Affective Computing and Autism

RANA EL KALIOUBY,[a] ROSALIND PICARD,[a]
AND SIMON BARON-COHEN[b]

[a]*Massachusetts Institute of Technology, Cambridge, Massachusetts 02142-1308, USA*

[b]*University of Cambridge, Cambridge CB3 0FD, United Kingdom*

ABSTRACT: This article highlights the overlapping and converging goals and challenges of autism research and affective computing. We propose that a collaboration between autism research and affective computing could lead to several mutually beneficial outcomes—from developing new tools to assist people with autism in understanding and operating in the socioemotional world around them, to developing new computational models and theories that will enable technology to be modified to provide an overall better socioemotional experience to all people who use it. This article describes work toward this convergence at the MIT Media Lab, and anticipates new research that might arise from the interaction between research into autism, technology, and human socioemotional intelligence.

KEYWORDS: autism; Asperger syndrome (AS); affective computing; affective sensors; mindreading software

AFFECTIVE COMPUTING AND AUTISM

Autism is a set of neurodevelopmental conditions characterized by social interaction and communication difficulties, as well as unusually narrow, repetitive interests (American Psychiatric Association 1994). Autism spectrum conditions (ASC) comprise at least four subgroups: high-, medium-, and low-functioning autism (Kanner 1943) and Asperger syndrome (AS) (Asperger 1991; Frith 1991). Individuals with AS have average or above average IQ and no language delay. In the other three autism subgroups there is invariably some degree of language delay, and the level of functioning is indexed by overall IQ. Individuals diagnosed on the autistic spectrum often exhibit a "triad of strengths": good attention to detail, deep, narrow interest, and islets of ability (Baron-Cohen 2004). In this article we consider how such strengths could be harnessed through the use of technologies to navigate the social world.

Address for correspondence: Rosalind W. Picard, Sc.D., FIEEE, MIT Media Laboratory, E15-448, 20 Ames Street, Cambridge, MA 02142-1308. Voice: 617-253-0611; fax: 617-253-5922.
e-mail: picard@media.mit.edu

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Autism remains a behaviorally specified condition, the diagnosis relying on interviews and/or direct observations (LeCouteur *et al*. 1989; Lord *et al*. 1989, 1994, 2000). The diagnosis criteria include a "marked impairment in the use of nonverbal behaviors, such as eye-to-eye gaze, facial expression, body posture, and gestures to regulate social interaction," and rely on the clinician's judgment about the individual's ability to engage in social interactions, process social information and deal with social anxiety. Interventions, too, are mostly behavioral and are aimed at addressing the social interaction and communication difficulties in autism.

One of the central psychological themes in autism research is that of empathizing. Often characterized as the ability to "put oneself into another's shoes," empathizing is the capacity to attribute mental states, such as feelings, thoughts, and intentions to other people, and to respond to their mental states with an appropriate emotion (Mehrabian and Epstein 1972; Spiro 1993; Omdahl 1995; Eisenberg 2000; Harris 2003; Baron-Cohen and Wheelwright 2004). Empathy is a set of cognitive and affective skills we use to make sense of and navigate the social world (Davis 1983). The cognitive component of empathy, also referred to as theory of mind (Wellman 1992), mindreading (Whiten 1991; Baron-Cohen 1995), or taking the intentional stance (Dennett 1987), involves setting aside one's own current perspective, attributing mental states to the other person, and then making sense and predicting that person's behavior, given his or her experience. Mental states include emotions, cognitive states (such as beliefs), volitional states (such as intentions and desires), perceptual states (such as seeing or hearing), and attentional states (such as what the person is interested in). The affective component entails having an emotional response to the mental state of others. To be an empathic observer, your feeling must be appropriate to that of the person observed, for instance feeling compassion to another's distress.

Good empathizers also have good "people intuition" (sometimes known as folk psychology or common sense psychology). People intuition is the set of assumptions we make about the relationships between people's behavior, mental states, and situation (Wellman 1992). It is the basis for our social judgments about others, including the production and comprehension of pretence (Leslie 1987; Pratt and Bryant 1990), understanding that seeing-leads-to-knowing (Pratt and Bryant 1990), making the appearance-reality distinction, and understanding false belief (Wimmer and Perner 1983). When we empathize, we respond in ways that acknowledge feelings of others and we are sensitive to other's different beliefs and perspectives. In addition, empathizing allows us to share perceptual space with others, which is crucial for social learning, joint action, and joint attention (Baron-Cohen 1995). To make sense of a social situation, most people will naturally follow others' gaze direction. When people focus on nonsocial stimuli (e.g., background objects), as is often the case in autism, they may miss the gist in the social interaction (Klin *et al*. 2002, 2003).

Despite their interest in making friends, many individuals with autism report having difficulties empathizing in a spontaneous way during real-time social interaction and lacking people intuition. These difficulties vary with the severity of the condition, and include difficulty reading other peoples' nonverbal cues and mental states (Joseph and Tager-Flusberg 1997; Frith 2003), atypical gaze processing (Volkmar and Mayes 1991; Klin *et al*. 2002; Pelphrey *et al*. 2005), restricted emotional expression (Hill *et al*. 2004), difficulties gauging the interests of others in conversation (Fletcher *et al*. 1995; Volkmar and Klin 2000), and frequently launching into monologues about narrowly defined and often highly technical interests, such as railway tables or maps (Klin and Volkmar 1995).

Over the past 10 years, researchers in affective computing (Picard 1997) have begun to develop technologies that advance our understanding of or approach to affective neuroscience and autism. Affective computing has contributed to these fields in at least 4 ways: (i) designing novel sensors and machine learning algorithms that analyze multimodal channels of affective information, such as facial expressions, gaze, tone of voice, gestures, and physiology; (ii) creating new techniques to infer a person's affective or cognitive state (e.g., confusion, frustration, stress, interest, and boredom); (iii) developing machines that respond affectively and adaptively to a person's state; and (iv) inventing personal technologies for improving awareness of affective states and its selective communication to others.

While much of the work in affective computing has been motivated by the goal of giving future robots and computational agents socioemotional skills, its researchers have also recognized that they face similar challenges to those who try to help people with autism improve such skills. Computers, like most people with autism, do not naturally have the ability to interpret socioaffective cues, such as tone of voice or facial expression. Similarly, computers do not naturally have common sense about people and the way they operate. When people or machines fail to perceive, understand, and act upon socioemotional cues, they are hindered in their ability to decide when to approach someone, when to interrupt, or when to wind down an interaction, reducing their ability to interact with others. A large part of natural learning involves reading and responding to socioemotional cues, so this deficit also interferes with the ability to learn from others. The field of affective computing aims to change the nature of technology so that it can sense, respond, and communicate this information. In so doing, the field has a lot to learn from people with autism, from progress they have made, and from the friends, families, and staff who work with these individuals. We should point out that we are *not* using autism as a metaphor, unlike the postautistic economics network (Post-Autistic Economics Network 2000) or Wegner's (1997) description of autistic algorithms. Our use of autism is restricted to the clinical definition.

A SYSTEMATIC APPROACH TO EMPATHY

So what do you do if, as in the cases of both autism and technology, empathizing is not something you naturally apply to the social world? You systemize. Systemizing is the drive to analyze and build systems and is one of the most powerful mechanisms to understand systems and predict change (Baron-Cohen, 2002). Systemizing involves sensing, pattern recognition, learning, inference, generalization, and prediction.

Persons diagnosed with ASC are extreme systemizers, showing intact or superior systemizing abilities, such as excellent attention to detail, islets of ability in topics like prime numbers, calendrical calculation, or classification of artifacts or natural kinds (Shah and Frith 1983; Jolliffe and Baron-Cohen 1997; Baron-Cohen *et al*. 2002; Baron-Cohen 2006). Many people with ASC attempt to systemize empathy, analyzing conversations and interactions, as it unfolds and for hours after it is over (Blackburn *et al*. 2000; Mixing Memory Blog 2005). For many, this is a tiring and draining exercise that makes it difficult to react in real time. As one person with an ASC put it:

> I study people almost to the point of obsession. I find some people's actions/motivations etc. extremely intriguing. Some people puzzle me. Often after I've had a conversation with someone I cannot sleep at night because I am analyzing the conversation. I rerun the whole thing, look at what went wrong and what didn't, work out what might have actually been meant by that, think about more accurate answers, etc. I also plan conversations ahead of time if I know I am going to have to talk to someone. In fact, conversations/social interactions all seem like a strategy game to me. You have to plan your moves in advance, work out all the possible ways the opponent might respond, and try and work out different courses of action for each of these. The only problem is, often in real time and life, the other person makes a move you haven't accounted for, resulting in the end of any conversation. Thus, while I spend vast amounts of time analyzing social situations, the practical side of things is still highly stressful and very hard to do successfully (Blackburn *et al*. 2000).

These first-hand accounts from people with autism stress that coping strategies are indeed needed for autism and suggest that systematic approaches to teaching empathy might be helpful. For example, recent interventions in autism providing computer-based methods of teaching emotion recognition have lead to an improvement in recognizing emotion (Golan *et al*. 2006). These accounts also illuminate the complexity of the social world and the challenges inherent in crafting a real-time intelligent response to high-speed complex and unpredictable information. There are no computational technologies that can perform feats of real-time socioemotional interaction. Today's most powerful robots perform much worse than people with autism at these challenges. Not only do they have difficulty understanding natural language, but they miss most of the socioaffective cues that can be used to decode the message. Robots also miss most of the facial and gestural cues, and cannot infer how these interact with what is said.

People with ASC who can systemize information about social situations can help researchers who are trying to build affective robots and agents, and future socioemotional technologies. For example, individuals with ASC tend to have a literal interpretation of what people say to them (Baron-Cohen 1988; Attwood

1998). Jonathan Bishop has developed a portable digital assistant (PDA) to help people with autism interpret frequently used idioms (Bishop 2003). For example, the system may explain that a comment, such as "Nice weather today," is not a statement of fact, which would be the literal interpretation, but an invitation to engage in casual conversation. The same technology can improve natural language processing in machines, helping them know how to better interpret what people say to them. These technologies need systematic ways to represent and handle social interactions, and people with autism have a unique ability to show researchers how to do this.

Systemizing empathy is an enormously challenging endeavor. For a start, the social world is a highly complex system of enormous variance (Baron-Cohen 2006). To date, there is no "code-book" available that maps a person's observed nonverbal cues to internal state and behavior. People with the same mental state may express these using different nonverbal cues, with varying intensities and durations. And people may use expressions that reflect mental states that are different from their true feelings or thoughts. Furthermore, when placed in the same situations, people may react differently. Empathizing is a highly uncertain process. We are never 100% sure of a person's mental state; instead, we infer mental states from observable behavior and contextual cues with varying degrees of certainty (Baron-Cohen 2003), and our average performance is probably far from 100%. For example, when shown face-videos, a panel of 18 people were only 54% accurate on labeling six categories of mental states, such as agreement, thinking, and confusion (el Kaliouby 2005).

Systemizing empathy is also challenging because affect is hard to measure (Picard *et al*. 2004). There are no continuous sensor systems that can reliably measure affective state. Without reliable sensors, how can we quantify exactly normal eye contact? There is a need to develop sensors, interfaces, signal processing, pattern recognition, and reasoning algorithms, for continuous tracking of a person's affective interactions. These technologies will be key in assessing an individual's specific areas of strengths and weaknesses, as well as measuring the efficacy of various interventions.

Affective computing over the past 10 years has been developing sensing and recognition technologies that, together with insights from people with ASC, may eventually facilitate systemizing the social world. In the next section we summarize several of the recent innovations that enable technology to sense affective states, and that have an obvious potential application to provide people with ASC with a direct "print out" of other's mental states. One of the biggest obstacles to empathy and mindreading that people with ASC report is that they cannot easily detect and read another's mental states—that they are largely unobservable. Affective computing highlights how such internal states are not wholly unobservable, that there are indicators that can make mental states more transparent or magnified, and that if these can be detected by technology, the human observer can make use of them.

AFFECT SENSING

The ability to sense a person's affective-cognitive state is the first step in mindreading. Despite many advances in brain imaging, there is not yet any technology that can read your innermost thoughts and feelings and communicate this to another. However, there are a growing number of portable sensors that can capture various physical manifestations of affect. These novel sensors are like perceptual mechanisms. Examples include tiny video camcorders to record facial expression, head gesture and posture changes, microphones to record vocal inflection changes, skin-surface sensing of muscle tension, heart-rate variability, skin conductivity, blood-glucose levels, and other bodily changes. Although they started off as bulky, affective "wearables" are now embedded in jewelry or woven into clothing (Picard and Healey 1997). Affective wearables are different to existing medical devices that measure similar signals, in that the wearer is in control. The wearer can take it off, or turn it off, or leave it, choosing when and where to gather information. The analogy is with a hearing aid or a pair of spectacles.

We have developed several kinds of systems for communicating affective information at the MIT Media Laboratory. FIGURE 1 shows portable forms of affective sensors, from left to right: expression glasses, blood-volume pulse earring, pressure-sensitive mouse, galvactivator, chest-worn heart monitor, and skin-conductance shoe. Here are some brief highlights about some of the wearable or portable devices:

(i) *Expression glasses* discriminate facial expressions of interest or surprise from those of confusion or dissatisfaction, allowing students to communicate feedback anonymously to the teacher in real time, without having to shift attention from trying to understand the teacher (Scheirer *et al*. 1999).

(ii) The *Galvactivator* is a skin-conductance sensing glove that converts level of skin conductance to the brightness of a glowing LED (Picard and Scheirer 2001). Skin conductance increases with many kinds of autonomic arousal, especially ramping up with novelty, significance, and stress. Hirstein's team (Hirstein *et al*. 2001) highlighted differences in skin conductance patterns among many people with autism. This glove can help wearers reflect on their personal response patterns.

FIGURE 1. Portable forms of affective sensors.

(iii) *StartleCam* is a wearable camera system that saves video based on a physiological response, such as your skin conductance arousal response, tagging the data with information about whether or not it was exciting to you (Healey and Picard 1998).
(iv) Affective state can also be inferred from the way we interact with and manipulate objects. An increase in physical pressure applied to a *pressure-sensitive mouse* has been shown to be associated with frustration, caused by poor usability in a computer interface (Qi *et al*. 2001; Qi and Picard 2002; Dennerlein *et al*. 2003).
(v) Location, proximity, audio and motion sensors signal socioaffective displays, such as dominance, excitement, and nonaggression, across populations (Pentland 2006).

More recent wearables that are made by industry include:

(i) The *SenseWear Pro2 armband* measures changes in energy expended, energy balance and weight loss using a heat-flux sensor, skin temperature, galvanic skin response, an accelerometer, and an electrocardiogram (ECG) sensor attached on the upper arm. Even though the armband is not specifically being marketed as an affective technology, it could be modified to detect and communicate affect variables to the wearer and to others, for example, monitoring and analyzing patterns of stress, frustration, and productivity.
(ii) *EmSense Corporation* is developing small, wearable sensors including dry ECGs that create a model of a user's emotions.
(iii) *Fraunhofer* has developed a research prototype glove that senses heartbeat, breathing rate, blood pressure, skin temperature and conductance, and an ECG shirt using conductive yarn and flexible electronics.
(iv) Goodwin's team used a *wireless heart rate monitor* (LifeShirt, Vivometrics, Inc., Ventura, CA) to monitor the cardiac responses of low-functioning persons with autism under repeated conditions of environmental stressors (Goodwin *et al*. 2006).

The above technologies are all at varying degrees of development and availability. But we can also speculate about other possible technologies that could become available, such as *swallowable pills* or *implantable sensors*, that analyze bodily fluids for hormones and neurotransmitter levels. For example, levels of dopamine act on voluntary movement and emotional arousal, producing effects, such as an increased heart rate and blood pressure; serotonin affects sleep and temperature. Drawing on research that links food, affect, and cognition to circadian rhythm (Wurtman and Danbrot 1988), affect-sensing swallowable pills would measure hormone and neurotransmitter levels and then send the measurements wirelessly to on-body portable devices. While neurotransmitter levels are currently not easy to sense without drawing saliva or blood or using other invasive procedures, and the data is not made available wirelessly, new implantable and swallowable sensors are already in progress, exploiting nanoscale technology.

As with any wearable system however, there are design issues. Wearable systems are certainly becoming smaller, but there are still issues with the number of wires flowing in and out of the sensors and with sensors slipping off. Battery power is a challenging issue too. Finally, sensors-on-the-go need to be robust to noise that arises from activity unrelated to the signal being measured. Heart rate, for example, can increase significantly with physical exertion or with sneezing, as well as with anger. Addressing these challenges is a prerequisite for the adoption of these wearable systems in everyday applications.

AFFECT RECOGNITION, LEARNING, AND GENERALIZATION

In her doctoral dissertation, Rana el Kaliouby (2005) developed a computational model of mindreading as a framework for machine perception and mental state recognition. This framework combines bottom-up vision-based processing of the face (e.g., a head nod or smile) with top-down predictions of mental state models (e.g., interest and confusion) to interpret the meaning underlying head and facial signals over time. The framework comprises multilevel, probabilistic architecture which mimics the hierarchical way with which people perceive facial and other human behavior (Zacks *et al*. 2001) and handles the uncertainty inherent in mindreading. The output probabilities represent a rich modality analogous to the information humans receive in everyday interaction through mindreading. FIGURE 2 shows the real-time output of the mindreading software showing different granularity of head gesture and facial analysis. The horizontal bars show the probability of various head gestures and facial expressions. The bottom line graphs show the probabilities of the mental states; the radial chart summarizes an interaction, showing the most likely mental states over time.

This model allows also multiple asynchronous sensors to be combined. One view of autism, the “weak central coherence” theory, emphasizes the importance of sensory integration. The theory contends that people with ASC process information at the local (rather than the Gestalt) level, often failing to integrate multiple sources of sensory information (Happé 1966; Frith 2003). If the primary deficit in autism is indeed one of integrating information at a global level, it is easy to imagine how theory of mind or empathy would suffer. This is because different affective modalities often complement each other, or substitute for each other when only partial input is available, or may contradict one another as in deception. Thus, compared with unimodal systems that assume a one-to-one mapping between an affective state and a modality, multimodal systems yield a more faithful representation of the relationship between mental states and external behavior. Our MIT group continues to develop novel approaches to combine multiple modalities, such as face and

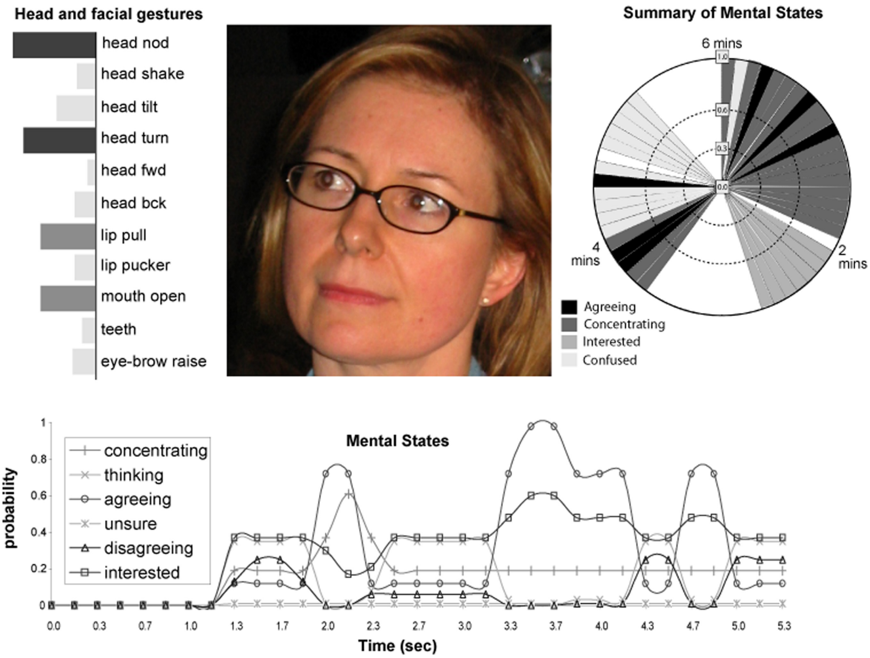

FIGURE 2. Real-time output of the mindreading software.

posture, to infer affective states, such the level of engagement (interest versus boredom), of learners (Kapoor *et al*. 2004, 2005).

Another challenge is generalization. Generalization is the capacity to apply knowledge from one context to new contexts. In autism, it is uncertain whether with existing interventions, individuals are able to successfully transfer the knowledge they acquire. Computers also have problems generalizing from the examples they were trained on, to the analysis of new unseen information. The field of machine learning is perpetually trying to improve the ability of computers to generalize. With the advent of more robots and agents that will interact with people, there is increased interest in enabling machines to learn better by learning from people in natural colearning situations, not just from people who "program" the computer or robot (Breazeal 2002). But such learning again requires socioemotional skills, such as the ability to see if the person teaching you is shaking their head and frowning.

As part of what we call the socioemotional intelligence prosthesis, we are exploring new kinds of systems that learn with people through natural interaction (el Kaliouby and Robinson 2005; el Kaliouby *et al*. 2006). The intelligent system we aim to build is a colearner with the person with ASC in trying to learn how to recognize and respond to socioemotional cues (Picard *et al*. 2004). One possibility for such a system is to exploit this common learning goal and perhaps play games with the individual, to assist him or her with continuously learning to generalize, occasionally bringing in non-ASC experts for corrective feedback and validation. The non-ASC person(s) could be present physically, or remotely connecting in through the technology, to help with the learning process. Social or emotion tagging, a situation where the parents and/or caregivers of a child with autism accompany the child and "tag" events with social labels, is a promising approach albeit expensive and impractical. Through the use of a head-mounted wearable camera/microphone, parents and caregivers could "eyejack" the child's visual field and tag the world remotely. This is both practical and cost-effective; it allows the child to be more independent, while continuing to enable parents and caregivers to share experiences with the child and help with learning.

TECHNOLOGIES THAT ENHANCE EMPATHIZING

Many persons with ASC prefer to communicate with and through computers because they are predictable and place some control on the otherwise chaotic social world (Moore *et al*. 2000). How can we harness their interest in technology to systemize the social world? For young children and those at the lower end of the autism spectrum, sociable robotics and dolls are a good approach to helping social interaction skills. The use of robots allows for a simplified, predictable, and reliable environment where the complexity of interaction can be controlled and gradually increased. It is also more realistic and engaging than interacting with a screen. The *Affective Social Quotient* project is one of the early projects at MIT Media Lab to develop assistive technologies for autism using physical input devices, namely four dolls (stuffed dwarfs), which appeared to be happy, angry, sad, or surprised (Blocher and Picard 2002). The system would play short digital videos that embody one of the four emotions, and then encourage the child to choose the dwarf that went with the appropriate emotion. When the child picked up the stuffed toy, the system identified its infrared signal and responded. Use of the dolls as physical input devices also encouraged development of joint attention and turn-taking skills, because typically another person was present during the session. Other robot platforms have been used for autism intervention, encouraging social behavior, such as turn-taking and shared attention (Dautenhahn *et al*. 2002; Scassellati 2005). Robotics may also be useful for individuals at the higher end of the autism spectrum, who would need help with the subtle, real-time social interactions. One can imagine a variation of LEGO—already known to be helpful as an intervention in autism (LeGoff 2004)—that combines rules and mechanics to allow for social explorations. Robotics could also be used by groups of children for improvisation, and directing play, encouraging turn-taking between children.

Affect sensing and affect recognition are technologies that are readily applicable to autism interventions. Affect sensing and recognition technologies can

FIGURE 3. The self-cam chest-mounted video camera.

help increase self-awareness, and provide novel ways for self-monitoring. One of the first problems we encountered when having a person wear a camera with software to interpret the facial expressions of a conversational partner was that the person with ASD might not even look at the face of the other person. Thus, the wearable camera might point at the floor or at a shirt pocket, or a nearby object instead of at the face that needs to be read. One possible solution is via a device, such as the *eye contact sensing glasses* (Vertegaal *et al*. 2001), wearable glasses that recognize when a user is in eye contact with another person. These glasses can be used to measure the magnitude and dynamics of eye contact in people with ASC. These patterns can then be compared to eye contact in people without ASC. It can also be used as an intervention to encourage people with ASC to pay more attention to the face.

In some cases there are privacy concerns with wearing a camera that records those around you. Out of such concerns, Alea Teeters in our lab developed the *self-cam* shown in FIGURE 3 (Teeters *et al*. 2006). Self-Cam is a small, lightweight video camera that is worn over the chest and points at one's face.

The camera is connected to a small portable handtop that is belt-mounted on the hip, and has a built-in microphone for recording audio. Facial expression analysis software on the handtop identifies head and facial gestures (e.g., head nod and smile) and mental states (e.g., agreement, confusion and interest). In the real-time mode, the camera tracks and analyses the mental state of its wearer in real time, and communicates these mental state inferences to the wearer visually or via audio clips and/or tactile vibration. Self-Cam only records the face of the wearer, which solves privacy problems related to filming other people in the environment without their consent. If more than one person is wearing the Self-Cam, this information can be exchanged between different wearers. Thus, Self-Cam is a fun way for people to explore social situations that are relevant to them (e.g., the faces of family and friends) without accidentally recording data from people who do not want to be recorded. It also avoids the problems mentioned above of having to make sure the camera sees a face, because self-cam is almost always pointed directly at the wearer's face.

In a forthcoming collaboration between MIT Media Lab and the Groden Center—a school and intervention center for autism based in Providence, Rhode Island—we will evaluate the scientific and clinical significance of using Self-Cam to improve the recognition of emotions from faces in young adults with AS and high-functioning autism. In the study, the person with ASC as well as the interaction partner (a teacher) will each wear a Self-Cam, so that neither participant feels singled out. Wearers will review the videos recorded during the sessions and interact with the computerized facial analysis software at their own pace. This will enable the wearer to associate emotion and mental state labels, and to review specific social situations in slow motion (because people with ASC often report that nonverbal cues, such as facial expression, are too subtle and quick to discern in real time). Parents, teachers, and clinicians may play the video back for the wearer and provide feedback (e.g., help identify facial expressions and pair them with emotion labels) and reinforcement. With such a system we can also explore the question of whether looking at one's own facial movements (while of course knowing what one is personally feeling) will enhance interest in looking at faces in general. If people with ASC can start to associate their own facial expressions with their own feelings, this might enhance their natural interest in other people's faces.

MOVING UP THE AUTISM SPECTRUM

According to the E-S theory of sex differences, there are at least three types of brain, derived from two orthogonal dimensions—empathizing and systemizing (Baron-Cohen 2002), diagrammed in FIGURE 4 (numbers are standard deviations from the mean). The first is characterized by systemizing being stronger than empathizing, a profile more common in males. The second type has the profile of systemizing and empathizing being balanced. The third

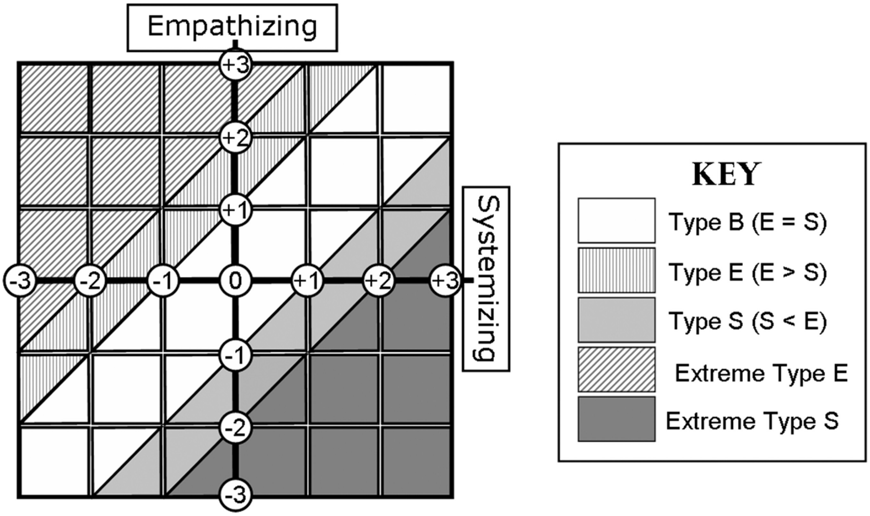

FIGURE 4. The main brain types.

involves empathizing being stronger than systemizing, a profile more common in females. Autism appears to correspond to an extreme of the male brain, with systemizing being intact or above average, alongside empathizing being impaired (Baron-Cohen 2006). One of the interesting aspects of this theory is that the brain types are continuous, blending seamlessly with normality. That is, we are all situated somewhere on the same continuum, and one's position on the continuum reflects a different cognitive style and inclination toward systemizing or empathizing. An important implication of this dimensional model is that the line between ability and disability is blurred. This view of autism as a different kind of mind is shared among an increasing number of individuals with autism and families (DANDA 2003), and is dubbed the neurodiversity model of autism.[1]

One's empathizing skills while in part genetically predisposed (Skuse 1997) and in part influenced by prenatal testosterone (Chapman *et al.* in press) are not fixed. Empathizing may vary as a function of the person's early experience (Bowlby 1982), current affective state, and the surrounding context. One factor that may improve or impede our ability to empathize is stress and anxiety. We have explored several approaches to measuring stress using physiological sensors, heart rate, pedometer, accelerometer, context beacons, and location (Picard and Du 2002; Healey and Picard 2005); other physical symptoms include blood pressure, muscle tension, and sleep problems. Affective state may also affect the ability to empathize. For instance, when angry, one's current emotional state might cloud the ability to see another person's perspective.

[1] http://www.neurodiversity.com.

Similarly, a person who is preoccupied may fail to notice the nonverbal cues of others, misreading their mental state.

The technologies that improve empathizing in autism should in theory also contribute to improvements in these skills in the general population. As Malcolm Gladwell shows in *Blink*, a person's knowledge base of people intuition can be broadened, affecting one's ability to make accurate snap judgments (Gladwell 2003). Technology may augment people's capacity to empathize and improve their people intuition (whether or not they are diagnosed with autism) in at least three ways: increased self-awareness, improved communication with others, and better social learning. For instance, a wearable system that continuously measures stress or anxiety signals can help the wearer regulate arousal, raising self-awareness and encouraging people to switch perspectives under conditions of high arousal. Another application is a personal anger management wearable system that would detect states, such as anger, and attempt to calm the wearer, perhaps even through empathizing verbally with the wearer (Klein *et al*. 2002). Technologies that sense various aspects of the person's affective and physiological state can be used for self-monitoring. Making this knowledge available in a simplified and easy to visualize manner is a good motivational factor to change habits. (It has been shown for instance, that daily self-weighing is a strong motivational factor for losing weight).

This information about oneself could also be selectively communicated to others to enhance group communication. An example is the *Communicator system* (Rubin *et al*. 2003) that uses a combination of nano/info technologies that allow individuals to carry with them electronically stored information about themselves, such as interests, background, and affective state, that can be broadcasted as needed in group situations. Participants would have the ability to define or restrict the kinds of information about themselves that they would be willing to share with other members of the group.

ETHICAL CONSIDERATIONS

Along with the potential benefits, we recognize that there are important ethical considerations that arise with the development of these technologies. An exhaustive discussion of these ethical considerations is beyond the scope of this article; instead, we will suffice with a few examples that highlight the importance of being sensitive to the needs of the end-users of this technology, be they autism researchers and practitioners, or individuals diagnosed with autism and their families.

Besides the privacy issues of sensing and broadcasting affective state information (Reynolds and Picard 2004), one issue to consider is whether individuals with autism need treatment or technology "fixes" at all. We agree that ASC involve a different cognitive style, allowing many individuals with autism to focus deeply on a given subject, which can lead to original thought.

We thus prefer to design technologies that do not try to "fix" people, but rather that can be used by individuals to augment or further develop their natural abilities. If these new technologies hold the promise of improving empathy, this should only be undertaken with the individual's consent, where it is possible to obtain it, or with their parent's consent in the case of a young child. Unlike medical interventions where there is a risk of unwanted side effects, affective computing based interventions may have highly specific effects (on empathy) while leaving other domains (e.g., systemizing) unaffected. We adopt a user-centered design and development approach to ensure that individuals with autism and their caregivers are involved in the development phases of intervention technologies that they need the most.

Another ethical consideration is whether exposing affective state information creates opportunities for others to manipulate one's behavior and thoughts using this information (see Reynolds (2005) for examples). Even in situations where the use of technology is honest, there are still potential concerns. If an individual with autism wears an assistive system that senses the affective state of others, then this would raise the expectations of interaction partners, increasing (rather than decreasing) the social pressures on the person with autism to respond to these cues in real time. Such a system might be more burdensome than helpful. It is essential that researchers address these considerations and explore the potential opportunities brought by a convergence in autism research and affective computing with open-mindedness about the possible successes or failures of such an approach.

CONCLUSION

This article highlights several opportunities for convergence between affective computing and autism, and presents some progress in that direction. The Department of Health and Human Services has called for new approaches that improve real-world functioning of individuals with autism, throughout their school-age years and beyond (Department of Health and Human Services 2004). The Cure Autism Now's Innovative Technology for Autism Initiative, intended to create a merger of technology with other fields, is yielding an interdisciplinary approach to the challenge of utilizing technology to improve the lives of people with autism (Cure Autism Now 2006). Industry funding too is on the rise. For instance, Motorola funded the "mood phone," a phone designed to interpret the mood of the person on the other end of the line, that is meant to help people with AS who are unable to recognize emotional cues in the speech of others.

In summary, this article presents affect sensing and recognition as core technologies, and describes their application as assistive and learning devices for individuals with autism. The opportunities for benefit are two way: helping people with autism, and helping technologies to be smarter about socioemotional interaction. People with autism, especially those who have developed solutions to systematize and understand social interaction can help technologists with their efforts to build systems that do exactly that. The opportunities are rich for two-way collaboration in technology-enhanced human interaction.

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