoach shows a model student participating in a job interview.

The very nature of being available anytime and anywhere makes mobile devices particularly appealing for the support of activities of daily living and other everyday tasks. For example, in a three-person study Bereznak and colleagues (Bereznak et al., 2012) demonstrated that mobile video modeling on the iPhone can be used for self-prompting of vocational and daily living skills in persons with autism. However, this work indicated that mobile devices might need to be used long-term rather than short-term because they had to be returned in two of the three cases after a maintenance probe. Video modeling, when taken mobile, has advantages over traditional video modeling described in Chapter 4. Likewise, prompting systems, when made mobile, can be moved into new environments. For example, Mechling and colleagues (2009) demonstrated that students with autism could follow cooking recipes using a PDA while adjusting prompting levels over time in a study involving three students. Carlile and colleagues (2013) examined a variety of leisure skills in four students, aged 8 to 12, in the home and found that an iPod Touch–based Activity Schedule was effective in helping students stay on task and follow their schedules. However, these systems still require students to know when and how to use the system to remind themselves of their tasks.

Context-aware systems, systems that use information sensed from the physical surroundings to automatically adapt application behavior, can support these kinds of activities automatically (Rangel & Tentori, 2011). For instance, the COACH system uses environmental sensing coupled with a tablet-based interactive system to support hand washing (Bimbrahw et al., 2012). Although this prototype currently relies on heavy amounts of custom hardware mounted on site, one could imagine a future system in which the sensing architecture can dynamically connect to an individual's mobile device, be on the mobile device, or worn on the body. The HANDS project, likewise, relies on artificial intelligence and sensing of context alongside configurable manually entered data to support teaching and development of social skills (Ranfelt et al., 2009). Finally, agents delivered through mobile internet-enabled devices have been shown in a study of ten participants with autism and three with general social phobia to effectively translate spoken phrases that were confusing or offensive into more easily understandable language, thereby supporting learning of emotional communication (Bishop, 2003).

Researchers have also examined other types of wearable and mobile technologies with individuals on the autism spectrum. For example, Marcu and colleagues (2012) conducted a field trial with five families of children with autism ages 10 to 15 using wearable cameras to document their everyday lives. In this work, they found the children were interested in and tolerant of the cameras, but social acceptability remained a problem. Communication between the children and their parents was facilitated through the captured images.

5.2.3 MOBILE DATA CAPTURE

Some of the earliest work in human-computer interaction around technologies for autism focused on the idea that mobile and ubiquitous computing solutions could be used to automate the extremely challenging and onerous task of data collection for caregivers of children with autism. Much of this work is covered in detail in the Video and Multimedia chapter, because as a behavioral tool, video has been extremely important in documentation surrounding autism. In this section, we briefly overview some of the work that has been done in *mobile* data capture for autism.

The Walden Monitor prototype is a combination wearable and Tablet PC-based system that combines two existing paper-based data collection instruments: the Child Behavior Observation System (CBOS) and the Pla-Chek (pronounced PLAY-check) in use at a private school in Georgia (White et al., 2003). During the time of the research project, teacher aides entered the classroom for ten consecutive days and observed a particular child with autism, counting a ten-second interval and recording positive or negative results for a variety of variables, such as proximity to or interaction with an adult. These data served as indexes into video captured by a wearable camera mounted on the teacher aide. This system produced positive results in the highly constrained private school environment in which it was deployed, but it also shed light on issues that could arise with this same kind of data capture in other environments (Hayes et al., 2004). Ultimately, this tool was not tenable at the time of its development for long-term use, but the advent of new wearable technologies such as Google Glass (see Figure 5.5) may change the technological landscape enough for widespread use of these kind of mobile video recording technologies.

Figure 5.5: A Google Glass wearer. Photo credit: Flickr CC: Loïc Le Meur.

In the home, mobile technologies can be even more important for data capture. Not wanting to instrument an entire house to record everything its inhabitants do, parents might prefer instead to be able to capture and store only when and where needed. This kind of on-demand mobile data capture raises interesting questions about how to capture the right moments of interest. Kientz and Abowd (2009) examined this issue, relying on a host of persuasive techniques to encourage data capture as well as the equally important question of how to encourage review of these captured data. Mobile and ubiquitous computing tools have the potential to allow for review of data during casual moments of downtime and in a variety of environments. However, they still suffer from the challenges of getting people to review the data they have captured. Kientz's (2012) work highlights the way in which embedding access activities into capture activities can in some ways force reflection on the data, even if only momentary; a strategy repeated outside the autism world in personal informatics (Li et al., 2011).

Even with the advent of computerized data capture, manual recording of data is still difficult and error-prone (Ash et al., 2004). Thus, some researchers have focused on the automatic capture of sensor-based data using mobile platforms (for a more thorough review of this emerging area see Chapter 8 on Sensor-Based and Wearable technologies). For example, accelerometers embedded in toys or on a person can be used to infer activities (Kientz et al., 2007). As these kinds of sensors are increasingly available directly in the mobile phone platform rather than through custom hardware, these applications become more feasible to deploy on a large scale. Likewise, advanced computational power of mobile devices allows for other kinds of sensing and computational modeling, as exemplified outside the autism domain. For example, Ertin and colleagues (2011) demonstrated the feasibility of using wearable sensors to monitor breathing patterns, electrocardiography, galvanic skin response, body temperature, and movement as indicators of stress. And Chang and colleagues (2011) showed the possibilities for detecting depression through a person's speech patterns. We will explore these on-body modes of sensing more in Chapter 8.

5.3 CLASSIFICATION APPLIED TO MOBILE DEVICES

In Figure 2.1, we tagged two of our twenty representative articles as using mobile devices as a technology platform. These included vSked (Hirano et al., 2009) and MOSOCO (Escobedo et al., 2012). Here we describe how each of these fits into the classification scheme defined in Chapter 2, as well as discuss overall trends we observed for technologies making use of the mobile device platform.

vSked (Hirano et al., 2009): To support teaching collaboration and cooperation as well as language and academic skills, Hirano et al. developed vSked, an interactive visual scheduling and reinforcement system for use in classrooms. The vSked system was originally developed with the goal of *intervention/education*, specifically with a focus on visual scheduling, and includes both a *shared interactive surface* to show the overall schedule of the classroom and *mobile devices* for the students to use individually. The initial emphasis of the system on transitioning between activities, independently engaging in classroom tasks, and other *life/vocational skills*, eventually gave way to the inclusion of *academic skills* as the teachers using the system adapted it to their needs. Additionally, the combination of a shared display with personal displays encouraged the development of *social/emotional skills*. The vSked system is used by *individuals with autism* and their *peers* in a *school* setting, facilitated by *educators*. This paper, describing a *quasi-experimental* deployment with one classroom was published in a *computing* venue, the ACM SIGCHI conference. The level of maturity at the point of this publication was functional prototype.

MOSOCO (Escobedo et al., 2012): The Mobile Social Compass (MOSOCO) system incorporates *virtual and augmented reality* into a mobile platform. The system was designed to support the generalization of skills learned through the Social Compass social skills curriculum (Boyd et al., 2013) and therefore targets the *social/emotional skills* domain. This paper describes a *quasi-experimental* study in which *students with autism* and their *neurotypical peers* used MOSOCO as part of an *educational intervention* in *school*, primarily during recess and lunch. This paper was published in a *computing* venue, the ACM SIGCHI conference. The level of maturity was *functional prototype*, and the system required substantial researcher support to work in the uncontrolled environment of school free time.

Perhaps more than any other platform in this book, mobile devices are showing an increasing tendency to be used in schools, homes, and other environments while simultaneously changing rapidly technologically and having limited empirical support for effectiveness of these interventions. When we look across the research that has been conducted, however, there is immense promise for the potential of these technologies. As they become even less expensive and more ubiquitous, we expect the trend of developing autism-specific software as well as autism-relevant but nonspecific software for these devices to expand. In light of this explosion, and the need for insurance companies and schools to spend their money according to evidence-based practices, regulatory agencies, such as the Food and Drug Administration in the United States, are looking to require developers to support their claims—or change them[18]—when they carry more than minimal risk to their users. This development should spur additional empirical evidence and scientific research into the use of mobile tools for autism.

There has been limited empirical testing at this point of commercial applications. However, we expect this to change in the future, and the likely venues for publishing those results includes both autism-specific and other social science or health related venues. On the other hand, substantial work has already been published in computing venues, which are focused on more experimental technologies, not yet ready for the mass market. Given the recent trend for researchers to develop prototypes that can be released to the mass market, through for example the Google Play store, this trend may change over time, with the lines blurring between research prototypes, commercially available product, andpublicly available but free prototype tool.

As of now, many parents, clinicians, and educators may find themselves frustrated by an interest in using a low-cost device, such as an iPad or Android phone, and having insurance regula-

[18] http://www.fda.gov/NewsEvents/Newsroom/PressAnnouncements/ucm369431.htm

tions and acceptable use policies provide enough barriers that purchasing a custom, more expensive device, such as the DynaVox becomes more feasible. However, we expect this attitude to change, much as initial regulations regarding laptops purchased for employees—only to be used for work activities—have gradually been reduced or eliminated as employers have begun to understand the unrealistic nature of purchasing and maintaining multiple multi-use devices for different functions.

Given the mass proliferation of mobile devices, there is no limit to the users and domains for which these tools might be applied. Thinking of mobile devices in terms of the personal computer of the 1980s or the Internet-connected devices of the 1990s gives some indication of the size and scope of the mobile device space we expect to see going forward. Likewise, in our review, the technologies used already support a wide range of labels in our categorization.

5.4 FUTURE DIRECTIONS

Mobile devices are becoming more powerful, less expensive, and more ubiquitous. Ninety-one percent of American adults own mobile phones of some kind, and 56% of American adults are smartphone adopters.[19] In general, the younger and more educated you are, the more likely you are to use a smartphone. However, even low-income households now report heavy use of these tools.[20] Tablets and e-Readers have also experienced dramatic growth in use in recent years. At the same time, the long awaited age of "wearable computing" may finally be upon us with the introduction of such tools as Google Glass. These multi-purpose devices allow for use of assistive and educational functionality alongside that of leisure and socialization. At the same time, technological platforms that are largely invisible—either because they are accepted and prevalent (e.g., smartphones, tablets) or because they are discreet (e.g., hearing aides, Google Glass)—allow for assistance to be delivered in more socially acceptable forms than previously obtainable.

[19] http://pewinternet.org/Reports/2013/Smartphone-Ownership-2013.aspx
[20] http://pewinternet.org/Commentary/2012/February/Pew-Internet-Mobile.aspx

CHAPTER 6

Shared Active Surfaces

In this chapter, we discuss shared, active surfaces and their use with individuals on the autism spectrum. Using our platform classification scheme, shared active surfaces *include applications that are intended for multiple users in a co-located, mostly synchronous interaction, such as large displays, tabletop computers, electronic whiteboards, etc.*

6.1 OVERVIEW

In recent years touchscreens have advanced far beyond their initial simple interaction capabilities. They can now accept multiple types of input, including finger and stylus input, from multiple interacting people in a range of sizes. Portable touchscreen devices, such as tablets and phablets (i.e., smart phones and tablets combined, such as the iPad Mini), allow for multi-touch interaction almost anytime and anywhere. At the other end of the size spectrum, computationally enhanced tables (e.g., DiamondTouch (Dietz & Leigh, 2001), see Figures 6.3 and 6.4; PixelSense[21]) allow face-to-face interaction and multiple simultaneous inputs from individuals acting independently or as part of a group (Morris et al., 2006). This may be especially appealing to children with autism, because they do not force the children to associate moving a physical device (e.g., a mouse) with moving a cursor on the screen (Reed, P. (ed.), 1997; Whalen et al., 2006) particularly useful given that the task of mapping the change in planes can be so difficult for some.

These platforms can be useful in teaching social skills, such as turn-taking, or in allowing for prompting and augmented learning from a peer or caregiver. These kinds of shared interactive surfaces are often inherently appealing, particularly to users with autism, in much the same way as other shared interfaces, such as video games or even standard computer workstations are. Their capabilities for enabling multiple people to interact in a fairly naturalistic manner simultaneously, however, takes them one step farther in terms of encouraging interaction around and through a shared interface (Piper et al., 2006).

Because they have only been commercially available for a limited time, research into the use of shared interactive surfaces for autism is found more in technology-related publication venues than clinical or educational (Chen, 2012). However, as commercial products, these technologies have the potential to be used in a variety of clinical and educational settings, and for the research surrounding their use to expand substantially. In particular, this hardware enables researchers to ask important questions around the role these surfaces can play in supporting group-level interactions in therapeutic interventions, clinical encounters, decision-making, and more. Not yet priced at a

[21] http://www.microsoft.com/en-us/pixelsense/default.aspx

level that would allow for widespread home use, tabletops may lag tablets and phablets to some degree, but research conducted in this area is promising so far. Although these technologies can be used for standard individual use or even non-co-located shared use, their real innovation lies in the ability to use them synchronously with multiple co-located people. Thus, it is this use case that is the focus of this chapter.

6.2 SHARED ACTIVE SURFACE TECHNOLOGIES FOR AUTISM

Shared active surfaces have been used in a variety of ways, including the development of both academic and social skills. With most tablet and tabletop-based systems, users can engage in individual learning, thereby taking advantage of any of the kinds of programs described in the personal computer and web and mobile chapters (Chapters 3 and 5). However, given the unique capabilities for group interaction through these platforms, the majority of research in this area has focused on collaborative work and social skills, as we describe in this section.

Few studies to date have examined the differences in various hardware configurations, relying instead on feasibility and basic efficacy studies to determine the potential for these technologies. We expect this to be an area of much interest to autism researchers in the future, particularly those with an interest in social skills, visual supports, and technology. In one such study, as part of an MS thesis, Rebecca Parenteau concluded that there is no conclusive recommendation as to whether to present stimuli vertically on a scan-board or horizontally on a tabletop (Parenteau, 2011). Instead, based on a changing criterion study design with three students with autism, she recommends presenting stimuli in discrete trials to determine which presentation may improve acquisition rates. This study should be repeated with a larger sample to determine whether the lack of conclusive results stems from the limited sample size or whether other factors might be at play that could be used to determine appropriate approaches for these students.

6.2.1 LARGE, CO-LOCATED TOUCHSCREEN DISPLAYS

Although most shared active surface research projects focus on tablets and tabletop designs, some also make use of large touchscreens mounted vertically on desks or walls, such as the vSked project as well as a research effort focused on serious games for children with PDD-NOS. In the multi-year vSked project (see Figure 6.1), researchers examined the replacement of paper-based systems for prompting, communication, teaching of academic skills, and token-based rewards in two classrooms (Cramer et al., 2011; Hayes et al., 2010; Hirano et al., 2010). This system included small tablet-sized interactive touchscreens (see discussion in Chapter 5) to be used by individual students at their desks and a shared active surface at the front of the classroom, primarily operated by the teacher but also at times by aides and students. Using an A-B-A study design, which began and ended with best practice paper-based tools, over several iterations of the prototype system, vSked was demonstrated to support students in learning both academic and social skills based on 202 hours of observation across 16 students, two teachers, and eight aides in two classrooms (Hirano et al., 2010). Additionally, this project demonstrated that shared active surfaces could be used to improve communication among classroom staff as well as coordination and even friendly competition amongst students (Cramer et al., 2011).

Figure 6.1: vSked system uses a combination of wall-mounted displays and smaller tablets (Hirano et al., 2010).

In the Serious Games for PDD-NOS project, researchers at the University of Groningen and the Organisation for Applied Scientific Research in The Netherlands (TNO-NL) were interested in whether a vertical shared multi-touch surface could be used to teach both academic and social skills to students with PDD-NOS (van Veen et al., 2009). In this effort, six levels of mathematical problems were used to teach specific collaboration skills in a special needs elementary school with 14 students (1 girl) aged 8 to 12. By playing the game for ~20 minutes per day, students saw improvements in collaboration within the game but were not able to show improvement in classroom skills.

The results of both the PDD-NOS games and vSked projects are promising. They indicate that shared active surfaces can be used in academic environments, such as classrooms. Indeed, other researchers have implored the community to think about games and other technologies within educational environments rather than specifically designed "educational technology" (Giusti et al., 2011). However, more work still needs to be done, including longer-term deployments to examine how well the technologies motivate students over time as well as how they might better support generalization outside of the program. Although the costs are quite high for these kinds of surfaces currently—particularly those with multi-touch capabilities and in the tabletop form factor—their prices are rapidly coming down. Additionally, with some work on the part of researchers or commercial product designers, existing SmartBoards, ever present and underused in so many classrooms, could be repurposed for these applications. Additionally, multi-touch capabilities are beginning to be incorporated into smaller form factors, as described in the following section.

6.2.2 MULTI-TOUCH TABLETS

Increasingly, the Google Play Marketplace, Windows Marketplace, and iTunes App Store are filled with "apps for autism" for use on the increasing variety of tablets and phablets available in the commercial marketplace. As noted in the mobile devices chapter, getting schools and insurance providers to pay for these multi-use devices—particularly when they have phone capabilities—can be challenging. As evidence of their efficacy increases, however, and as they become more commonplace, we expect this trend to change to some degree. Additionally, schools are currently struggling with acceptable use policies in light of parental and student interest in using communication enabled mobile devices in the classroom (Cramer & Hayes, 2010).

Tablets support multi-touch to a varying degree. Most can accept a variety of inputs. However, they do not typically support knowing who is producing which input, which can make developing for multiple users/players challenging. Despite this limitation, many commercial applications have been developed and some research conducted to support children with autism through these platforms.

For the most part, these efforts are described in the mobile chapter (Chapter 5). However, one research project particularly stands out within this work focused on using multi-touch tablets to teach social skills and is worth discussing as part of an examination of shared active surfaces, the Open Autism Project (see Figure 6.2). In this work, Hourcade and colleagues (2012) conducted participatory design with 26 students with autism, their teachers, and others concerned with the development of technologies for autism to create a suite of activities for multi-touch tablets (see Figure 6.2). The applications designed as part of this project were focused on encouraging social interactions "through creative, expressive, and collaborative activities" (Hourcade et al., 2013). In an A-B-A study of 8 children (3 girls) aged 10 to 14 with high-functioning autism, which began and ended with app use with custom-made matching paper-based activities in the middle condition, the researchers demonstrated that "children spoke more sentences, had more verbal interactions, and were more physically engaged with the activities when using the apps" (Hourcade et al., 2013).

Application	Activities	Skills
Drawing	Collaborative storytelling and self-expression	Creativity, storytelling, fine motor skills, turn-taking, sharing and collaborating, compromising one's interests with the interests of others
Music authoring	Collaborative and individual music composition	Creativity, fine motor skills, turn-taking, sharing and collaborating
Untangle	Visual puzzle solving	Talking aloud to cooperatively solve the puzzle, fine motor skills, turn-taking
Photogoo	Emotion modeling	Understanding others' emotions, fine motor skills, detecting and predicting others' facial emotions

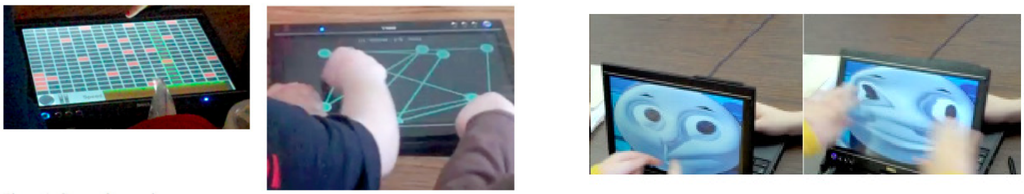

Figure 6.2: Hourcade et al.'s suite of applications for multi-touch tablets (Hourcade et al., 2012).

Although the majority of work in this chapter is dedicated to collaborative engagement with multi-touch active surfaces, Hourcade and colleagues' work indicates the potential for individual engagement with these technologies alongside collaborative. Thus, it is key to consider ways in which any given intervention may be developed for use under a variety of conditions, including but not limited to the number of students and facilitators required or allowed to engage with it at one time.

6.2.3 USING TABLETOP INTERACTIONS TO DEVELOP AND PRACTICE SOCIAL SKILLS

By far the most published research in shared active surfaces for autism focuses on the use of tabletop interfaces in support of social skills for children, adolescents, and even adults with autism. These tabletop interfaces, often created explicitly to support Groupware (Grudin, 1994), naturally support a group of people working on them simultaneously or even together, enabling a wide variety of interesting interventions that would not be possible with other technological platforms.

One of the first projects in this area, SIDES (see Figure 6.3), involved a game collaboratively designed with a middle school social skills class over several months (Piper et al., 2006). This game explicitly encouraged collaboration and decreased competition through a cooperative puzzle activity to be completed by four players on a DiamondTouch table that allowed the system to determine automatically whose turn it was and who was touching which locations on the interface. They tested their prototype game first with five students (all male, average age 12.6) from the same social skills class with which they had been working and then with two groups of four students of similar ages to the first evaluation (ONE female), finding that games on these types of shared active surfaces can be motivating as well as effective in facilitating group work. Additionally, the authors note some key design considerations, many of which have been taken up by other projects described in the following paragraphs. In particular, they note that while identification of the users is helpful in enforcing game rules, the particular way in which the DiamondTouch identifies users—through tethered capacitive sensing—limits players in their physical interactions. Likewise, although they note that the students were largely able to use the system without any additional support, and in fact preferred system-enforced rules to those imposed by a human facilitator, the technology is still limited in its capabilities and requires an adult moderator to help the students process what they are experiencing through the game.

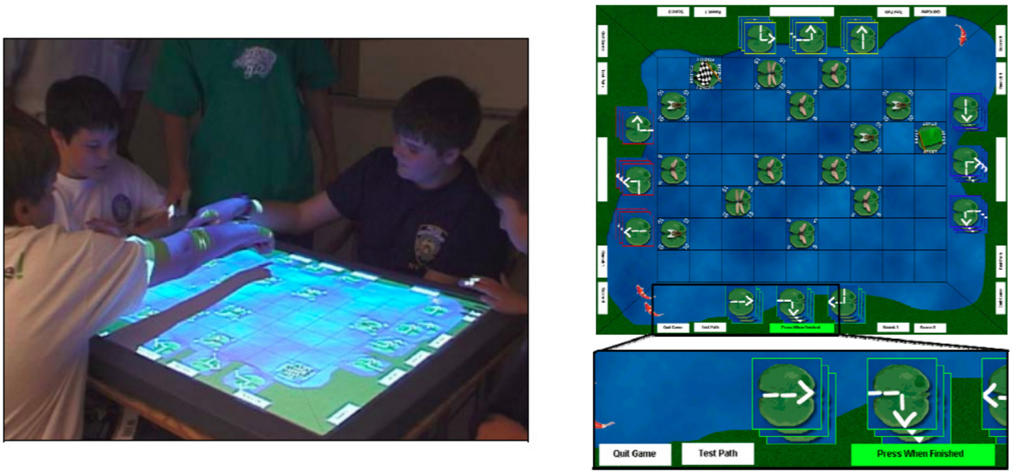

Figure 6.3: SIDES tabletop game uses the DiamondTouch platform to enforce turn-taking (Piper et al., 2006).

A relative explosion of tabletop games and interventions followed shortly after the SIDES project in the research literature. Most related to SIDES is a collaborative puzzle game (see Figure 6.4) built on the DiamondTouch platform (Battocchi et al., 2009) that was trialed with 70 typically developing boys and 16 boys with an autism diagnosis (Battocchi et al., 2010). In this work, the authors found that enforced collaboration had overall effects on collaboration and that the amount of coordination also increased for the children with autism through the use of an increased number of negotiation moves.

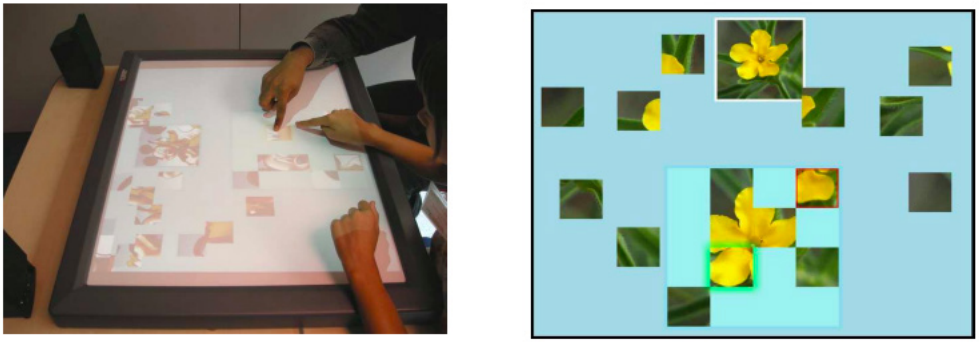

Figure 6.4: Collaborative puzzle game for DiamondTouch (Battocchi et al., 2009).

Originally developed for use by typically developing children during museum visits, the StoryTable system, also built on the DiamondTouch platform, was evaluated with 35 child dyads and found to encourage more complex language in stories and more evenly distribution participation in their creation (Zancanaro et al., 2007). The same research team then hypothesized that this interface might be useful to support children with high-functioning autism. The team conducted a pilot intervention A-B-A study, in which six boys (in dyads) with high functioning autism, aged 9 to 11, used the StoryTable during eight sessions across three weeks to develop a collaboratively authored story (Bauminger et al., 2007; Gal et al., 2009). Based on a variety of outcome measures and analysis of the first twenty minutes of each session, the authors conclude that use of a co-located interface for these students can have positive effects on social interaction quality as well as quantity of repetitive and stereotypical behaviors. They further claim that the multi-user feature inherent to the DiamondTouch platform was particularly helpful in enforcing some tasks to be done together and thereby improving the social skills measured experimentally.

Building on this concept of storytelling to support social skills development, we now turn to the TrollSkogen project (Figure 6.5), in which the researchers use the concept of a Troll Forest, borrowed from Scandinavian fairytales, as a platform for "micro-applications" designed to support learning of a variety of skills (Zarin & Fallman, 2011). The researchers evaluated this system with six children aged 5 to 8, all with diagnoses of either autism or Down Syndrome finding that the micro-applications were helpful in allowing for some autonomy and choice by the children—namely which application to invoke at which time—while allowing for skill scaffolding and customization or expansion with ability over time.

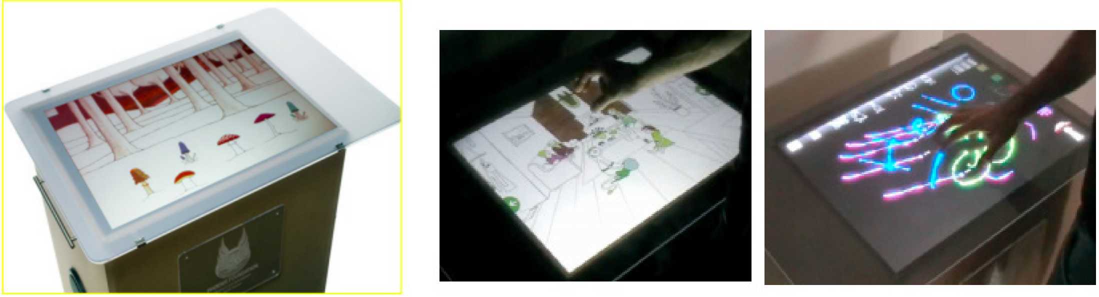

Figure 6.5: TrollSkogen project on an interactive tabletop surface (Zarin & Fallman, 2011).

In a similar effort, the Join-In suite of applications on a tabletop system supports teaching of social and other skills to children with autism (Weiss et al., 2011). In this work, the authors focused on three key dimensions to be supported by the design: joint performance of an action, sharing of personal resources to achieve a common goal, and planning together to coordinate actions and resources (Giusti et al., 2011b). The authors deployed the applications with two therapists who in turn used the system for social competence training with eight children with autism to determine whether the suite was usable and playable, involved the players in engaging and motivating experiences, and encouraged collaborative behavior. Based on this experience, the authors make several key recommendations:

- Move from educational games to games in educational settings.
- Address the game culture of today's children.
- Empower both the facilitator (Zancanaro et al., 2011) and the child.
- Switch easily between verbal, behavioral, and physical user interactions, a key finding in the SIDES paper as well (Piper et al., 2006).
- Ensure that elements for supporting ecological validity and "real-world" generalization exist.

6.3 CLASSIFICATION APPLIED TO SHARED ACTIVE SURFACES

In Figure 2.1, we tagged two of our twenty representative articles as using shared active surfaces as a technology platform. These included The Story Table (Gal et al., 2009) and SIDES (Piper et al., 2006). Here we describe how each of these fits into the classification scheme defined in Chapter 2, as well as discuss overall trends we observed for technologies making use of the shared active surface platform.

The Story Table (Bauminger et al., 2007): To support teaching collaboration and cooperation, pro-social behaviors, and language conversation and pragmatics, Bauminger et al. created The Story Table. This system supports the domain of *social and emotional skills* by creating an *educational intervention* through a tabletop display (in this case, specifically the DiamondTouch from Motorola). The authors previously conducted an *experiment* with 35 dyads used the system to facilitate complex and mature language (Zancanaro et al., 2006). The *functional prototype* uses a story metaphor and the overall concept of ladybugs traveling on the table in relation to the children's behaviors. In this paper, the authors used the system with three dyads of high-functioning children with autism to evaluate whether an intervention to support social skills could be developed around this technology. This pilot intervention study used an A-B-A design, and the results indicate that the intervention can produce positive effects on some behavioral and communicative skills, particularly in the school setting in which the intervention was conducting. The work was published in a computing venue, specifically the 6th Annual Workshop on Social Intelligence Design.

SIDES (Piper et al., 2006): SIDES is a four-player tabletop puzzle game educational intervention that supports children learning *social and emotional skills*, including increased collaboration and decreased competition. The authors evaluated the system in a *quasi-experimental* study with five students using a *functional prototype* from a social cognitive therapy class (all male, all with a diagnosis of some kind of neurodevelopmental disorder). Their results indicate that students were engaged in the system, but excitement around the technology itself sometimes created new behavioral challenges. This system, meant to be used by *children with autism*, can also be augmented with use by *clinicians/therapists* or *educators*, and in fact, the authors found that some therapist coordination greatly improved the results of the system's use. This paper was published in a computing venue, CSCW, an ACM conference on computer-supported cooperative work.

The advent of easily programmable tabletop platforms, like the DiamondTouch and eventually the Microsoft Surface—now known as PixelSense, greatly expanded interest in research around shared active surfaces. Likewise, other interaction paradigms, such as those afforded on walls and other surfaces by large displays, the Kinect, the Wii, and other systems, has expanded the definition of these surfaces. However, they are still very expensive to buy commercially and challenging technologically to create. Thus, the work is still fairly preliminary. As these products come down in price and people use more small-scale interactive surfaces, such as tablets, we expect to see more work in this area. The majority of shared interactive surface work in our review was focused, perhaps unsurprisingly, on social skills. These platforms provide a compelling set of functionality for exploring social skills, particularly when they allow multiple users to interact with them at once.

6.4 FUTURE DIRECTIONS

Although research in shared active surfaces for autism is relatively recent compared to other technological platforms, similarities in interaction between them and the currently used best practice of paper-based systems enable transfer of a wide variety of interventions and approaches to this platform with relative ease. Of course, the interactive and computational features of these platforms also allow for the development of new interventions. Most of this research has so far focused on establishing the feasibility of such approaches. However, initial efforts have investigated the efficacy of these approaches in accomplishing the goals set forth, particularly for large co-located touch-screens, multi-touch tablets, and tabletop interfaces. However, there is room to go beyond this work through larger-scale clinical trials or evaluation of the specific features of the platforms themselves as described above or through the expansion into other application areas and increasing technological innovation as described in the next section. Given the expense of the systems, especially tabletop platforms like the DiamondTouch and Microsoft PixelSense, these may still be a ways off.

As tabletop, multi-touch, and other shared active surface technologies become more commonplace, it is likely that we will see a surge in both research and commercial applications in this space. In particular, the placement of these systems in homes, schools, and clinics for the therapeutic interventions described above may open the door for use of the hardware for other purposes. For example, one could easily imagine the Abaris system described in Chapter 4 or the Walden system described in Chapter 5 making use of shared interactive surfaces to support therapy as well as record-keeping rather than piecemeal solutions of computationally enhanced pens and paper, tablets, video capture, and physical artifacts (Hayes et al., 2004).

Another area of expansion is in the development of multi-sensory environments that include shared interactive surfaces (Chapter 6), as well as sensors (Chapter 8), mobile technologies (Chapter 5), virtual environments(Chapter 7), and other elements covered in detail elsewhere in this book. One research project has begun to step in this direction, MEDIATE. This system is an immersive physical-digital environment that is highly dependent on a variety of shared active surfaces for the floor and walls. Intentionally neither "therapeutic nor educational," the goal of MEDIATE is to let people with no verbal skills "express themselves" and have fun. The floor surface reacts to footsteps by generating sound, the screen walls react to movement and touch, and so on (Parés et al. 2004; Parés et al. 2005).

Shared active surfaces have been demonstrated repeatedly to be easy to use even for people with low vision, low motor skills, and other physical disabilities. The ability to use them collaboratively is encouraging and exciting for the development of a variety of peer and facilitator-based interventions. Additionally, beyond the need for and likelihood of larger and more complex trials of these technologies, we predict that a variety of innovative uses both independently and in concert with other technologies will be seen in the near future.

CHAPTER 7

Virtual and Augmented Reality

In this chapter, we describe a brief overview of work involving virtual reality, augmented reality, and avatars with individuals on the autism spectrum. For the purposes of this work and using our technology platform classification scheme, virtual and augmented reality *includes the use of virtual reality, augmented reality, virtual worlds, and use of virtual avatars.*

7.1 OVERVIEW

Virtual reality (VR) is a technique for simulating real, augmented, or fully imaginary environments (VE) and avatars using computer graphics. Avatars are virtual embodiments (humanoid or otherwise) that represent VR users or simulated interaction partners in VEs. VR employs a variety of digital displays (full immersion rooms, computer monitors, headsets, etc.) and input devices (mouse, joystick, keyboard, instrumented gloves, etc.) to enable users to experience and/or interact with VEs and avatars. Collaborative virtual environments (CVE) are those that allow multiple users to be present and interact within VEs at the same time. Augmented reality (AR), sometimes also called Mixed Reality, includes the use of virtual elements combined with elements of the real world, such as through the use of head-mounted displays or digital overlays on live video (e.g., a common example of this is digital advertising during sporting events).

Since their inception, virtual and augmented reality have been used as a technological platform for conducting research, education, and therapy in the general population and, as reviewed in this section, has increasingly included individuals on the autism spectrum.

Defining experiential features of virtual and augmented reality include interactivity, immersion, and presence, where immersion is the degree to which a virtual reality user feels engrossed or enveloped and presence is the degree of feeling situated within the virtual environment (Burdea & Coiffet, 2003). Similarly, Azuma (1997) states that augmented reality "*enhances a user's perception of and interaction with the real world. The virtual objects display information that the user cannot directly detect with his own senses. The information conveyed by the virtual objects helps a user perform real-world tasks*."

7.2 VIRTUAL REALITY APPLICATIONS

The application of VR technologies for use by individuals on the autism spectrum began in the 1990s through the pioneering work of Dorothy Strickland (Strickland, 1996; Strickland, 1998; Strickland, et al., 1996) and Cheryl Trepagnier (Trepagnier, 1999). Since their incipient efforts, and the subsequent work of others (notably Sarah Parsons and colleagues), it has been suggested that VR is an especially useful technological medium for individuals on the autism spectrum in preparation for, as an adjunct to, and/or in place of learning concepts and skills in real-world environments. The myriad putative affordances associated with virtual reality technologies for autism that have been suggested (as reviewed in Parsons & Mitchell, 2002; Parsons, et al., 2004; Parsons, et al., 2013; Rizzo, et al., 2006; Vera, et al., 2007) include:

- They are programmable spaces that can be carefully selected and controlled, thereby enabling tailoring of content to meet individual needs;
- They are repeatable and facilitate practicing skills across a range of contexts and periods of time;
- They circumvent face-to-face interactions, which might be uncomfortable and/or overwhelming for individuals with autism while learning new skills;
- The interactivity they facilitate is entertaining and can increase motivation to learn and practice skills;
- They reduce the cost of traveling to some environments repeatedly;
- They permit access to inaccessible environments that are unsafe until basic skills are learned;
- They support role-playing within realistic settings from different perspectives;
- They reduce environmental complexity and simplify stimuli to enhance salience;
- They can be paused permitting an educator or researcher to narrate what is being seen, what to attend to, and how to respond;
- Their verisimilitude supports learning that increases the probability of skills transferring to real-world environments;
- They represent a safe environment to make mistakes, incrementally building confidence in users before applying skills in the natural environment;
- Individuals with autism appear to learn how to use and interact with VEs and avatars quickly and show significant improvements in a few trials; and
- While not systematically tested, it has been suggested that VR is well suited for determining whether a variety of psychological theories (theory of mind, executive function, weak central coherence, embodied cognition, etc.) are intact or impaired in individuals with autism (Rajendran, 2013).

We next describe VR studies conducted with individuals on the autism spectrum to evaluate access and presence; measure sensory perceptual functioning; and assess and/or teach safety skills, social attention, emotion recognition, and social skills.

A number of studies have found that individuals with autism experience high levels of immersion and presence, successfully navigate VEs, can track stimuli presented within them, and fail to report any negative sensory side effects (Brown, et al., 1997; Charitos, et al., 2000; Eynon, 1997; Kijima, et al., 1994; Mineo, et al., 2009; Parsons et al., 2004; Strickland, 1998; Strickland et al., 1996; Wallace, et al., 2010). One study has evaluated the use of fully immersive VR to assess visual and vestibular functioning as it relates to postural reactivity in individuals with autism (Greffou, et al., 2012).

One major thread of research has been teaching individuals with autism different skills in a way that is safer and less threatening than a "real world" experience might provide. For example, studies have demonstrated that a variety of safety skills can be successfully taught to individuals with autism using VEs, including crossing the street (Josman, et al., 2008) (see Figure 7.1, left) and responding to fires (Strickland, et al., 2007) and tornado warnings (Self, et al., 2007). More recent studies have combined eye-tracking technology with VEs to assess gaze patterns to peer avatars as an index of social attention abilities (Alcorn et al., 2011; Jarrold, 2013; Lahiri, et al., 2011). Findings indicate that this paradigm can both distinguish individuals with autism from typically developing individuals and enhance social attention through virtual manipulation.

Similar to other technology platforms, the recognition of emotions in others and the acquisition of social skills has also been an important application area. A number of studies have demonstrated that CVEs (Cheng, 2010; Fabri & Moore, 2005; Moore, et al., 2005) and avatars (Fabri, et al., 2007; Golan et al., 2010; Hopkins et al., 2011; Mower, et al., 2011) are useful to assess and teach individuals with autism to recognize, understand, and appropriately respond to basic emotions and facial expressions. Finally, the greatest number of VR studies with individuals on the autism spectrum to date focus on teaching social skills generally (Neale, et al., 2002; Parsons, et al., 2006; Parson et al., 2004) and symbolic play (Herrera, et al., 2008), social cognition (Michelle, et al., 2013), social conventions (Mitchell, et al., 2007; Parsons, et al., 2005), virtual peer interaction (Cobb et al., 2002; Tartaro & Cassell, 2008) (Figure 7.1, right), and peer-to-peer VR-mediated interaction (Bauminger, et al., 2007), specifically.

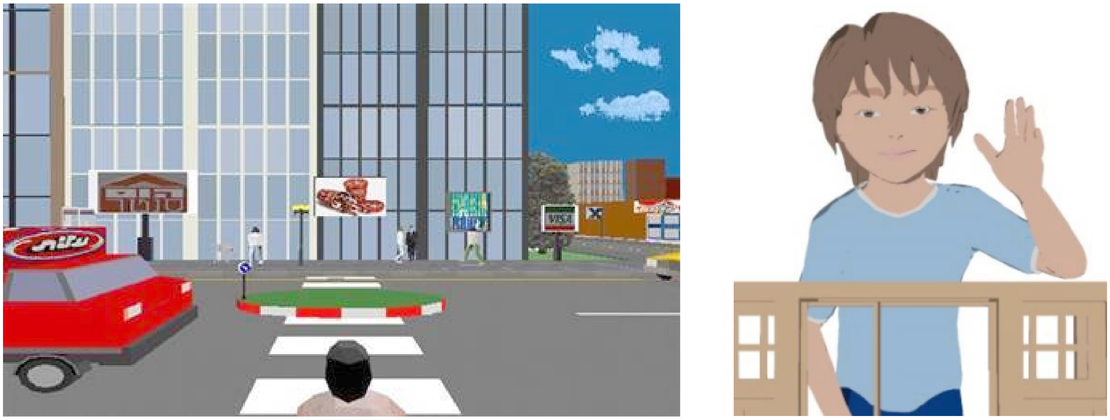

Figure 7.1: (A) Left: Using virtual reality to teach street safety (Josman et al., 2008). (B) Right: a virtual peer for teaching social skills (Tartaro & Cassell, 2008).

7.3 AUGMENTED REALITY APPLICATIONS

The application of AR to autism has not been as common as VR. However, there are a number of advantages to it that make it a promising area of exploration. Because it combines both real and virtual characteristics, it can be a useful tool for scaffolding generalization of skills learned in a virtual world to the real world. In addition, it can allow individuals with autism to receive additional help as a prosthetic while engaging in everyday activities.

As an example, and as discussed in Chapter 5, Escobedo and colleagues (2012) developed a system called MOSOCO, which uses AR to prompt students to practice social skills used in the classroom (see Figure 7.2). In the three-week deployment of the prototype, researchers saw improvements in both quantity and quality of socialization for three students with autism as well as nine neurotypical peers.

Figure 7.2: The MOSOCO system uses AR to teach social skills (Escobedo et al., 2012).

Casas and colleagues (2012) have used Microsoft's Kinect to combine the virtual and real worlds for individuals with autism. The Kinect is a good platform because it does not require the user to wear or hold anything to interact with a virtual environment. Casas and colleagues' system created what they call a Pictogram Room on a screen, which superimposes images over a live video to teach individuals different skills, such as body awareness and interacting with others (see Figure 7.3). Their small evaluation with five students with autism mostly focused on testing the feasibility of it, with three of the students being successful in carrying out tasks with the system.

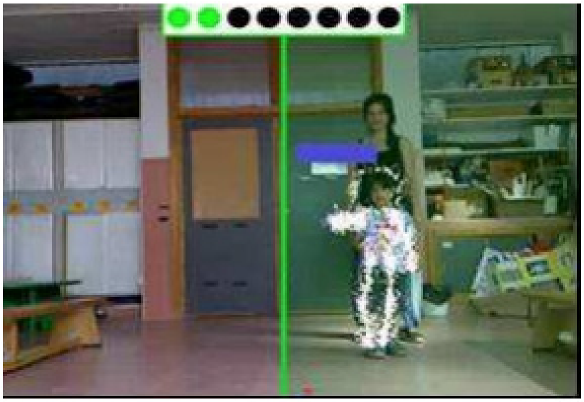

Figure 7.3: The Pictogram Room scene for teaching about body position (Casas et al., 2012).

Bai and colleagues (2012) developed an AR tool with the goal of helping comprehension and flexibility of object substitution during pretend play (see Figure 7.4). Their system is still a proof of concept that has not yet been evaluated rigorously, but has received positive feedback from autism domain experts on its feasibility and appropriateness.

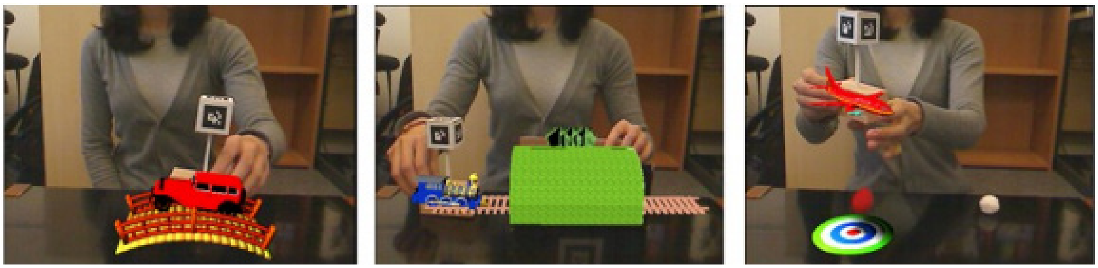

Figure 7.4: AR tool for teaching pretend play (Bai et al., 2012).

7.4 CLASSIFICATION APPLIED TO VIRTUAL AND AUGMENTED REALITY

In Figure 2.1, we tagged three of our twenty representative articles as using virtual or augmented reality as a technology platform. These included Sam—a virtual peer (Tartaro et al., 2008); virtual residential street, school playground, and school corridor scenes (Wallace et al., 2010); and Social Mirror (Hong et al., 2012). Here we describe how each of these fit into the classification scheme defined in Chapter 2, as well as discuss overall trends we observed for technologies making use of virtual and augmented reality platforms.

Sam—a virtual peer (Tartaro et al., 2008): Sam—a virtual peer was classified as *virtual & augmented reality* because it includes augmented reality and a virtual avatar. We classified it as targeting both *social/emotional* and *language/communication skills* given its focus on evaluating contingent discourse with Sam that involved turn taking, listening, and responding in a collaborative narrative. The goal of the system is *scientific assessment* and the target end users are *persons with autism*, *clinician/therapist*, and *researchers*. The setting for the work was a *research lab* and the work was published in the proceedings of the International Conference of the Learning Sciences (ICLS), an *educational* venue. Empirical evaluation included comparing measures of Theory of Mind and contingent utterances between a small group of children with autism and small group of typically developing children as they interacted with a human peer vs. virtual peer in a counter-balanced design. Therefore, we categorized it as *experimental*. Sam is currently at the stage of a *functional prototype*.

Virtual residential street, school playground, and school corridor scenes (Wallace et al., 2010): This work was classified as *virtual & augmented reality* because it includes virtual reality and virtual avatars. We classified it as targeting *social/emotional* with the goal of *scientific assessment* given its focus on evaluating sense of presence in virtual scenes and social attractiveness of a virtual avatar through self-report questionnaires. Target end users are *persons with autism* and *researchers*. The study was performed in a *research lab*, published in an *autism-specific* journal, and was *descriptive* in nature. The system is currently at the stage of a *functional prototype*.

Social Mirror (Hong et al., 2012): The Social Mirror was classified as *personal computers and web* and *virtual & augmented reality* because it includes an Internet-based application designed for access via a computer-based web browser and augmented reality (i.e., full-length mirror display embedded in the natural environment that embodies the social networking tool). We classified it as targeting *social/emotional* and *life/vocational* skills with the goal of enhancing *intervention/education* by enabling users to gather social advice on their personal appearance and hygiene. Target end users are *persons with autism*, *family/caregiver*, and *peer* and the intended setting for the system is the *home* environment. The work was published in Computer Supported Cooperative Work and Social Computing (CSCW), a *computing* venue. The empirical support included focus groups and is thus *descriptive*. The system is currently at the stage of a *functional prototype*.

While domain variety was observed across the literature reviewed in this section, the majority of work in *virtual and augmented reality* tended to focus on *social/emotional* and *life/vocational skills*. The purpose for most deployments was *scientific assessment* of *persons with autism* in *research labs* for *researchers* to evaluate characteristics of autism during virtual peer interaction and exploration/navigation of virtual environments. Publication venues were rather evenly split between *computing* and *autism-specific* venues, with most empirical support at the *descriptive* level. Nearly all systems reviewed are *functional prototypes*.

7.5 FUTURE DIRECTIONS

As detailed in a number of recent reviews (Bellani, et al., 2011; Parsons & Cobb, 2011; Parsons, et al., 2013; Rajendran, 2013; Wang & Reid, 2011), the following issues need to be overcome in future research to turn the potential leisure, research, and teaching utility of virtual and augmented reality and avatars into reality for individuals with autism. An astute reader will likely determine that many of these criticisms of VR and AR research apply in general to all research applying technology to interventions and assessments for autism.

First, few studies explicitly and systematically evaluate whether newly acquired skills in virtual and augmented reality generalize to real-world environments. Assessments across virtual and natural environments are needed to substantiate the claim that skills transfer between settings. Second, most virtual and augmented reality studies are exploratory, proof-of-concept, and include small samples of individuals with autism. Hypothesis-driven studies repeated by independent investigators that include larger and more diverse samples of well-characterized individuals with autism are needed to evaluate claims that virtual and augmented reality are efficacious in this population. Finally, many of the virtual and augmented systems employed in studies to date are extremely expensive and require computer science experts to support their use.

More affordable and intuitive systems are needed to enable wide-scale deployment, evaluation, and adoption. We are hopeful that this will be possible in the near future, as new, affordable technologies become available. This includes the Microsoft Kinect, a three-dimensional camera used primarily for gaming used by Casas and colleagues (2012), and Google Glass, a lightweight augmented reality headset that super-imposes virtual components on a real-world view. Likewise, newer technologies are becoming less bulky and cumbersome, which will likely improve acceptance of individuals with autism who have sensory issues.

CHAPTER 8

Sensor-Based and Wearable

In this chapter, we describe sensor-based and wearable technologies that have been used with individuals on the autism spectrum. Based on our classification scheme's definition, sensor-based and wearable technologies *include the use of sensors (e.g., accelerometers, heart rate, microphones, etc.), both in the environment and on the body, or computer vision to collect data or provide input*.

8.1 OVERVIEW

The technologies reviewed in this chapter are commonly referred to as "ubiquitous computers" (Weiser, 1991), "wearable computers" (Starner, 2001, 2002), and collectively by some as "telemetrics" (Goodwin et al., 2008). The commonality among them is their discreet size or form factor, capability of measuring data wirelessly, and ability to produce and transmit synchronized, time-stamped datasets to remote locations for viewing and analysis.

The motivation behind the use of sensors in ubiquitous computing is to "weave themselves into the fabric of everyday life until they are indistinguishable from it" (Weiser, 1991, p. 94). They involve embedding sensing technologies in the environment, including objects within them, and constitute "living laboratories" and "smart rooms" capable of wirelessly monitoring surroundings and inhabitant behavior (Abowd et al., 2000; Intille et al., 2005). These instrumented spaces and objects often include sensors to record interior conditions (temperature, humidity, light, etc.), person-object interactions (e.g., RFID attached to common items), and human behaviors (video cameras, microphones, motion sensors, etc.).

"Wearables" are on-body perception systems sewn into articles of clothing or embedded into accessories such as shoes, gloves, glasses, and jewelry (Healey, 2000). For example, small, wireless physiological sensors have been developed to unobtrusively record cardio vascular, respiratory, and skin conductivity in freely moving people (Wilhem & Grossman, 2010). Miniature actigraphs and accelerometers capable of objectively quantifying posture and physical activities have been embedded in wristbands, bracelets, and belts (Bao & Intille, 2004). Wearable audio-capture technologies that utilize small, unobtrusive microphones to record sounds created by the user (e.g., speech, gestures) and ambient auditory events in the environment (Mehl et al., 2001; Stager et al., 2003) have also been developed. Discreet cameras integrated into wearable pendants and eyeglasses to determine where a user is looking and what she or he is seeing are also emerging (Dickie et al., 2004; Vertegaal et al., 2001) and are even available as commercial products (e.g., SMI,[22] Tobii,[23] and Positive Science[24]).

8.2 SENSOR-BASED AND WEARABLE TECHNOLOGIES FOR AUTISM

Ubiquitous and wearable sensors support the following three key advances in autism research and intervention efforts: ecological validity, repeated assessment, and mitigation of reactivity to measurement.

Ecological validity refers to the relation between assessments of behavior in experimental contexts and behavior as it is produced in the real world (Brunswik, 1947; Schmuckler, 2001). Often used synonymously with *generalizability*, ecological validity connotes *representativeness* or *naturalness*. The overwhelming majority of autism-related research is conducted in laboratory, hospital, and clinical settings. However, the most ecologically valid behavior assessment strategies are those that make observations in the real world where behavior, and all of its structural and functional relationships, occur naturally. For individuals with autism, these include home, school, and community settings.

Conducting repeated assessments in autism-related research efforts is critical given heterogeneity in symptom presentation and varied developmental trajectories observed in the population. Both of these factors constitute important individual differences that can be obscured by averaging responses across people and relying on few measurement types and points in time.

Reactivity refers to the phenomenon of measurement processes producing change in what is measured (Campbell & Stanley, 1996). Reactivity is an important factor when evaluating individuals with autism since most standardized assessments includes foreign and invasive procedures (e.g., fMRI, EEG, aptitude testing) conducted in unfamiliar settings (laboratory, hospital, clinical settings) with unfamiliar people (trained test administrators) that require enormous amounts of self-regulation to comply with. This not only threatens internal, external, and construct validity, but can also create selection biases wherein only the most able individuals with autism participate in research studies (the consequent of which is little representation from those with autism who are less able or more sensitive to novelty). An obvious strategy for reducing the effects of behavioral reactivity is to use observation procedures that are passive (i.e., collect data without conscious input from the person being observed), involve little or no alteration of environmental stimuli, and which minimize evaluation apprehension.

[22] http://www.smivision.com/en.html
[23] http://www.tobii.com/
[24] http://www.positivescience.com/

As demonstrated below, a variety of ubiquitous and wearable sensors have been usefully employed with individuals on the autism spectrum (including those with a range of functional abilities), including telemetric video, audio, physiological, and physical activity sensors.

8.2.1 VIDEO ASSESSMENTS

As exemplified in this chapter, ubiquitous and wearable video sensors have been used to assess developmental status, capture salient life experiences, and teach social-emotional abilities in individuals on the autism spectrum.

When asked about initial concerns regarding their child with autism, at least 30–50% of parents recall abnormalities dating back to the first year (Gillberg et al., 1990; Hoshino et al., 1987; Volkmar et al., 1985). Similarly, studies of early home videos reveal behaviors indicative of autism in children later diagnosed compared to those of typically developing children (Baranek, 1999; Mars et al., 1998; Osterling & Dawson, 1994). According to both information sources, children with autism in the first year of life are distinguished by a failure to orient to name, decreased orienting to faces, reduced social interaction, absence of social smiling, lack of spontaneous imitation, lack of facial expressions, lack of pointing/showing, and abnormal muscle tone, posture, and movement patterns.

Although parents' retrospective reports and home video analyses clearly point to abnormalities in an autistic child's early development, this body of research is potentially limited by a host of methodological problems (for those interested in a more detailed review see Zwaigenbaum et al., 2007). For instance, a parent's incidental observations regarding subtle social and communicative differences may be limited compared to systematic assessments by trained clinicians. Parents' tendency to use compensatory strategies to elicit their child's best behaviors (with or without awareness) may also affect their behavioral descriptions. Retrospective parental reports may also suffer from distortions of recall, especially when parents are asked to remember behaviors that occurred many years earlier. Retrospective reports can include significant inaccuracies with respect to the description and perceived timing of early behavioral signs. Finally, environmental manipulations and systematic presses for specific behaviors cannot be controlled for in retrospective studies.

Home video analysis has significant strengths over retrospective parental reports as it allows the observation of behaviors as they occur in familiar and natural settings, and enable objective ratings of behavior by unbiased and trained observers. However, this methodology also has potential limitations. The primary shortcoming is that parents typically record videotapes to preserve family memories rather than document their child's behavior systematically over time. As a result, footage from different families varies as a function of length of time the child is visible, activities recorded, and quality of recordings. Moreover, if children do not behave as expected or desired, parents may re-record taped segments until they obtain more favorable responses. Observations from home videos also vary considerably between children and depend on particular contexts selected for taping. Another potential problem relates to sampling contexts of home videotapes in so much as they may not have provided sufficient opportunity for social communicative behaviors to be adequately assessed.

Despite these shortcomings of naturally recorded home videos, or perhaps even motivated by them, computer vision researchers have explored automated analysis of social interactions of home videos. Some of the most impressive work has been done by Rehg and colleagues (Prabhakar et al., 2010; Wang et al., 2009), attempting to extract the quasi-periodic patterns of social interactions, such as peek-a-boo, in home videos.

To overcome some of the shortcomings of home video recording, ubiquitous video systems can be deployed prospectively in home settings to more fully capture, quantify, and communicate early behavioral manifestations of autism. For instance, Vosoughi and colleagues (2012) created the Speechome Recorder, a portable version of the audio/video recording technology developed for the Human Speechome Project (Roy et al., 2006) (see Figure 8.1). The Speechome Recorder is a lamp-like form factor containing a dual camera system—one overhead camera facing down and the other camera facing horizontally at the height of a young child. Both cameras use 185-degree angle-of-view lenses able to record at 15 frames per second at a resolution of 960 by 960 pixels, enabling determination of interactions with surrounding people and objects throughout a room. The system also includes a boundary layer microphone that uses the surface in which it is embedded as a pickup. This allows a microphone placed in the head of the recorder to pick up speech in any corner of the room. All data captured by the Speechome Recorder can be stored locally on device and/or transmitted securely over Ethernet.

To date, four Speechome recorders have been deployed. Of the four households, three contain typically developing children and one has a child with autism, all 2 years of age. Recordings using the device averaged two to three hours per day for two to three consecutive months. The purpose of the deployments were to supplement a longitudinal study of language development in children with autism to assess language comprehension; investigate the relationships between children with autism's early language development and their later language/cognitive outcomes; and determine how more detailed measures of online efficiency in language comprehension might predict children with autism's individual variation. While data analysis is still underway, promising preliminary results have been presented at the International Meeting for Autism Research (Chin et al., 2013) and Society for Research in Child Development (Chin et al., 2013).

Figure 8.1: Video feeds from the Human Speechhome Project (Roy et al., 2006).

Point-of-view wearable image capture systems have also been used with individuals on the autism spectrum (see Figure 8.2). For instance, Hayes and colleagues (2010) and Marcu and colleagues (2012) deployed Microsoft SenseCams (Hodges et al., 2006) to periodically capture children with autism's views of the environment or automatically capture images based on changes in onboard sensors (light, temperature, accelerometer) throughout the day. The purposes of these deployments were to enable minimally verbal children with autism to capture, share, and discuss life experiences with caregivers and teachers in home, school, and community settings, and to populate more personalized and situated picture-based communication systems. Rehg and colleagues have also been applying point-of-view imagery to determine mutual gaze between a child and a clinical examiner (Han et al. 2012).

Figure 8.2: SenseCam wearable camera used with children on the autism spectrum (Hayes et al., 2010).

Difficulty communicating and engaging in real-time social interactions is another core characteristic of individuals with autism, including those who have verbal abilities and normal to above average intelligence (Klin et al., 2005). As a result, social interactions can be complex, confusing, and tiring for many with autism, making it difficult to establish peer networks and work and learn in traditional educational and workplace environments. In response to these social-emotional difficulties, researchers at the MIT Media Lab and Groden Center (school for individuals with autism) collaborated to create iSET (interactive Social-Emotional Toolkit) to help individuals with autism better understand and interact with others in natural conversations (Madsen et al., 2009). Through a technology-augmented game, participants were assigned the goal of capturing facial expressions from their teachers and peers using tablet computers running real-time facial expression inference algorithms. The system also included an offline component where an individual with autism and their teacher could review previously recorded video together and learn about ecologically valid facial expressions at their own pace.

8.2.2 AUDIO ASSESSMENTS

Communicative ability, including speech and language, is one of the primary differences seen in children with autism compared to typically developing peers. For instance, children with autism are found to communicate less frequently when young; develop language later; produce abnormal patterns of sound, atypical vocalizations, and repetitive speech; and have impaired conversational and narrative skills (Tager-Flusberg et al., 2011). Ubiquitous and wearable microphones are being used to discriminate between autistic, speech delayed, and typically developing children's speech with very high accuracy using computational markers of repetitive speech (van Santen et al., 2013), prosody (Chaspari, et al., 2012; van Santen et al., 2010), vocalization frequency (Oller et al., 2010), and vocalization composition (Xu et al., 2009).

8.2.3 PHYSIOLOGICAL ASSESSMENTS

Communication and socialization difficulties, sensory problems, deficits in executive function, and behavioral rigidity common in individuals with autism can make them exceedingly vulnerable to stressors and limit their ability to cope (Baron et al., 2006). Ineffective coping to stressors can lead to anxiety, and research suggests comorbid anxiety is present in between 33–84% of individuals with autism sampled (van Steensel et al., 2011; White et al., 2009). However, most of this research is based on parental report measures since many individuals with autism either lack communication abilities altogether or, for those with language, have difficulties identifying and describing their feelings through self-report (Hill et al., 2004). It can also be difficult for observers to infer internal arousal states in persons with autism given their reduced behavioral and affective expression of distress (Tordjman et al., 2009). Contemporary researchers have attempted to overcome unreliable self-reports and reliance on behavioral and affective observations by wirelessly recording physiological activity to specific stressors in freely moving individuals on the autism spectrum (Goodwin et al., 2006; Groden et al., 2005; Kushki et al., 2013) (see Figure 8.3). Researchers have also employed telemetric physiological monitors to evaluate sensory responses (Woodard et al., 2012), affective responses (Liu et al., 2008), and challenging behaviors (see next section for more detailed description of this class of behavior) in individuals with autism (Barrera et al., 2007; Willemsen-Swinkels et al., 1998) given the difficulty observing all of these phenomena reliably and/or anticipating them in sufficient time to provide adequate support.

Figure 8.3: Lifeshirt by Vivometrics, Inc.,[25] used by Goodwin et al. (2006).

8.2.4 PHYSICAL ACTIVITY ASSESSMENTS

Accelerometry offers a practical and low-cost method of objectively monitoring the ways in which free-living humans move and manipulate objects. An accelerometer is an electromechanical sensor that measures static (constant force of gravity) and dynamic (moving or vibrating) acceleration forces. An active area of research with accelerometers is the measurement of physical activity in individuals on the autism spectrum, particularly those who engage in challenging behaviors.

Challenging behaviors are common concerns in individuals with autism, have major impacts on their quality of life and that of their caregivers, and seriously affect the ability to reside in and benefit from more "normalizing" environments. Challenging behaviors commonly refer to aggression toward others, property destruction, self-injury (head hitting, biting, etc.), stereotypical motor movements (hand flapping, body rocking, etc.), and elopement (i.e., abruptly running away).

[25] http://vivonoetics.com/products/sensors/lifeshirt/

Standardized parent or teacher-report checklists (e.g., Rojahn et al., 2001), direct observation (Foster & Cone, 1986), and video-based methods are the most common ways of recording challenging behaviors. However, they all have drawbacks. While filling out checklists is useful and efficient, they fail to capture intra-individual variation in the form, amount, intensity, and duration of challenging behaviors (Pyles et al., 1997). Direct observation—which involves watching and recording a sequence of behavior in real time—can be unreliable due to the speed with which challenging behaviors can occur, difficulty determining when a behavior has started and ended, and ability to estimate behavioral quantities over a finite period of time (Sprague & Newell, 1996). Video-based methods—which involve video capture of behavior and offline coding and analysis—is more reliable than checklists and direct observation given the ability to review videos repeatedly and slow playback speeds. However, they are tedious and time consuming, making them expensive and impractical for most researchers to use (Matson & Nebel-Schwalm, 2007).

In an effort to overcome these methodological problems, researchers are exploring the use of wireless accelerometers and pattern recognition algorithms to provide automated measures of challenging behaviors that may be more objective, detailed, and precise than rating scales and direct observation, and more time and cost efficient than video-based methods. For instance, in a series of studies, stereotypical motor movements have been automatically detected with up to 90% accuracy in individuals with autism in both laboratory and class-room settings (Albinali et al., 2009; Albinali et al., 2012; Goodwin et al., 2011) (see Figure 8.4). Automated recognition of other challenging behaviors commonly produced by individuals with autism including aggression, self-injury, and forceful contact with objects in the environment (desks, walls, etc.) has also been conducted and yields promising results to assist in determination of eliciting stimuli and document response to intervention (Plotz et al., 2012).

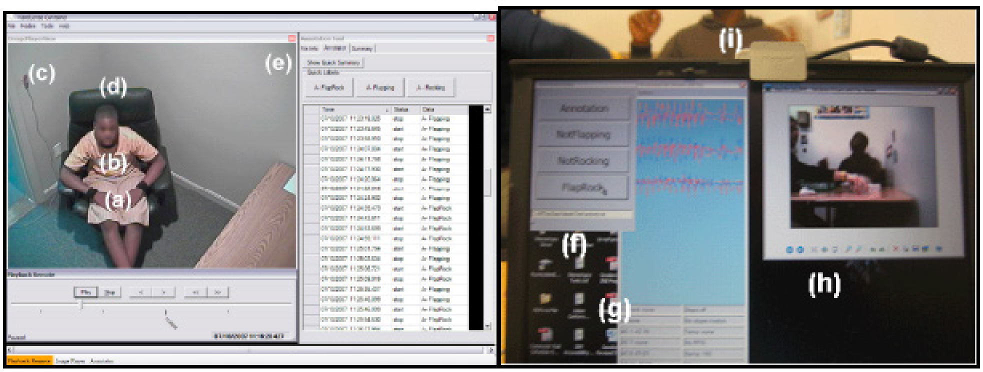

Figure 8.4: Body-worn accelerometers to sense stereotypical movements (Albinali et al., 2009).

Finally, it has been demonstrated that it is possible to automatically characterize the way individuals play by using toys instrumented with accelerometers and running pattern recognition algorithms on resulting data (Westeyn et al., 2012). While this work is promising and yields satisfactory recognition results, it focused on a group of typically developing adults and one typically developing five-year-old child. Children with autism have yet to contribute data to such paradigms/analyses.

8.3 CLASSIFICATION APPLIED TO WEARABLE AND SENSOR-BASED TECHNOLOGIES

In Figure 2.1, we tagged four of our twenty representative articles as using sensor-based or wearable technologies as a technology platform. These included MITes (Albinali et al., 2009), Child's Play (Westeyn et al., 2012), Life Shirt (Goodwin et al., 2006), and Social-Emotional Prosthetic (el Kaliouby et al., 2006). Here we describe how each of these fit into the classification scheme defined in Chapter 2, as well as discuss overall trends we observed for technologies making use of sensor-based and wearable platforms.

MITes (Albinali et al., 2009): We classified this work as *sensor-based and wearable* addressing the domain of *restrictive/repetitive behaviors* as it employed MIT Environmental Sensors (MITes)—tri-axial, wireless accelerometers—and pattern classification to automatically detect stereotypical motor movements. The goal of the system is *scientific assessment* and targets *persons with autism* and *researchers* as end users. The work was carried out in both a *research lab* and *school* setting, and was published in UbiComp, a *computing* venue. Empirical support was *correlational/quasi-experimental* and the system is presently a *functional prototype*.

Child's Play (Westeyn et al., 2012): We classified this work as *sensor-based and wearable* and *video and multimedia* as it incorporated toys instrumented with accelerometers, cameras and a computer to record and annotate play behavior with the toys, and a video playback interface to support retrospective review of recorded sessions. The system addresses the domains of *social/emotional* and *restrictive and repetitive behaviors* with the goal of *diagnosis/screening* and *scientific assessment*. Target end users of the system include *persons with autism*, *family/caregiver*, and *researcher*. Settings for the work include the *home*, *school*, and *research lab*. Results from the study were published in *Personal and Ubiquitous Computing*, a *computing* venue. Empirical support for the work is *descriptive* and the system is currently a *functional prototype*.

Life Shirt (Goodwin et al., 2006): We classified this work as *sensor-based and wearable* targeting the domain of *sensory/physiological/motor* as it employed an ambulatory measure of heart rate to assess physiological responses to potential stressors. The goal of the work is *scientific assessment* and *persons with autism* and *researchers* are the target end users. The study was conducted in a *research lab*, and results were published in *Focus on Autism and Other Develop-*

mental Disabilities, an *autism-specific* journal. Empirical support was *experimental* comparing cardiovascular stress responses between five children with autism and five age- and sex-matched typically developing controls. The system used to collect heart rate data wasp*ublicly available* at the time of publication, but is no longer manufactured commercially.

Social-Emotional Prosthetic (el Kaliouby et al., 2006): We classified this work as *sensor-based and wearable* and *video and multimedia* as it integrates a wearable camera and other sensors, combined with machine perception algorithms. The system targets domains of *social/emotional* and *language/communication skills* by recording and analyzing facial expressions and head movements of the person with whom the wearer is interacting. The system goal is to facilitate *intervention/education* both in *persons with autism* and their *peers*. The envisioned setting for this system is the *community*, and a description of the system was published in the Proceedings of the International Workshop on Wearable and Implantable Body Sensor Networks (BSN), a *computing* venue. Empirical support for the system is *descriptive* and it is currently a *concept/non-functional prototype*.

The work reviewed in this area was quite diverse, including both embedded and wearable video, audio, physiological, and physical activity sensors to facilitate *diagnosis/screening*, *scientific assessment*, and *functional assessment* in the areas of *social/emotional*, *language/communication*, and *restrictive/repetitive behaviors*. Target end users of these systems tended to focus on *researchers* with data collection carried out in *research labs*, though not exclusively. Publication venues for the work most often appeared in *autism-specific* and *computing* journals and proceedings. Empirical support varied, but included a higher number of *correlational/quasi-experimental* and *experimental* findings than other interactive technology platforms covered in this book. Most systems reviewed are currently functional prototypes.

8.4 FUTURE DIRECTIONS

There are several potential future directions for the use of ubiquitous and wearable sensors in autism research and intervention. With notable exception of the computational speech and language studies cited, most of the examples in this chapter involve relatively small samples of individuals with autism. Larger samples of participants with autism, ranging in age and functioning abilities, would be useful to assess replication and generalizability of findings. Extending deployments of these sensors for longer periods of time in natural settings, especially with non-technical researchers who were not involved in developing the systems but have domain expertise in autism, would demonstrate system reliability, validity, and robustness. Finally, it would be interesting to see if sensor fusion (as initially demonstrated by the multi-institutional Computational Behavior Science efforts led by Rehg) (Rehg et al., 2013; see www.cbs.gatech.edu) and data analytic optimization could enable just-in-time feedback that could be used to assess, evaluate, and intervene with individuals on the autism spectrum in real time.

CHAPTER 9

Robotics

In this chapter, we describe an overview of works relating to robotics and autism. While virtual agents are sometimes considered robots, and have included individuals with autism (e.g., Welch et al., 2010), this section focuses on physical instantiations (both anthropomorphic and humanoid) that collect data and/or carry out behaviorally contingent actions (both autonomously and operated remotely by humans) with individuals on the autism spectrum. For the purposes of this work, we defined robotics research as: *Includes physical instantiations of digital interactions. Includes both humanoid or anthropomorphic robots and general digital devices that carry out physical tasks. Includes both autonomous robots and those operated remotely by humans*.

9.1 OVERVIEW

Robotics is an expansive and rapidly developing field that formally grew out of the principles of cybernetics in the 1950s (Weiner, 1948). It includes a number of subdisciplines ranging from environmental sensing and navigation (Niku 2001), to object manipulation (Bicchi & Kumar, 2000), to human-robot interaction (Goodrich & Schultz, 2007). The latter forms the basis for work being conducted with individuals on the autism spectrum, and is formally referred to as Socially Assistive Robots or SAR (Feil-Seifer & Mataric, 2005; Tapus et al., 2007), a relatively recent emerging subfield with roots in Social Robotics, robots that interact and communicate with humans or other autonomous physical agents by following social behaviors and rules attached to their roles (Breazeal, 2004; Fong et al., 2003). The cardinal feature of SAR is its focus on understanding and developing ways for robots to sense and influence behavior change in humans; it is thus inherently interdisciplinary, drawing heavily from psychology, sociology, and related fields.

Most contingent human-robot interactions involve cameras and other sensors embedded in a setting, or in a robot itself, enabling a researcher to control the robot remotely. This control can be instantiated from an adjacent or distant room or within the same room by manipulating hidden controls, using a well-established paradigm known as Wizard of Oz (Riek, 2012). While the ultimate goal is to have robots sense and contingently interact with humans in a fully autonomous way, that reality may still require years or even decades of research given the limitations of current robotic sensing and navigation and the enormous complexity, uncertainty, and dynamism of human behavior.

9.2 ROBOTIC TECHNOLOGIES FOR AUTISM

In addition to enabling basic and advanced robot functionality, sustained engagement is a necessary prerequisite for meaningful human-robot interaction. Given joint attention and social understanding impairments often observed in individuals with autism (reviewed in more detail below), several researchers have focused their efforts on determining, developing, and evaluating robot design attributes that facilitate lasting engagement. Variations in a robot's physical appearance, interactivity, and methods of contingent action have been the most widely studied to date. Not surprisingly, responses from individuals with autism along these dimensions are not uniform, likely owing to the heterogeneity in abilities, perceptions, and preferences within the autistic population. Regardless, some conclusions can be drawn, namely that most (though not all) individuals with autism prefer robotic characteristics to human characteristics (Figure 9.1), interactivity over passivity, and behaviorally contingent responses (Dautenhahn & Werry, 2004; Feil-Seifer & Mataric, 2009; Feil-Seifer & Mataric, 2011; Goan et al., 2006; Piogga et al., 2008; Piogga et al., 2005; Robins et al., 2006; Stanton et al., 2008). Generally speaking, observed engagement levels between robots and children with autism have been observed to be high, a promising finding that, as reviewed in greater detail below, has opened up the possibility of using robots in a myriad of ways with individuals on the autism spectrum. These applications can be most easily sorted into assisting with diagnosis and promoting a variety of social-emotional skills.

Figure 9.1: Two types of robots. Left and Center: bubble-blowing robot, Right: humanoid robot (Feil-Seifer & Mataric, 2009).

9.2.1 ASSISTING WITH DIAGNOSIS

As discussed in Chapter 1, there is no specific biomarker, laboratory test, or neuropsychological assessment procedure to identify autism; it is defined exclusively by behavioral criteria assessed by an experienced and formally trained observer. Scassellati and colleagues (Scassellati, 2005; Scassellati, 2007; Tapus et al., 2007) have theorized that socially assistive robots can aid in the diagnosis of autism in two primary ways (see Figure 9.2). First, because robots can be programmed to provide consistent actions, diagnosticians could use them to ensure that identical social stimuli are presented to those being evaluated within and across sessions, potentially reducing administrative bias in testing (Klin et al., 2000). Second, through embedded or linked sensing modalities, robots could quantitatively record social behaviors (head orientation, eye gaze, tone of voice, object interactions, etc.) that are currently qualitatively rated by trained human observers during test administration. Collectively, these robot-enabled capabilities have the potential to enhance consistency of testing procedures and enable behavior samples to be analyzed in more precise, standardized, and objective ways.

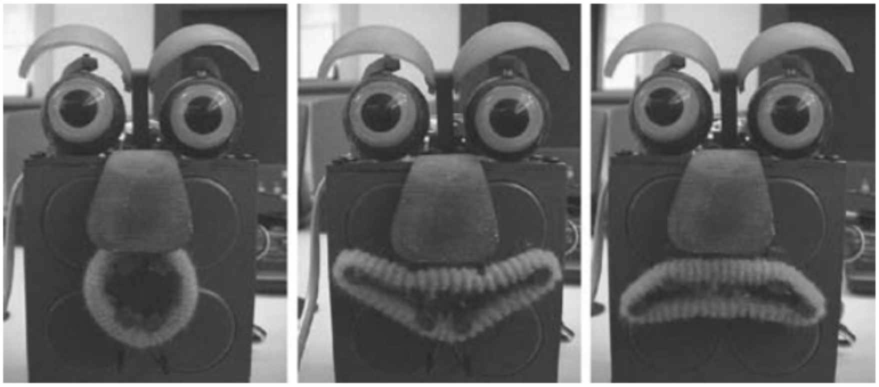

Figure 9.2: Robotic facial expressions of the ERSA robot (Scassellati, 2007).

9.2.2 PROMOTING SOCIAL-EMOTIONAL SKILLS

Thus far in the research, a primary usage of socially assistive robots is to enable individuals with autism to learn, engage in, and enhance social-emotional skills (e.g., Michaud & Théberge-Turmel, 2002). There are several different ways robots are being used to facilitate these behaviors, including evoking joint attention, eliciting imitation, mediating turn-taking, and modeling emotions, as we describe next.

Joint attention, which refers to the ability to share a common focus of attention either by following a pointing gesture or looking in the same direction another person is looking, is a cardinal impairment in autism (Mundy et al., 1990; Tomasello, 1995). Joint attention is critical for developing language and social communication (Mundy & Neal, 2001) and a prerequisite to forming Theory of Mind (Charman et al., 2001). A good number of studies in autism using robots has been to elicit joint attention (Dautenhahn, 2003; Dautenhahn et al., 2009; Da Silva et al., 2009; Feil-Seifer & Mataric, 2009; Kozima et al., 2005; Kozima et al., 2007; Piogga et al., 2006; Robins et al., 2009; Robins et al., 2004). Interestingly, it has been observed that many individuals with autism in these studies are able to engage in joint attention with robots despite failing to do so with unfamiliar adults. The exciting possibility, though not yet tested, is that robots could be used to stimulate joint attention initially and then serve as a scaffold to generalize the skill in human-to-human interactions.

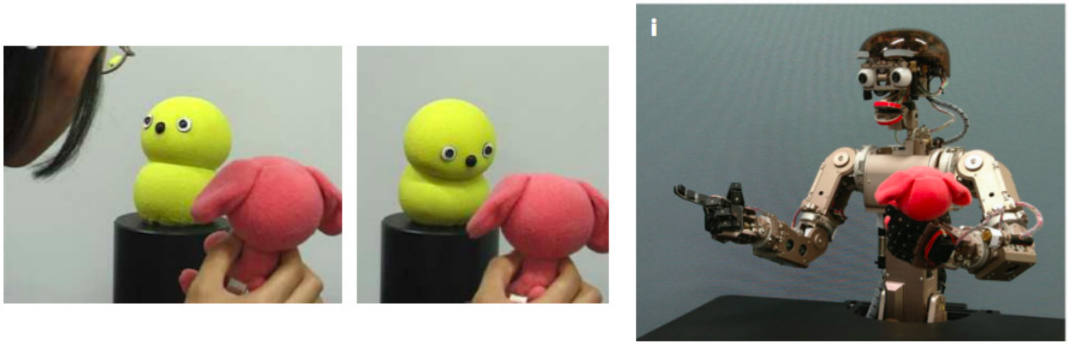

Figure 9.3: Right, Center: Keepon robot (Kozima et al., 2007) and Left: Bandit (Feil-Seifer & Mataric, 2008; Scassellatti et al., 2012).

Imitation is another key component of social learning and inter-subjectivity, and represents an additional central deficit in individuals with autism (Rogers, 1999; Rogers & Bennetto, 2000). Several studies have shown that robots can enhance imitation skills in individuals with autism (Bird et al., 2007; Boccanfuso & O'Kane, 2011; Duquette et al., 2008; Pierno et al., 2008; Torres et al., 2012). Similar to the joint attention findings, there is interest from researchers in seeing if imitation learning with robots could be leveraged and transferred to interactions with humans.

Like joint attention and imitation skills, turn-taking is a critical skill needed to meditate social interactions, and is often impaired in autism. A few studies have found that robots can serve as a powerful point of common interest between two individuals with autism and be a catalyst for social interaction (Costa et al., 2010; Feil-Seifer & Mataric, 2009; Robins et al., 2009; Robins et al., 2005; Wainer et al., 2010; Werry et al., 2001). Given the general interest of researchers in teaching social skills, such as turn-taking, using other technological platforms (see for example, the chapter on Shared Active Surfaces), there may be room for examining cross-platform and multi-modal approaches to these kind of skills that include robotics with other technological approaches.

Finally, it has been suggested that difficulties perceiving and producing emotions in self and others can give rise to or exacerbate some or all of the diagnostic features of autism. A small but growing number of researchers have begun to explore whether robots can sense, embody, and teach emotions to individuals with autism using neurological (e.g., EEG), physiological (cardiovascular, electrodermal, etc.), gestural, vocal, eye gaze, and facial expression sensors (Liu et al., 2008; Mazzei et al., 2011; Mazzei et al., 2012). These types of technologies are discussed in more detail in Chapter 10.

9.3 CLASSIFICATION APPLIED TO ROBOTICS

In Figure 2.1, we tagged one of our twenty representative articles as a robotics technology platform, called Behavior-Based Behavior Intervention Architecture (Feil-Seifer et al., 2009). Here we describe how this work fits into the classification scheme defined in Chapter 2, as well as discuss overall trends we observed for technologies making use of robotics platforms.

Behavior-Based Behavior Intervention Architecture (Feil-Seifer et al., 2009): We classified this work as *robotics*, *video and multimedia*, and s*ensor-based and wearable*. Using the system, a robot interacts with and observes an individual with autism in terms of his or her *social/emotional* skills through a combination of video, audio, and physiological sensors onboard, embedded in the environment, and/or worn by the individual under observation. The goal of the system is to facilitate *diagnosis/screening*, *intervention/education*, and *scientific assessment* for *persons with autism*, *clinician/therapists*, and *researchers* as target end users. The work was carried out is a *research lab*, and published in *Experimental Robotics*, a computing journal. Empirical support was experimental and the system is currently a *functional prototype*.

The literature reviewed in this area was quite diverse. While robotics was a core feature, several systems also included video and multimedia and sensor-based and wearable sensors. The domain most often targeted was *social/emotional* with the goals of *scientific assessment* and *intervention/education*. Target end users of these systems tended to focus on *researchers* with data collection carried out in research labs. Publication venues for the work most often appeared in *computing* venues, but some also featured in *autism-specific* journals. Empirical support was mostly descriptive and *correlational/quasi-experimental,* with few *experimental* results. Most systems reviewed are currently *functional prototypes*.

9.4 FUTURE DIRECTIONS

As discussed in recent reviews (Diehl et al., 2012; Ricks & Colton, 2010; Scassellatti et al., 2012), there are a host of both challenges and opportunities for existing and future research in the nascent but rapidly growing field of robotics and autism. While robots appear to engage and elicit various types of clinically significant behaviors in individuals with autism, the majority of published literature at this time is theoretical and preliminary rather than data-driven and confirmatory. Thus, moving forward, it is important to attend to the variety of methodological approaches appropriate in the various venues that might publish work on robotics and autism as well as to ensure broad dissemination of these findings in ways that can be interpreted by clinicians, researchers, and technologists with a variety of backgrounds. One challenge in this area, however, is that robots are fairly expensive and can thus be hard to scale beyond research labs. Research efforts to take the best of what robotics has to offer and translate it to a more affordable and scalable package could help take this promising field to the next level.

Beyond overcoming the challenges mentioned above, there are additional opportunities for individuals with autism to benefit from socially assistive robots beyond the research applications reviewed earlier in this chapter. For instance, researchers could begin exploring operationally whether robots can serve as a "model social agent" (Dautenhahn, 2003) or "social crutch" (Scassellatti, 2007), providing real-time feedback or encouragement to individuals with autism in both therapeutic and naturalistic settings. Such capabilities would capitalize on the apparent intrinsic appeal of robots, their ability to respond uniformly and record data in a standardized fashion, and extend function beyond just assessment to an assistive technology wherein an individual with autism could use the robot to practice and/or mediate and/or reflect on interactions with therapists, caregivers, and peers. Extending a robot's ability to sense and appropriately respond in the moment to an individual with autism or his or her interaction partner based on their respective autonomic and affective states also represents an exciting area for further exploration and development (Picard, 2009; Picard, 2010).

CHAPTER 10

Natural User Interfaces

In this chapter, we describe what has come to be termed "natural user interfaces" (NUIs) and review how they have been used with individuals on the autism spectrum. Natural input encompasses a large variety of non-standard input techniques, such as the use of pen, gestures, speech, tangible computing, and eye-tracking technologies. For the purposes of this chapter, we define NUIs in our classification scheme as follows: *Natural user interfaces involve the use of input devices and techniques beyond traditional mice and keyboards. Specific input techniques include pens/writing, gestures, speech, eye-tracking, and tangible computing. Natural user interfaces also involve interaction with a system rather than just providing passive input*.

10.1 OVERVIEW

"Natural user interfaces" has been adopted as a generally accepted term to refer to a new class of computerized interactions that extend beyond traditional mice and keyboards. Hinckley (2002) defines an interface as natural if "the experience of using a system matches expectations, such that it is always clear to the user how to proceed, and that few steps (with a minimum of physical and cognitive effort) are required to complete common tasks." Although Hinckley does not name specific technologies, interactions that use gestures, speech, touch, and gaze are types of input that fall into this category. Abowd and Mynatt (2000) further describe the application area of natural interactions as it relates to third-generation ubiquitous computing technologies.

Although some would consider multi-touch surfaces such as iPads, Microsoft Surface, and more to be NUIs, we exclude them from this category because they are included in Shared Active Surfaces discussed in Chapter 6. We also contrast NUIs with sensors or wearable devices discussed in Chapter 8, as these techniques tend to focus on sensing passive input rather than back-and-forth explicit interactions.

NUIs have seen good success when used by individuals with autism, likely because they enable a variety of input mechanisms specific to the needs of individuals who present with different sensory impairments. For example, if an individual with autism has problems with their visual channel, they might be able to use speech-based interaction or physical gestures as input. However, there are some challenges in this space, as some types of channels may be problematic for different individuals. In the case of an individual with autism who exhibits stereotypical motor movements, such as body rocking or hand flapping, it may be difficult to ascertain communicative physical gestures. Other natural input types that do not use motion, such as eye-tracking, might be more suitable for individuals who exhibit these behaviors, though may also present a challenge if individuals engage in too much movement. Another primary advantage of NUIs is they often involve a lower learning curve for people with cognitive impairments, and thus may be easier to use than a keyboard or more complex input device. They also have the advantage of being nearly ubiquitous, and thus may reduce stigma associated with having to use, carry, or wear a specialty device.

In general, NUIs have the largest variety of inputs compared to other types of technologies we reviewed, enabling a multitude of applications for individuals with autism. Speech, pen, and physical gestures can be used as alternative inputs to almost any existing technology, and some technology designers have used these types of interactions to make applications easier for individuals with autism to use. New applications are also being developed to specifically take advantage of these types of NUIs for autism, such as games and therapy applications. In the subsequent section, we discuss specific examples that take advantage of these platforms.

10.2 NATURAL USER INTERFACE TECHNOLOGIES FOR AUTISM

In this section, we describe specific technologies deployed with persons on the autism spectrum that include pen and physical gesture-based interactions, tangible computing, speech recognition, and eye-tracking systems that are interactive.

10.2.1 PEN AND GESTURE

Pens and physical gestures have the advantage of blending seamlessly in environments in which they are used. Because individuals with autism are often reported to be enamored with technology, using more obvious devices like tablets and laptops may serve as a distraction in classrooms or therapy situations (Kientz & Abowd, 2008). Pens in particular are advantageous in this regard, since many practices within the autism community are still very much paper-based (Marcu et al., 2013). One trend for NUI systems has been to include digital pens as an input mechanism for therapy sessions. For example, the Abaris application discussed in Chapter 4 (Kientz et al., 2005; Kientz, 2012; Kientz et al., 2006) combines audio and video recording with digital-pen and paper (using Anoto technology[26]) and speech recognition to capture data from therapy sessions to allow better record-keeping and collaborative review (see Figure 10.1).

[26] http://www.anoto.com

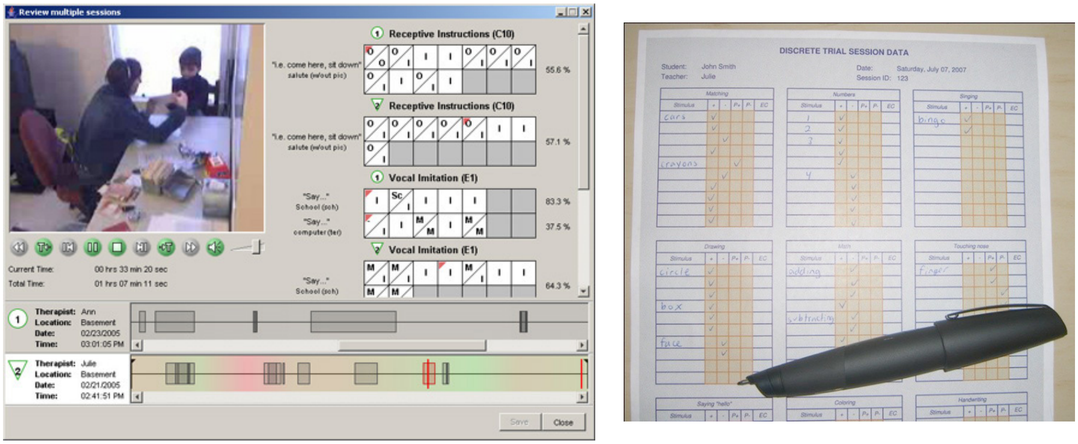

Figure 10.1: (A) Left: screenshot of Abaris video review screen. (B) Right: digital pen and paper input form (Kientz et al., 2006; Kientz et al., 2005; Kientz, 2012).

A number of projects detailed in Shared Active Surfaces, Robotics, Virtual Reality, and Sensor and Wearable chapters in this book have used gestures as a means of interaction for individuals with autism. Gestures include both natural movements like pointing and dragging, as well as learned gestures such as pinching, panning, or tapping. Gestures can be arbitrary or symbolic, such as those used in American Sign Language. One application of gesture-based NUIs is the MEDIATE project (Parés et al., 2004). MEDIATE is a multisensory environment (see Figure 10.2) created to facilitate interaction and play in children with severe autism or those who are nonverbal. The immersive environment uses large projection screens with audio and a number of environmental motion sensors. Individuals in the space can move about freely, and the large display and audio responds to their body movements based on changing pitch, tone, and speed.

Figure 10.2: MEDIATE multisensory environment (Parés et al., 2004).

10.2.2 TANGIBLE AND TACTILE COMPUTING

The greatest number of projects in the area of NUIs relating to individuals with autism has been in the area of tangible or tactile computing (the terms are often used interchangeably). Tangible computing is the use of physical objects that can be grasped and manipulated to interact with a virtual environment or system (Ishii & Ullmer, 1997). Tangible objects may include building blocks, small figures, plush dolls or animals, robots, toys, or other custom-made objects. The interaction may occur locally on the device itself, with a complementary display, or with an entire room environment. The applications often use RFID tags and readers, computer vision, or other sensors to recognize when and how a user interacts with an object.

A recent study (Sitdhisanguan et al., 2012) compared the use of tangible user interfaces, touch-based interfaces (e.g., those described in Chapter 6), and desktop-based interfaces for computer-based training with individuals on the autism spectrum (e.g., those described in Chapter 3). Results suggested that tangible and touch-based interactions were easier to use, and that tangible systems were more effective teaching tools than standard desktop-based applications or non-computer-based systems. Another study showed that even a simple device that vibrates in a child's pocket was a promising approach in rewarding verbal initiations (Taylor & Levin, 1998). Others have done general explorations of different types of technology within the tangible space (Keay-Bright & Howarth, 2012), as well as explored the use of tactile feedback with a robot outfitted with special skin that could respond to and record a child's touch (Amirabdollahian et al., 2011).

Tactile computing can be especially useful for individuals with autism who may be more drawn to virtual worlds than to the physical world initially, as we described in Chapter 7. They can be used to scaffold their experiences to enhance engagement and interactions in the real world. Farr and colleagues (Farr et al., 2010) describe tangibles as having the ability to "provide a safety net for encouraging social interaction as they allow for a broad range of interaction styles." Their work included an augmented knight's castle toolset that used RFID tags to activate sounds as the child plays with an object, including recorded audio in a child's voice (see Figure 10.3). They conducted a small experiment on this technology to determine whether configurability of the knight's castle toy set encouraged social interactions. They found it encouraged greater occurrence of orientation behaviors and more parallel and cooperative play than solitary play.

Figure 10.3: Augmented Knight's castle game (Farr et al., 2010) that uses RFID tags and readers to identify when the player interacts with objects.

Topobo is another tangible user interface construction kit (see Figure 10.4, left) designed for children with autism, which is a programmable environment that is easy to learn (Farr et al., 2010). They compared the use of Topobo and standard LEGO blocks in a small experiment with six children with autism. Their study indicates that the programmable Topobo set elicited higher levels of social interactions than just LEGO, as well as more parallel play rather than solitary play. Other technology approaches have also used building-block type toys with electronic enhancements to promote creativity, interaction, and teamwork (Drain et al., 2011).

Affective Social Quest, by Blocher and Picard (2002), used plush dolls combined with an on-screen video to help teach emotion recognition to individuals with autism (see Figure 10.4, right). In the application, the on-screen video displayed an emotion, and the child was tasked with finding a physical doll that matched the expression. When the correct doll was found, a wireless two-way communication protocol triggered rewards both on-screen and via the doll itself, which vibrated and made an emotion similar to the one displayed on-screen (e.g., giggling for a happy doll). The system was evaluated with six children with autism who used the tool across three days to determine its feasibility.

Figure 10.4: (A) Left: Topobo (Farr et al., 2010). (B) Right: Affective Social Quest (Blocher & Picard, 2002).

In addition to using tangible computing for children already diagnosed with autism, there has been a recent effort to use sensors embedded in tangible objects, such as children's toys, to understand how young infants play with objects and to look for early warning signs of autism, such as repetitive play or self-stimulatory behaviors (Westeyn et al., 2012) (see Figure 10.5).

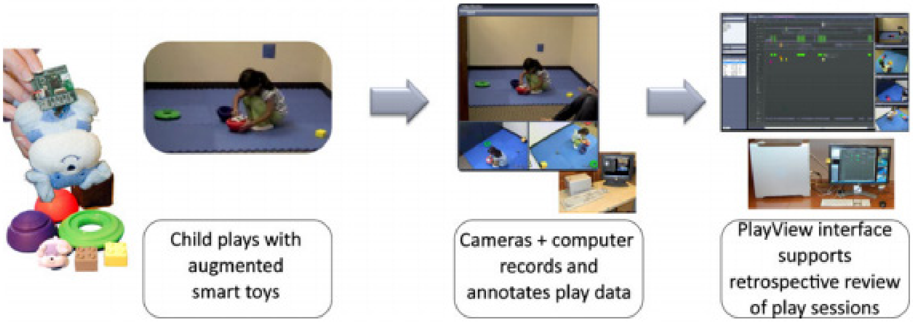

Figure 10.5: Toys augmented with sensors to understand and characterize children's play behaviors (Westeyn et al., 2012).

10.2.3 SPEECH AND AUDIO

Because many individuals with autism are minimally verbal or have difficulty with spoken language, there have been fewer applications that make use of speech recognition as a way of interacting with a computerized system. The use of audio and speech processing has largely focused on assessing speech of individuals with autism or for recognizing speech prompts from adult caregivers. For example, a number of the applications discussed in Chapter 9 used speech as an assessment tool, such as measuing repetitive vocal behaviors. The Abaris system mentioned previously also used speech recognition, but focused on the speech of the therapists working with children for indexing video streams (Kientz et al., 2005; Kientz et al., 2006).

One notable example of an interactive technology for use with individuals with autism is that of Hailpern and colleagues (2009a). In their system, children engage with an interactive system that visualizes their non-speech vocalizations. The idea is to encourage these vocalizations in non-verbal children with autism through animations, sound, and stimulating rewards. Hailpern and colleagues have deployed this system with numerous children on the autism spectrum in a lab setting, and found they could be used to stimulate any vocalization with the Spoken Impact Project (Hailpern et al., 2009b) and to encourage multi-syllabic vocalizations with VocSyl (Hailpern et al., 2012) (see Figure 10.6). The design process for these systems is also described (Hailpern et al., 2012).

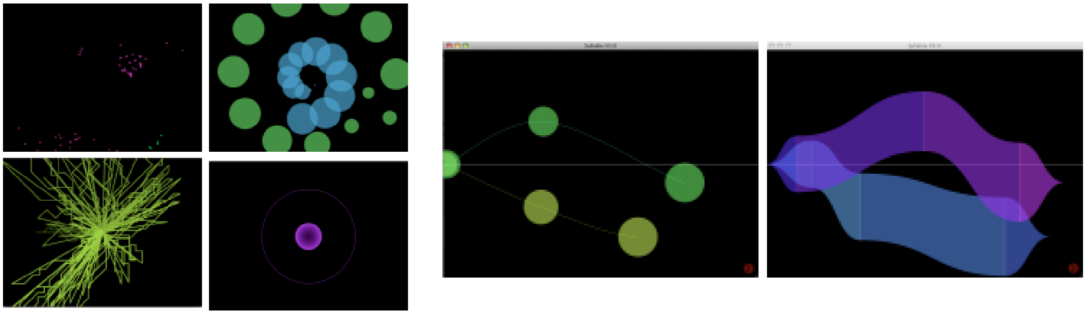

Figure 10.6: Visualizations from (A) left: Spoken Impact Project (Hailpern et al., 2009) and (B) right: VocSyl (Hailpern et al., 2012).

10.2.4 FACE, GAZE, AND EYE-TRACKING

Because many individuals with autism are non-verbal and/or have difficulty reading emotions in others, technologies that use face or eye-tracking have been popular as a means of identifying ways of understanding attention and teaching facial expressions. As discussed in Chapter 3, Ould Mohammed and colleagues (Ould Mohamed et al., 2006) used gaze tracking and facial orientation to conduct attention analysis in children with autism who were interacting with any type of desktop software. The approach was intended to help children categorize elementary perception, such as whether something is strong, smooth, quick, slow, big, small, etc. This type of approach can be used by other software applications to determine where children attend to in interactive applications, which may improve the design of future applications and interactions.

Another project, Virtual Buddy (Figure 10.7), used eye-tracking in very young children with autism aged 24 to 52 months as a form of intervention in social situations (Trepagnier et al., 2006). The system, which employed a virtual face, monitored whether children engaged in socially appropriate behaviors such as making eye contact, following the face's gaze, and pointing in the same direction. Appropriate behaviors were rewarded with video clips of the child's favorite shows. At the time of publication, the system had undergone pilot testing and was recruiting for a larger study. A similar project used a robot with a life-like facial display, called FACE, which integrated facial and eye-tracking to determine what individuals with autism were attending to during interactions with the robot. Although the system has only been used with two children, there has been promise demonstrated in this space to conduct therapy and improve social skills (Pioggia et al., 2005).

Figure 10.7: Virtual Buddy system (Trepagnier et al., 2006).

While the previously described work has used facial, gaze, and eye-tracking in individuals with autism themselves, additional work has focused on facial expression analyses of neurotypical peers or conversation partners as a tool for assisting individuals with autism in social interactions. Researchers who study Affective Computing (el Kaliouby et al., 2006; Picard, 2009) have looked at using facial expression tracking as a social prosthetic for individuals with autism. By using a wearable camera, an individual can use it to scan the faces of people with whom they are interacting and use sophisticated algorithms to provide feedback about the emotions the system detects (Madsen et al., 2009).

10.3 CLASSIFICATION APPLIED TO NATURAL USER INTERFACES

In Figure 2.1, we tagged four of our twenty representative articles as using natural user interfaces as a technology platform. These included the Spoken Impact Project (Hailpern et al., 2009a), Abaris (Kientz et al., 2005), an eye-tracking study (Klin et al., 2002), and computational prosodic markers (van Santen et al., 2010). Here we describe how each of these fit into the classification scheme defined in Chapter 2, as well as discuss overall trends we observed for technologies making use of the natural user interfaces platform.

Spoken Impact Project (Hailpern et al., 2009a): We categorized this work's interactive technology platform as *natural user interfaces* due to speech being the primary input mechanism. The domains covered by the project include teaching of *language/communication* skills and also because it attempts to encourage speech and vocalizations, which can be a type of restrictive or repetitive interest. The goal of this work was primarily to teach skills or encourage new vocalizations, so this was categorized as *intervention/education*. The target end users for this work include the *person with autism* themselves, as well as a *clinician/therapist* who may be working with them. The research studies were primarily conducted in the setting of a *research lab*, though future use could be for a *clinic* or *school*. The publication venue for this project was at the CHI conference, which is a *computing* venue. Finally, the studies conducted were of the type *correlational/quasi-experimental*, and the Spoken Impact Project has reached the maturity of a *functional prototype* that is not yet available for public use.

Abaris (Kientz et al., 2005): The Abaris project was categorized as a *natural user interface* due to its use of a digital pen and speech recognition. However, it also includes a traditional desktop application and video recording and capture, so secondary interactive technology platforms include *personal computers and web* and *video & multimedia*. The therapy supported by Abaris, Discrete Trial Training, primarily has the function of teaching in the domains of *language/communication skills*, *academic skills*, and *life/vocational skills*. The goal of the therapy, and thus Abaris, is for *intervention/education* as well as being used for *parent/clinical training* by allowing for reflection on therapy practices. Abaris was developed for target end users of the type *clinician/therapist* and *educator* for both *home* and *school* therapy settings. The work was published originally at the UbiComp conference, which is a *computing* publication venue. The research study was of the c*orrelational or quasi-experimental* design, and the maturity of Abaris is a *functional prototype* that is not yet available to the public.

Eye-Tracking (Klin et al., 2002**):** The article reviewed applies the use of eye-tracking technologies to understanding whether fixations on natural social situations can be predictors of social competence for individuals with autism. Because the study uses eye-tracking, its interactive technology platform is classified as a *natural user interface*. The application was applied to fixation on social situations, and thus the domain is *social/emotional skills*. The short-term goal for this work was a *scientific assessment* of how individuals with autism respond differential to social stimuli, with the eventual goal for this work being *screening/diagnosis*. The target end users for this work were *researchers* since the data collected was for scientific research, and the setting was also a *research lab*. The work was published in the *Archives of General Psychiatry* journal, which is a *medical* publication venue. The study conducted was *experimental* in nature, and the eye tracking technology used is *publicly available*.

Computational Prosodic Markers (van Santen et al., 2010): In the reviewed article, van Santen and colleagues used computational analysis of audio to analyze how prosody differs between individuals with and without autism. The technology used was speech input and computational analysis, so the technology platforms are *sensor-based* and *wearable* and *natural user interfaces*. The work was analyzing how speech differs for individuals with autism, and thus the domain is *language/communication*. Similar to the previous article, the short-term goal is for *scientific assessment*, but the data collected could eventually be for used for *diagnosis/*

screening. Because the data was collected by the research team, the target end user is *researcher* and the setting is a *research lab*. The work was published in the journal *Autism*, which is an *autism-specific* publication venue. Finally, the study conducted was *experimental*, and the technology used is a *functional prototype* but to our knowledge is not yet available to the public.

Because many of the technologies in this chapter move beyond what may be considered mainstream platforms, most of the applications in this space came from the *computing* publication venue. We also found that a number of the technologies in this space were more *conceptual* or *functional prototypes*, and most were not yet publicly available due to many of the technologies being fairly novel. Although there were exceptions, such as the Spoken Impact Project, a number of technologies were designed for people other than the *person with autism*, perhaps due to the difficulty of using some of these technologies directly. There did not seem to be many technologies that had *experimental* validation, unless they were comparing the use of a technology by a person with autism to a person without autism. Most studies were *correlational* in nature. We did not see any specific trends for the domain or goals for technologies that used natural user interfaces.

10.4 FUTURE DIRECTIONS

Because of the relatively new aspects of natural user interfaces and the increasing practicality of sensor-based interaction, we believe this is a growing area with much promise. We expect that much of the future work on technology for individuals with autism will be within this space as new sensing and interaction paradigms are developed and established. For example, we are seeing promising work using Microsoft Kinect as an interaction platform for individuals with autism, which will likely increase the number of systems that use gesture-based input. The Lakeside Autism Center in Issaquah, Washington, has shown the Kinect to be a promising platform for engaging individuals with autism in social activities and in physical therapy–like capabilities.[27] The newest versions of Microsoft Kinect are including more advanced facial tracking as well, which will increase affordability and access to these devices.[28] As mobile interactions on tablets become more fluid and widespread, it is possible that pen input on paper may decline in popularity. Finally, as eye-trackers and facial recognition improves in accuracy, these demos may become more practical for everyday use.

There is also potential for these types of activities to be adopted beyond just children to adults who may be more comfortable manipulating objects or making gestures than they might be learning to use a more traditional keyboard and mouse. The one downside to these applications is often their expense and their complication in getting set up and teaching people to use and recognize the types of interactions that are allowed by a system. In addition, as computing becomes smaller and more embedded in everyday objects, we will likely see more use of sensors embedded in tangible

[27] http://lakesideautism.com/tag/kinect/
[28] http://msdn.microsoft.com/en-us/library/jj130970.aspx

objects, increasing the reach and scale of tangible computing. Research is always expanding, and we believe will make natural user interfaces more intuitive to learn and interact with, especially for those with autism.

CHAPTER 11

Discussion and Conclusions

Autism includes a wide umbrella of disabilities, including communication and social impairments and restrictive interests and repetitive behaviors as well as a host of different and unique abilities and functioning levels. This highly prevalent condition presents itself in a wide variety of ways, engendering interest from a vast array of professional caregivers, researchers, and other stakeholders. Even within the research space, in particular, one can find a disparate group of individuals working in parallel and collaboratively toward the shared goals of understanding and supporting people with autism, as well as improving diagnosis and monitoring. The International Meeting for Autism Research (IMFAR[29]), the largest annual conference on autism, attracts large numbers of interdisciplinary researchers. Thus, people interested in autism generally and those with specific backgrounds in medicine, biology, genetics, psychology, education, physiology, speech and language, and technologies alike have become interested in the use of technologies in support of people living with autism.

The media attention and passion of people with autism and their teachers and families has fueled what some may consider to be a tech bubble in the autism space—myriad applications and devices, many of which have not been rigorously tested. Overall, the limited evidence as to the efficacy of these technologies is somewhat unsurprising given the limited evidence for other therapeutic approaches that have become popular—e.g., occupational therapy, music therapy, animal therapy, diets and supplements, etc. In an environment in which families may be desperate to try new therapies before their early intervention support runs out, waiting for research evidence may not be feasible or desirable. Thus, there is currently a great opportunity to build on early research and commercial successes, contribute to evidence-based practices, and develop holistic empirically grounded interventions.

Multidisciplinary research in any field struggles with issues of how to conduct research, where to publish, and what constitutes a contribution to the field. In the case of autism and technology, the basic science required to move the field forward includes both the development of novel technologies—some that may be theoretical only or include prototypes not nearly robust enough for regular use—and the construction of theoretical knowledge from empirical research and scientific models. Thus, translating basic science into real-world applications is extraordinarily difficult, because it involves both "tech transfer" and the development of interventions and policies that apply what is known in the scientific space to what is needed in the clinical or educational space. This pipeline requires both substantial funding across the way for innovation, technology development,

[29] http://www.autism-insar.org/imfar-annual-meeting/imfar

and empirical research, and knowledge about a wide variety of fields. Additionally, to influence all of these fields, researchers must understand and deploy diverse evaluation methods and meet variable standards appropriate to each field.

With respect to experimental standards used for evaluation, most of the testing in the autism and technology literature thus far typically observes small numbers of study participants for short periods of time in a single setting and conducts detailed qualitative analyses. Generally speaking, the research tends to be exploratory, open-ended, and descriptive. In contrast, behavioral scientists usually employ large numbers of participants over longer periods of time and across settings, evaluating outcomes quantitatively. This type of research tends to be inferential and confirmatory, guided by a set of theory-driven hypotheses that are stated a priori and evaluated statistically. Finally, in some areas of the social sciences—notably education and autism-specific venues—single subject study designs are common. The end result of these studies is primarily feasibility and preliminary efficacy. While all of these approaches have their strengths and weaknesses, a failure to reconcile or integrate them can create barriers for collaboration among disciplines.

With respect to methodological issues, the following represents a handful of concerns to be addressed in future autism and technology research that may bridge this gap. First, very few studies in this area employ gold standard assessments such as the ADOS, ADI, and Vineland needed to ascertain whether study participants meet diagnostic criteria for autism. This is important to substantiate claims that technologies tested are in fact impacting the lives of individuals with autism and not just those within the wide range of typical development. Second, very few studies measure or report on potentially important demographic (age, sex, race, socio-economic status, etc.), functional (e.g., developmental age, IQ, verbal ability, etc.), and confounding factors/associated conditions (e.g., anxiety, medication status, etc.) that may account for observed effects (or lack thereof) and at the very least provide the kind of context needed to interpret results. Third, the heterogeneity in autism makes it very difficult to know whether individual differences within the diagnostic group are driving outcomes. Larger samples of either more diverse or narrowly defined study participants are needed to clarify response types in trials. At the same time, deeper engagement with participants and more nuanced and careful qualitative observations and analyses can help transfer these results to other people and domains even if they cannot be generalized. Fourth, very few studies employ a control group or control condition to ascertain whether observed outcomes are attributable to features of study participants or the technology or some other factors. Although we recognize that controlled trials are only one way to determine if interactive technologies are accounting for responses above and beyond other interactions, they are a solid step that is understandable by clinicians and provide support for policymakers and administrators looking to implement evidence-based practices. Finally, conducting assessments across time and settings would help determine test-retest reliability, generalizability, and maintenance of observed responses.

This would be particularly important to substantiate the potential for interactive technologies to facilitate equal or better responses in individuals with autism than human-guided interactions.

For publishing outlets, technology research typically appears in the proceedings of discipline-specific annual conferences. While highly competitive and peer-reviewed, their length and focus necessitates limited description of participant samples and experimental design and more attention to technical and system-level details. In contrast, behavioral science research is typically published in discipline-specific monthly or quarterly journals in longer formats. While also highly competitive and peer-reviewed, their length and focus prioritizes in-depth descriptions of participant samples, psychometrics of assessments used, experimental design, and interpretation of findings, and less technical detail. As yet another model, medical research is typically published in monthly or quarterly journals in short articles with carefully defined formats.

Each publication outlet has its strengths and weaknesses and when faced with these articles, researchers from various fields tend to be able to interpret them. However, they are generally not cross-indexed by the various libraries (e.g., PubMed vs. JSTOR vs. ACM/IEEE), and students new to the field may not know to check venues that are less familiar to them. This review cuts across these venues as a starting point for a true multidisciplinary view of the field, and our classification scheme defined in Chapter 2 is a good start toward having a shared set of criteria and vocabulary across fields. However, this review is just one snapshot in time. Technology is rapidly evolving, and the field is maturing. Thus, as mentioned in Chapter 2, we have provided a Mendeley library[30] alongside this review with the ability for anyone to enter new publications and code them accordingly using tags. Using this crowd-sourced model, we can go beyond a static book and track the changes in the field as they develop. As just one example of this enormous growth, a search for autism in the ACM digital library—the premiere place to find computing references—shows a near exponential growth over the last four decades (see Figure 11.1).

[30] http://www.mendeley.com/groups/3745371/interactive-technologies-for-autism/

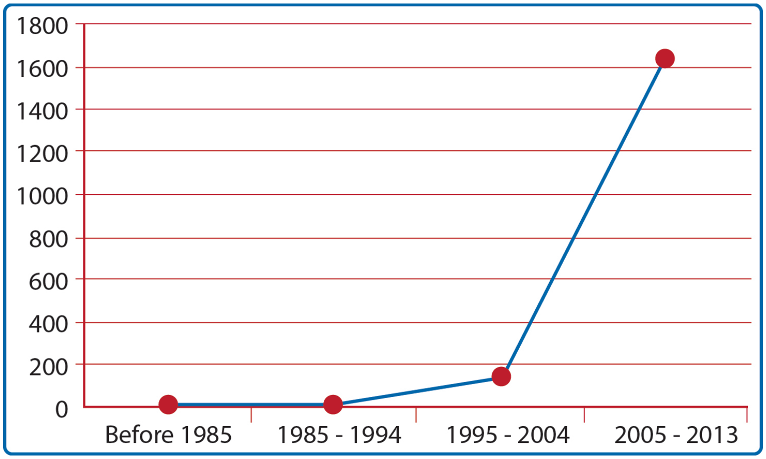

Figure 11.1: Growth of search results for "autism" in ACM's Digital Library.

Despite the massive growth, there is certainly room for more work in this space. As already noted in nearly every chapter, longer-term and larger numbers of participants in studies are needed to validate the preliminary results we have seen so far. Additionally, greater innovation across various technologies is still possible—and very necessary. We also need to consider cultural and language barrier issues for many of these systems, as there are many individuals with autism and their families for whom English is considered a second language. Finally, we must continue to expand those who we consider stakeholders in this space. Many early projects and papers focused on supporting the individual with autism directly, through augmentative communication and cognitive prostheses. As time progressed, clinicians and caregivers began to be considered as well. We have the potential to explore technologies for advocates, for those interested in neurodiversity, for neurotypical peers who want to include individuals with autism in their everyday activities, and more. As we explore these new perspectives, expand empirical datasets available across all these technologies and populations, and work to understand the long-term implications of technology use, we can take this nascent field into a strong, scientifically based, inclusive, and highly impactful discipline.

Never before has so much computational power been available in such small and portable devices. Likewise, the growing Internet connectivity to these devices supports mobile delivery of vast amounts of information. In the meantime, the growth of app stores and mobile marketplaces has democratized the software development community to a level not seen since the initial .com revolution. However, this kind of rapid growth and change does not come without risks. Too often clinicians, parents, teachers, and individuals with autism are seduced by claims of a new piece of software with limited empirical basis. As these technologies mature, researchers have the moral and ethical responsibility to take up this charge and go beyond the design, development, and preliminary testing of novel innovations. Now is the time to develop measures to determine not only feasibility and efficacy of these interventions, but also to identify the underlying mechanisms that enable matching design features to optimal outcomes. Likewise, consumers of new technologies must become savvier and insist that commercial products be tested, evaluated, and subjected to independent scrutiny. The inevitable bursting of the mobile bubble may not be as dramatic economically as that of the .com era or even the U.S. housing crisis, but it will usher in some sorting of truly efficacious applications from those that are less so. In the meantime, researchers and practitioners can help develop best practices for both creation and use of these technologies in the pursuit of better understanding and supporting individuals with autism.

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Dr. Gillian R. Hayes is an Associate Professor at the University of California, Irvine, in the Department of Informatics in the School of Information and Computer Sciences, in the Department of Pediatrics in the School of Medicine, and in the School of Education. She is an alumna of Vanderbilt University (B.S., 1999) and the Georgia Institute of Technology (Ph.D., 2007). For more than a decade, her research has focused on designing, developing, and evaluating technologies in support of vulnerable populations, including those with autism. Building on a background in computer science and a consulting career before academia, she focuses on methods for including people not traditionally represented in the design process or in research. She received a CAREER award from the National Science Foundation in 2008 for her work on mobile technologies for children and families coping with chronic illness and neurodevelopmental disabilities. She is the Director of Technology Research for the Center for Autism and Neurodevelopmental Disabilities, a major public-private partnership with clinical care, research, and education components. She is also the co-founder of Tiwahe Technology, a technology services firm focused on classroom-based and transition technologies for schools.

Dr. Gregory D. Abowd is a Regents' and Distinguished Professor in the School of Interactive Computing at the Georgia Institute of Technology. He is the father of two boys, Aidan and Blaise, who have been diagnosed on the autism spectrum. Since the early 2000s, he has devoted a large portion of his research career to developing technologies addressing challenges related to autism. He advised, and was subsequently inspired by, the doctoral research of Gillian Hayes and Julie Kientz, two of the coauthors of this book, and has advised numerous doctoral students on topics in this area, ranging from direct interventions to tools for clinicians, educators, or researchers to use in screening, diagnosis, and assessment of interventions. He is the Chief Research Officer of Behavior Imaging Solutions, which has commercialized some of the thesis research of the CareLog system designed and evaluated by Gillian Hayes and is currently pursuing commercialization of a portable in-home behavior capture system that is the thesis research of current Ph.D. student, Nazneen. Gregory served on the Innovative Technologies for Autism committee with Matthew Goodwin that was first part of the Cure Autism Now Foundation and has continued under the auspices of Autism Speaks. In 1998, he founded the Atlanta Autism Consortium to unite different stakeholder communities within the Atlanta area focused on research, education, and advocacy, and now serves as the president of that non-profit organization. He has published extensively in the area of technology and autism, and has received several professional awards from the Association of Computing Machinery (ACM) in recognition of that work, including being selected as a Fellow of the ACM.