Physiological Signals of Autistic Children Can be Useful

Karla Conn Welch

Using physiological measurements such as those from a person's heart rate, skin conductance, muscle contractions, and blink rates to study stress, engagement, and similar mental and emotional states has a rich history and a bright future. Research has shown that physiological signals can be evoked by different amounts of presence, the extent to which a user perceives an experience as real, in stressful environments. In general, it is expected that higher physiological activity levels will be associated with greater stress levels.

Individuals with autism are characterized as having difficulties with social interaction and communication and a tendency to fixate on limited interests and repetitive behaviors. The symptoms can range from mild to severe in degree, which is why autism is generally described as autism spectrum disorders, or ASD. Also, there are many challenges that come with living with an autistic person and for the person with autism. Monitoring physiological signals as indicators of affect can provide objective feedback about an important part of social interaction – understanding emotional cues.

This article covers the latest research concerning the measurement of physiological signals of children with autism, particularly for the study of changing emotions in various environments. Answers to important questions regarding autistic children's physiological activity are examined, and we will see that within a non-social environment, physiological responses are the same between children with and without autism but different in environments with social contexts. Moreover, physiological signals can be used as a reliable indicator of emotions of children with autism. Also covered are the latest developments in wearable sensor technologies available for measuring on-the-go. I review additional research that identifies body signals in response to stimuli and may help explain core social deficits in children with autism.

Physiological Signals

Physiological signals have been studied for decades in psychophysiology as a way to help explain human behavior, and many physiological signals are available for measurement. Electroencephalogram (EEG) analysis is an extensive research avenue related to understanding the inner working of the human mind. Muscle contractions (particularly of the face) and eye gaze activity along with changes in pupil diameter all have been studied for their insights into a person's thoughts, feelings, underlying motivations, attitudes, or intentions (i.e., a person's affective response). An interesting application of these signals is in affective computing research, an emerging area of research pioneered by Dr. Rosalind Picard that combines the detection of affective responses and artificial intelligence for improved human-machine interaction. For a general guide, [1] is a contemporary overview of physiological measuring methodologies and a detailed reference on best practices for psychophysiological experiments.

This paper briefly discusses three popular signals: galvanic skin response, heart rate, and body temperature. These have good potential for being streamlined into wearable devices embedded within clothing for possible long-term monitoring beyond lab settings. Galvanic skin response (GSR), also known as skin conductance, is a commonly measured signal when observing emotional responses. Fig. 1 shows GSR sensors from BIOPAC Systems, Inc. [2]. The sensors are usually

Fig. 1. The circular cavities of these GSR sensors from BIOPAC are filled with an electrode paste to aid in signal measurement.

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positioned on the fingertips of a participant's non-dominant hand, and the Velcro strap wraps around the finger to secure it in place. Any two of the pointer, middle, or ring fingers are acceptable. Although the fingertips generally produce strong readings, applicable locations for GSR measurement also include the middle phalanges (non-knuckle bone segments of fingers) of the pointer, the middle, or the ring finger; the palm of the hand; the inside of the wrist; and even the toes and the soles of the feet.

Heart rate data can also be collected from a sensor placed on a fingertip. When using a photoplethysmograph (PPG) to monitor the changes in light absorption in the skin of a fingertip, pulse information can be extracted. Skin temperature can be collected from multiple locations such as the fingertip, wrist, or even the nose. Decisions on sensor placement depend heavily on the activity in which a participant will be engaging and their personal tolerance level. For example, placing sensors on a participant's non-dominant hand makes for easy attachment, is usually comfortable during an activity, and frees up the dominant hand for interaction (Fig. 2).

Comparison between Children with and without Autism

Monitoring physiological signals is a way to measure emotional information that may not be apparent. Children with ASD often react outwardly in ways unlike developmentally typical children, so tailoring the measurement and interpretation of physiological signals to children with autism is necessary. For example, children with ASD might smile when they are actually in pain. They might show no expression or a neutral expression when they are enjoying an activity.

Inwardly, reactions of children with ASD may or may not be similar to typical children. Ten children with and ten without ASD were paired by age and found to have a similar GSR response for non-facial stimuli [3]. These responses were co-varyed for differences in performance IQ and verbal IQ. Other work showed that GSR responses were different in thirteen pairs of age, gender, and verbal IQ-matched children with and without ASD [4], where stimuli included examples of virtual human characters in a virtual reality environment that was

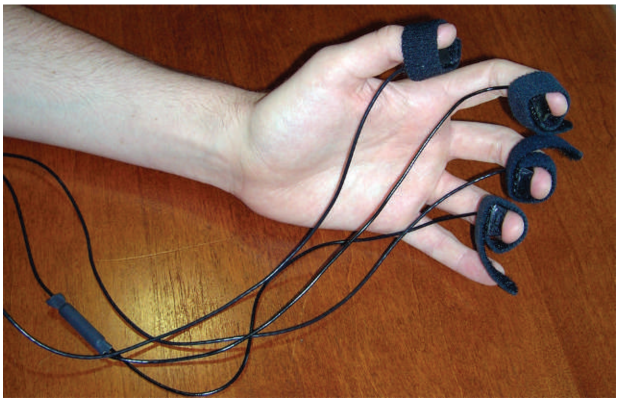

Fig. 2. Tethered sensors from BIOPAC collect pulse, conductance, and temperature information from a participant's fingers.

Fig. 3. A participant watching the virtual reality program.

presented on a computer monitor to tell a story (Fig. 3). The faces of the animated characters were created from front and side 2D photographs. Dr. Jeremy Bailenson, director of the Virtual Human Interaction Lab at Stanford University, formed the photos into 3D heads for use in virtual reality environments. As opposed to simplified cartoonish features, the authentic facial features captured in the photos (e.g., variations in skin complexion, brow line, nose dimensions, etc.) may have contributed to the interaction with the virtual characters being interpreted as realistically as possible within a virtual setting.

The virtual environment also allowed for highly-malleable stimuli versus less-controllable video or human actors. Both groups had a significant increase in GSR between low-anxiety situations (e.g., when faces were a comfortable distance away from the screen and the character used an averted eye gaze while delivering a first-person story) versus high-anxiety situations (e.g., when faces were close to the screen and the character used direct eye contact for the duration of the story). However, the ASD group's responses showed significantly higher GSR responses in both situations. The human face seems to have stimulated an exaggerated response from the ASD group compared to the typical group, and this response was elevated when the anxiety-inducing parameter was increased (e.g., enlarging the human face to simulate closer proximity).

Verbal reports from children with ASD have been shown in cases to be inconsistent with physiological recordings and presented stimuli, which may be evidence to not completely trust self-reports when answering questions about emotions [3]. Conversely, physiological measurements may be an objective and accurate alternative source of information related to emotional reactions. Reports from parents and autism clinicians have been found to be more consistent with changes in physiological recordings and changes in stimuli and are the current state of the art for indicating emotional changes during autism interventions.

Challenges in Understanding Emotional States

In addition to helping researchers and other people understand the emotional state of children with ASD, the measurement of physiological signals might help children with ASD understand their own emotions better. Although children with ASD may react differently to certain environments (e.g., a markedly negative reaction to eye contact when children without ASD may have no reaction or even a positive reaction as a sign of interest *or* a more negative reaction to an invasion of personal space than typical children have [4]), the measured signal can be used as part of a feedback system for children with ASD to explain what emotions they are feeling.

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A prevailing intervention focus is having children with ASD accurately describe their individual emotions or the emotions of others. Current techniques include matching emotions to pictures (e.g., match an index card with the word "angry" to someone with a furrowed brow and crossed arms) and having children with ASD practice appropriate facial expressions (e.g., practice smiling as an example of what to do when you are happy). The technologies are not yet available for implementation in an ASD intervention, but imagine the impact of an emotion-monitoring system that includes physiological sensors and a way to interface with the user or other people via a robot, virtual characters, or a smartphone application.

Producing a real-time affect-sensitive system to relay messages based on physiology-monitoring sensors would make a significant impact on ASD intervention. Such a system could be an assistant to a therapist, caregiver, or child by monitoring the physiological signals of the child and reporting predictions about the change in emotion of the child based on an individual model. The information gathered could produce individual feedback (e.g., a message alerting you or others that the sensors detect you are stressed and suggest you do some relaxation exercises).

The system could become a knowledgeable, objective consultant to therapists and caregivers so they can compare their own interpretations of the child's emotion. It also could become an alert system to the children with ASD so they can learn when to appropriately use the facial expressions they have practiced. If wearable sensors were used by the people around the children, general readings within the Bluetooth transfer range could be reported. For example, while waiting in line at a grocery store, a summary could be displayed on a smartphone that says 80% of the people in the area are also angry because of the wait. General readings of the public are a far-reaching goal but are made more possible with increases in the acceptability of wearable technology. Therefore, this objective feedback from physiology-monitoring sensors might enable children with ASD to make strides towards recognizing and understanding their emotions and possibly those of others.

Although the potential for physiological signals to aid individuals with ASD has been established, this type of research needs to be further explored. How much of an impact monitoring these signals could have on the lives people dealing with ASD has yet to be confirmed.

Although physiological signals can paint a detailed picture of a typical person's reaction to a life experience, these signals are notably informative for the ASD population. For example, children with ASD have difficulties dealing with unstructured time, such as waiting in line, and often become frustrated in these situations. If these signals could be monitored in a group and given as feedback to those around them, an individual with ASD might be eased by the information that others around him or her are also frustrated, information that typical individuals can pick up and use to calm themselves, but have an easier time interpreting the ever present cues than do individuals with ASD. Humans adapt their interactions with one another based on subtle cues from changes in facial muscles, eye gaze, or body posture. These interpretations are more likely to be correct between people without deficits in social processing.

For individuals with ASD, the deficits work both ways. Outwardly, these children do not express affective responses in a similar way to individuals without ASD, possibly due to a lack of understanding of their emotions as well as how to express them in a typically decipherable manner. Inwardly, they have difficulty decoding the cues coming from others around them, eventually leading to social misinterpretations such as poor choices of appropriate conversation topics or inappropriate times to change subjects.

Physiological Signals in Decision Making

I was part of a research group that developed a system that modeled an individual's affective response and used it in an interaction between the individual and a robot to promote a learning environment which bolstered positive feelings. During

Fig. 4. The robotic arm that was used in the study.

the interaction, the individual's physiological signals were measured, and the model made decisions about how to appropriately react to those signals [5]. The reaction came from a robotic arm that moved a toy-sized basketball hoop which was attached to its end effector (Fig. 4). The robotic arm was programmed with the individual's physiological models and the affective responses of a child with ASD and reacted in real-time to the child.

The affect-sensitive robot produced a much improved interaction compared to an interaction with a non-affect-sensitive robot; the children enjoyed the game more than they did in a random presentation of difficulty levels during game-play. The results are promising for the small group of children studied. The robotic system is programmed to emulate a clinician's decision-making process for evaluating emotions of children with autism. The autonomous robot's prediction of the child's emotional state (enjoyment vs. dislike) closely matched the clinician's report on emotion for all six participants. This initial finding needs to be supported with further research with a larger group of participants, and interactions with additional social content need to be examined as well.

When designing a more-mobile activity than sitting at a computer or watching images on a screen, researchers must be cautious that the physical activity does not significantly impact the recordings.

Selecting Effective Interventions

Physiological signals have potential to be an important part of screening processes when choosing the best intervention method because they can be an indicator of future performance for children with ASD. Reference [6] showed that young children with ASD have less ability to adapt and regulate vagal activity (i.e., heart-related physiological signals) during challenging social stimuli. This lesser ability to respond was a sound predictor of future impaired social-communication outcomes as compared to other children with ASD who showed better ability to receive cues from and adapt vagal activity to inciting social situations. This phenomenon was linked to later performance of expressive language and social-communication adaptive skills [6].

This evidence could support a physiology-based screening for individuals with ASD when selecting effective interventions that can leverage social or non-social approaches depending on the physiological profile of the child. Children with physiological signals indicative of an ability to control heart activity when presented with social stimuli could benefit more from socially-based interventions, whereas children who show difficulties regulating heart signals may respond better to non-social intervention strategies. Each intervention method can be beneficial for children, although tailoring treatment methods to an individual's needs and learning style will have the most impact on skill learning. Therefore, physiological signals could be very useful as part of a screening process. Such a screening could be streamlined by utilizing the power of microprocessors to perform signal processing routines quickly and reliably. This process could better inform clinicians and caregivers about projected future success rates when choosing between relevant treatment options.

Sensor Technologies

Hardware and software packages from BIOPAC Systems, Inc. [2] and Thought Technology, Ltd. [7] are widely used, although in-house designed devices are on the rise in research labs. For example, Picard created a wristband with embedded GSR sensors and specifically targeted individuals with ASD as potential users [8].

Wires between the sensors and data collection units remain an issue but not in the way most commonly thought. A frequently-asked question is how well wires are tolerated by users during psychophysiological studies, because the initial thought is that they will be excessively cumbersome. However, the wires are not a significant problem to most lab-based experiments, which is where the majority of studies take place because of the high level of controllability. In all of the studies I have conducted, the children with ASD are more interested in the activity that makes up the experiment and do not react to the sensors in any way that prohibits good data collection.

An argument can be made that wires are a problem, especially when studies seek to go beyond the lab or take on mobile activities. Some systems advertised as "wireless" still include wires from the sensor to a battery pack and data transmitter device. Such systems would suffer from any problem associated with wires, such as tolerance of wearable technology, but would have more mobile capacity than completely tethered systems. However, transmitters and data storage units for multiple signals can be up to the size of netbook computers and must be worn on the body. The distance to a receiver unit can also be limited. Long-range transfer of data in real-time has yet to be established, although advances are being made.

The main benefit of moving toward wireless sensors for data collection and storage is mobility of the activity. The addition of mobility opens up the realm of possible activities to explore. Now, instead of navigating around a room in virtual reality, a child can walk around a physical room while signals are being recorded. Such benefits still come with cautionary tales. When designing a more-mobile activity than sitting at a computer or watching images on a screen, researchers must be cautious that the physical activity does not significantly impact the recordings.

Through continued work, Picard developed the Q Sensor (www.affectiva.com), a completely wireless wristband version of a GSR sensor that also measures movement and temperature. No wires are necessary to connect the sensors to a separate data logger while data is being collected. Data from the Q Sensor can be recorded during daily activities for later download and annotation. An improvement would be a means to annotate in-the-moment for time-syncing and increased accuracy of recalled events and feelings, perhaps through a smartphone app. Therefore, more development and research needs to be conducted to make wireless devices mainstream, but the current status is encouraging.

Summary

Physiological signals can aid in improving social interactions and interpretations that even typical individuals sometimes have difficulty navigating successfully. (Insert your most cringe-worthy anecdote of a time you put your foot in your mouth here.) Add to social situations a population that has performance-impairing difficulties interpreting these situations, and you will see how these signals could be vital feedback about what the individual with ASD is feeling and what others around him or her are feeling. Therefore, measuring physiological signals can help all individuals better understand the emotional world around them, and this insight could be especially informative for anyone challenged with accurately understanding affective information, like the ASD population. We will always be social creatures, so emotionally-informative technology might play a pivotal role in our next cultural evolution.

References

[1] J. T. Cacioppo, L. G. Tassinary, and G. G. Berntson, *Handbook of Psychophysiology*, 3rd edition. New York: Cambridge University Press, 2007.

[2] "MP Systems: Sophisticated solutions for data acquisition and analysis," BIOPAC Systems, Inc., (2011). [Online] Available: http://www.biopac.com/Research.asp.

[3] D. Ben Shalom, S. H. Mostofsky, R. L. Hazlett, M. C. Goldberg, R. L. Landa, Y. Faran, D. R. McLeod, and R. Hoehn-Saric, "Normal physiological emotions but differences in expression of conscious feelings in children with high-functioning autism," *Journal of Autism and Developmental Disorders*, vol. 36, pp. 395-400, 2006.

[4] K. C. Welch, U. Lahiri, C. Liu, R. Weller, N. Sarkar, and Z. Warren, "An affect-sensitive social interaction paradigm utilizing virtual reality environments for autism intervention," In: J. A. Jacko (Ed.): *Human-Computer Interaction, Part III*, HCII 2009, LNCS 5612, pp. 703-712, Berlin/Heidelberg: Springer-Verlag, 2009.

[5] C. Liu, K. Conn, N. Sarkar, and W. Stone, "Online affect detection and robot behavior adaptation for intervention of children with autism," *IEEE Trans. Robotics*, vol. 24, pp. 883-896, 2008.

[6] L. R. Watson, G. T. Baranek, J. E. Roberts, F. J. David, and T. Y. Perryman, "Behavioral and physiological responses to child-directed speech as predictors of communication outcomes in children with autism spectrum disorders," *Journal of Speech, Language, and Hearing Research*, vol. 53, pp.1052-1064, 2010.

[7] "Hardware and Software Overview," Thought Technology, Ltd., (2011). [Online] Available: http://thoughttechnology.com/overview.htm.

[8] R. W. Picard, "Future affective technology for autism and emotion communication," *Philosophical Transactions of the Royal Society B: Biological Sciences*, vol. 364, pp. 3575-3584, 2009.

Karla Conn Welch (karla.welch@louisville.edu) is an Assistant Professor in the Electrical and Computer Engineering Department at the University of Louisville. Her research lab explores physiological signal processing, machine learning, and human-machine interaction for individuals with and without autism. She is a member of IEEE and the International Society for Autism Research (INSAR).

For additional information and technical details, see our sister publication, the *IEEE Transactions on Instrumentation and Measurement*:

R. Luharuka, R. X. Gao, and S. Krishnamurty, "Design and realization of a portable data logger for physiological sensing," *IEEE Trans. Instrum. Meas.*, vol. 52, no. 4, pp. 1289-1295, Aug., 2003.

O. A. Postolache, P. M. B. Silva Girao, J. Mendes, E. C. Pinheiro, and G. Postolache, "Physiological parameters measurement based on wheelchair embedded sensors and advanced signal processing," *IEEE Trans. Instrum. Meas.*, vol. 59, no. 10, pp. 2564-2574, Oct., 2010.