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AUTISM

THE MOVEMENT-SENSING PERSPECTIVE

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FRONTIERS IN NEUROSCIENCE

4 Dissecting a Social Encounter from Three Different Perspectives

Elizabeth B. Torres

CONTENTS

Chapter 2 closed with the question, is it time for a new model of autism spectrum disorder (ASD)? The psychological and psychiatric constructs defining ASD today describe issues with social interactions in very narrow ways. The methods of inquiry about social and cognitive issues are more an art than a science. They have turned into a stumbling block in scientific advancement, preventing progress toward the discovery of possible causes linking early sensory-motor issues in neurodevelopment with differences in social exchange that emerge later in life. This chapter uses a seemingly simple social encounter to illustrate how, by adopting different perspectives, one can better appreciate and objectively quantify the complexity of the social dyad. Using the hypothetical accounts of a behaviorist, a physiologist, and a computational neuroscientist as they each describe the same encounter, we show that indeed there is more than meets the eye.

INTRODUCTION

Our physical bodies are in constant motion from conception. Even when we are seemingly at rest, our heart is beating, our lungs breathing, and our physiological systems are processing all sorts of electrochemical reactions involving, among other measurable biophysical processes, the transduction and transmission of information across many layers of our nervous systems. And yet, at rest all these motions occur largely without our awareness. We do not see them, and as such, we do not describe them as part of our movements; we do not associate them with what we more generally call behavior. The continuous stream of minute fluctuations in our subtle inner motions, together with our overt actions, may have a profound impact on how we behave, socially or otherwise. Certainly, if you have a stomachache caused by a bad chemical reaction from some spoiled food you ate, you would not be talking about poetry or concocting some clever joke to amuse a crowd of friends. Most likely, you just rather be left alone until it passes.

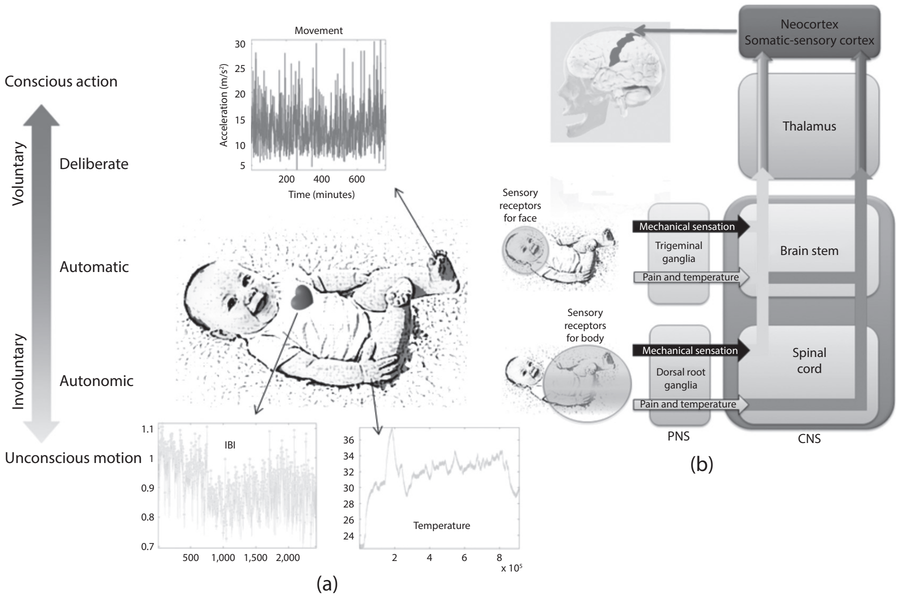

FIGURE 4.1 Extraction of micromovements is possible across different biophysical signals from physiological states registered in different body parts using wearable sensors. (a) Taxonomy of control levels involving different layers of micromovements mapping to different stochastic signatures. (b) Division of labor from early infancy during neurodevelopment impact different somatic motor networks in the face- and body-relevant dimensions of the social axes. (Reproduced with permission from Torres, E. B. et al., *Front. Pediatr.* 4:121, 2016.)

It must be terrible to not have that option, for example, as when having the physiology of your nervous systems in some continuous state of disarray that confines you to a lonesome existence in such a way you do not even realize, while others around you—perhaps unintentionally—interpret it as your being "antisocial" or having "low empathy." Conceivably, if they knew of your actual physiological state of disarray, they would try to assist you. But how would they know that your physiological systems are out of whack? They cannot see that in any way, unless they wore some kind of "special glasses" allowing them to see beyond what their naked eyes can naturally capture.

The minute fluctuations that occur in the motions that are sensed throughout the nervous systems can be measured with contemporary instrumentation and provide new lenses into subtle nervous systems' phenomena. We have coined the waveform representing these fluctuations in biophysical rhythms *micromovements* (Figure 4.1 and refer back to Chapter 1), as we extract them from bodily and mental rhythms and turn them into quantifiable data output by the nervous systems of the person. Paired with proper analytics, the micromovements can provide a new kind of special glasses to see beyond the obvious and inform us of central nervous system (CNS) and peripheral nervous system (PNS) interactions. To illustrate their use, let us first walk through a simple social situation as described by different (hypothetical) researchers, and then examine some social dyadic interactions using the micromovement perspective.

DISSECTING A SOCIAL ENCOUNTER THROUGH THE EYES OF DIFFERENT RESEARCH AREAS

Let us attempt to deconstruct the social encounter depicted in Figure 4.2. The encounter in question takes place between two people who may have seen each other once before. Through the length of time they sustain eye contact as they approach each other, they may admit to each other recalling their first fortuitous encounter sometime in the past, or they may right there and then decide to

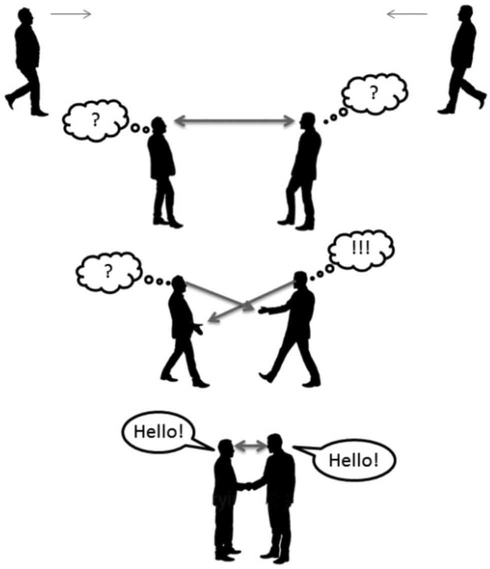

FIGURE 4.2 Genesis of a brief social encounter. Two fellows walking toward each other recognize their acquaintance from the distance and try to discern whether the other person is willing to admit to this mutual memory and engage in a brief social exchange, like a salutation and small talk. Body language involving sustained eye contact and facial microexpressions, including a smile, may give away the mutual willingness to stop, shake hands, and say hello. Alternatively, even a brief gesture like turning the body away from the interlocutor's body midline and avoiding eye contact, perhaps accompanied by spontaneous (flat) facial microexpressions denoting an unwillingness to engage, will determine the fate of this brief encounter.

make the eye contact so brief that there is no ambiguity in their unwillingness to proceed with a social exchange. Notice here that this is a deliberate decision, rather than a spontaneously occurring event.

If their eye contact was sustained long enough to go on with the social exchange, they may further provide mutual evidence for their willingness to proceed by orienting their body toward each other and extending their hands to prompt a handshake—we will safely assume here that this is an acceptable social form of salutation in the culture where these two individuals developed. And finally, they will execute the handshake and say hello to each other, perhaps going on to initiate some social chat.

This is a very hypothetical situation. We shall dissect that social encounter using the lens of a researcher whose area of expertise has to do with social behaviors, another researcher whose area of expertise focuses on the physiology of the nervous systems underlying that social behavior, and yet another view through the lens of a researcher whose area of expertise is modeling the types of sensory-motor integration processes and sensory-motor transformations that may underlie that social behavior through the use of mathematical and computational tools.

Finally, let us examine examples of dyadic social interactions using a research program that integrates all three accounts through an interdisciplinary collaborative approach.

BEHAVIORIST ACCOUNT FROM A PSYCHOLOGICAL PERSPECTIVE

To study this seemingly simple social exchange, the behavioral psychologist will most likely draw a discrete set of events and assign a discrete (ordinal) scale to each event unambiguously detected by the naked eye. The account may go as follows (for example): (1) eye contact, (2) smile, (3) handshake, (4) word exchange ("Hello!"), and (5) initiate chat. Each one of these five events may have a subscale, say from 1 to 10, with 1 signifying poor and 10 excellent, and some other considerations in between. The researcher will go on and collect data on each of these events (1–5) according to each of the numbers coded by hand to “quantify” the overall behavior. The behaviorist may then use traditional statistical tools and analyze the cross-sectional data by averaging scores across large numbers of subjects. This will build a normative data set with the potential to help identify atypical patterns in the future based on what is “normally” expected in such a social encounter (as defined by the inventory). Examples of such approaches abound in the fields of clinical psychology and psychiatry. In fact, these types of structured inventories are commonly used to gather criteria to diagnose disorders that involve social deficits as mental illnesses, as well as to treat them through behavior-reshaping methods or prescribed psychotropic medications (Lord et al. 1989, 2001; Lord et al.; American Psychiatric Association 2013). Notably, none of these clinical inventories ever characterized normative data, so they feature absolute ordinal values of some arbitrary scale. As such, they are not properly standardized.

Physiologist Account

The physiologist will set up high-grade instrumentation using a variety of sensors to register signals throughout the nervous systems. Today’s technological advances allow for noninvasive methods of data registration. Using contemporary (e.g., wireless) instrumentation, the physiologist will attempt to continuously register every detail of this exchange. She may track the eye motions to assess the length of time on a millisecond timescale that person-to-person foveation was sustained, quantify the saccades and the smooth pursuit eye motions throughout the exchange, and record (for example) heat activity from the facial muscles using thermal cameras strategically positioned to capture various facial configurations and detect universal signatures describing microexpressions of the face (Ekman and Rosenberg 1997). Then these data will be used to automatically infer possible emotional states. The physiologist may also record neck motions (perhaps with wearable inertial measurement units and wearable electromyographic sensors). Neck position and orientation will reveal trajectories of the head in the body, and eye tracking technology will reveal the position and orientation of the eyes in the head. This information will enable assessment of the system’s use of different frames of references during sensory-motor transformations required in simple goal-directed saccades and hand motions. Simultaneously, bodily rhythms from all movable joints will also provide important information from each individual in the dyad and from their interactions as the multiple degrees of freedom in both participants coarticulate and the synergies dynamically fall in and out of synchrony. As the bodily rhythms fluctuate, so do the speech rhythms that the physiologist can record with a microphone.

The speech, generated by the sensory-motor apparatus from orofacial structures, will provide a rich body of data to—in concert with the face data—further help assess emotional components of the encounter. Likewise, sensors coregistering electrocardiograms and electrodermal activity (EDA) will provide several layers of data to assess inter-beat-interval time variability and to help estimate sympathetic and parasympathetic states of the autonomic nervous systems, along with skin surface temperature, respiration patterns, and other physiological signals.

This formidable amount of data will then be analyzed under a variety of statistical frameworks, machine learning and pattern recognition algorithms that will permit the physiologist to unveil easy-to-interpret self-emerging patterns. Such patterns will have statistical power because very likely the sensors have high sampling resolution and collect a large number of measurements for each motion parameter of the eyes, face, speech, neck, head, body, and limbs. To help the interpretation of the results, it is very likely that the physiologist will aim at mapping functional outcomes to anatomical structures along the nervous systems. This will help her situate the results in relation to known neuroscientific principles and add new information to that body of knowledge. As the behaviorist, the physiologist will try and collect all the data in neurotypical individuals in order to create a normative set to reference atypical patterns to. This concert of multi-sensory-motor data will provide the underpinnings of the behaviorist’s account and further reveal information that escapes the naked eye. At a glance, the account of the social encounter by the physiologist seeks different layers of understanding from that of the behaviorist. Yet they are not at odds. They just study phenomena using different lenses and as such can provide different levels of description and interpretation. Without a doubt, both accounts are important, but to understand the underlying neurophysiology of the social encounter, the behavioral psychologist account falls rather short.

COMPUTATIONAL NEUROSCIENTIST ACCOUNT

The behaviorist's approach affords many possible interpretations and open-ended questions about this social encounter. It serves as a brainstorming phase of a research project, perhaps to begin formulating high-level questions about possible principles ultimately governing the encounter, with the caveat of never considering some of the phenomena that take place beneath awareness. The physiologist's approach, however, can provide the type of data conducive of objective criteria to complement, help verify, or expand the hypotheses that the behaviorist may formulate solely based on the obvious phenomena one can consciously perceive. Arguably, the above-described behaviorist's approach is often handcrafted to accommodate a priori defined criteria conforming to socioeconomic constraints. In the context of autism, these may include the availability of treatments (e.g., early intervention programs in the United States) or criteria for insurance coverage of prescribed psychotropic medications (also in the United States). The physiologist's approach can instead be centered on the patient to help provide outcome measures of physiological performance, so as to track the effectiveness or risk of treatments on the nervous systems of the patient, but also to help science develop new ways to uncover principles of the nervous systems' functions.

There is a third set of criteria to help dissect the social encounter in Figure 4.2. This involves that of a computational researcher. Here the goal is to go beyond hypothetical guesses or massive data gathering so as to analytically simulate aspects of the behavior potentially present in the encounter. The modeler will be able to obtain, via computer simulations, theoretical bounds on the data parameters empirically generated by the behaviors taking place during the social encounter. Once the simulations and boundary conditions are determined, the computational researcher can empirically verify parameter values from sensors directly measuring nervous systems' outputs that fall within typical or atypical ranges.

These analytical simulations will make predictions that the computational researcher will try to empirically challenge so as to be able to modify the model and make it as biologically plausible as possible. For example, visual processing by individual A of the approaching individual B is very complex to model, but current computational models of motion perception and motion recognition can be used to predict whether the motion is biological (Lange and Lappe 2006), as well as to predict the time to contact between the two approaching individuals (Lee 1980). Further, the modeler will have to address differences between biological motions of humans and nonhumans in order to flag that the encounter about to occur is likely to be with another person.

To assess the identity of the approaching individual B, the modeler will have to design the study of the processes following the above-mentioned highly complex visual recognition task. This will also include facial recognition and recognition of emotional states (Zhong et al. 2015). As individual B approaches observer A, a series of distance-based estimation will have to take place to assess the unfolding dynamics of motion and the time to close the gap of the encounter (Lee et al. 1999, 2001). These estimations will be required to transform the external retinotopic-based signals into internal kinesthetically based representations (Zipser and Andersen 1988; Torres and Zipser 2002). Such transformations from sensory to motor sensing coordinates will enable individual A to discern (1) the speed of the approaching person B, (2) an estimation of the awareness of the approaching person B about observer A, and (3) an estimation of the willingness of the approaching person B to facilitate or halt the encounter.

Models of facial recognition and recognition of emotional content in facial expressions (Ekman 2007) will necessarily have to be combined with models of foveation (Itti et al. 2005) and saccadic (Robinson 1973; Sparks and Mays 1990; Ron et al. 1994; Sparks 2002) and eye pursuit (Lisberger et al. 1987) motions so as to assess the likelihood that individual B will want to engage in a brief salutation. Assessment of that willingness entails probabilistic models to make predictions and gain confirmation of those predictions with variable degrees of certainty (Friston 2012a, 2012b). Most likely, they will entail Bayesian estimation models and neuroeconomic models of decision making (Glimcher and Fehr 2014). These models will enable balancing possible outcomes of anticipatory codes upon identification of "human individual whom I may have seen before is moving toward me." These may include "Should I sustain eye contact and say hello? Or should I turn my body and my face away from the incoming direction to give the signal that the brief encounter is not desirable at my end? What if I am OK with the encounter but the approaching party is not?" among other possibilities.

GUESSING MENTAL STATES OF THE OTHER PARTY IS HARD AND HIGHLY SUBJECTIVE

The computational researcher would need additional simulations to represent person A modeling possible mental states of the incoming person B. But unlike the portion of the decision-making process directly based on the person's internal sensory integrations and forward-and-inverse transformations to arrive at the conclusion of "I will willingly facilitate this encounter," the other set of integrations and transformation processes to estimate whether the other party B is interested in the encounter will be totally subjective and based on theorizing constructs about the other person's mind. That is, self-based assessments have the objective element of directly sensing, predicting, and inferring future actions and their sensory consequences based on one's own physical body and mental experiences. In marked contrast, when such assessments are based on the guesses of what the external stimuli (person B) may want to do, they carry large uncertainty. That externally based estimation process is far more difficult than the previously mentioned internally based process. And that level of uncertainty must be terrifying to a nervous system that cannot resolve such ambiguities internally in the first place, so as to anchor the world to a proper self-frame of reference. Without a frame of reference, all relative computations necessary to estimate distances and error correction codes will be impeded. Importantly, if supporting peripheral information necessary to help distinguish signal from noise is also compromised, the person will not be able to make timely decisions either. We will return to these aspects of the problem shortly for the cases of neurodevelopmental disorders on a spectrum, as they give rise to atypical social exchange. In this sense, conclusions about social deficits are currently reached without objective assessment, much less computational analytics of the types mentioned above. They are based on theoretical guesses about the other person's mental states, employing data-gathering techniques that are plagued with confirmation bias, severely incomplete due to the natural limited processing and information transmission capacities of sensory systems, and built on a foundation rather characterized by the accumulation of "scientific" evidence using a paradigm that does not admit to any of these caveats in the first place.

In the context of actual human social exchange, it is truly remarkable that despite the high uncertainties of mental theories people have about others, these types of social encounters take place. If one were to be conservative about possible outcomes and try to minimize uncertainty, most such social exchanges would not happen. And yet, they do happen. Implicitly, the nervous system takes such risk, an intriguing feature that may be possible to model using the neuroeconomics framework to balance error-driven versus reward-driven decision-making processes.

On this note, an entire subfield of psychology devoted to "theory of mind" (ToM) emerged some time ago (Baron-Cohen et al. 1985; Perner et al. 1989). In due time, this psychological construct also found a brain network seemingly devoted to ToM using the functional magnetic resonance imaging (fMRI) framework (Saxe and Kanwisher 2003), a framework that (sadly) shapes almost entirely the field of cognitive neuroscience. The fundamental flaws of the analytical techniques employed in this field and the interpretations of the handcrafted stories that emerge from their use and abuse have been eloquently described in various publications (Deen and Pelphrey 2012; Eklund et al. 2016). Yet, just as people in social encounters take the risk of guessing the mental states of others, so does the scientific community of cognitive neuroscience. They risk being wrong while making inferences on incomplete data and guessing their interpretations of how the brain may work out such complex social dynamics. Unfortunately, there seems to be more reward in the immediate outcome of publishing many papers under some black-box approach to data analyses, or gaining peer recognition and subsequent fame, than in unveiling basic principles with explanatory power. Perhaps being more conservative in the interpretations of those a priori handcrafted results will help open new questions, given that current questions are based on theoretical assumptions that for the most part, have not been empirically verified.

One of the problems here is that such bad science has had a direct impact in the lives of those affected by neurodevelopmental disorders that eventually affect social interactions. The claimed "hallmark" of cognitivists that the autistic person lacks a ToM is rather unfair. Likewise, the claims of their lacking empathy, being antisocial, and more generally purposefully lacking any type of interest in social exchange are rather troubling given that they are based on ordinal data from rather biased, made-up inventories that follow a self-fulfilling prophesy paradigm (Baron-Cohen et al. 1985; Leekam and Perner 1991; Sicotte and Stemberger 1999). Upon examination of the biophysical rhythms output by the nervous systems of the person with an observational diagnosis of autism spectrum disorder (ASD), we have learned that the statistical approaches and methods used in the above-mentioned body of work are severely incomplete and fundamentally flawed. And yet, in the absence of a neutral observer to reexamine such methods in light of new empirical evidence, such theories continue to be based more on art than science. They continue to have a negative impact in the lives of those families and contribute to the alienation and social rejection of the person affected by these heterogeneous sets of conditions.

Unlike the observational behaviorist and the guessing cognitivist, the computational modeler will have several additional layers of complexity to simulate once the encounter in Figure 4.2 takes place. Such simulations may involve, among other aspects, the neuromotor control of the face and body.

The face–body complex has well over 700 degrees of freedom (Evans 2015), including muscles, joints, and end effectors to carry out the necessary actions in this seemingly simple social encounter. How is the audiovisual information capturing the motions of the other person to be mapped onto the body of the viewer such as to create proper targets to spontaneously recruit and coordinate bodily joints and muscle groups? How can the potential affordances of the upcoming theoretical situation be anticipated to effectively steer the other person's attention (rather willingly) to our own desired outcomes? Seemingly trivial nuances could prematurely dissolve the potential social encounter. Among these are the tones of voice, speed and rhythms of the speech, inevitable facial expressions or bodily motions that fall largely beneath the person's awareness to be able to control them, and poor estimation of interlocutor distances.

A computational researcher trying to model the situation in Figure 4.2 would have to necessarily design various architectures considering hierarchical structures to cover multiple possible scenarios involving many layers of explicit and implicit information. Among these are cultural nuances (e.g., while Italians gesture abundantly during social exchange, and may speak simultaneously and loudly among a group, these practices would all be considered socially rude in British culture; likewise, many Asian cultures would consider it rude to look into the eyes of the interlocutor, whereas this is expected in U.S. culture, to the extent that not doing so is considered pathological).

Upon deploying computer simulations based on mathematical models of these multiple layers of interrelated motions from the eyes, the face, and the mouth (generating speech), accompanied by bodily rhythms, and so forth, the computational scientist would have to come up with proper models for entrainment and spontaneous versus controlled desynchronization of these elements. These would have to be designed in order to capture self-emerging nonstationary fluctuations during the exchange interleaved with steady-state segments. Such simulated behavior will have to give rise to multiple layers of temporal dynamics, as these are a hallmark of realistic social exchange. Indeed, concomitant processes will have different temporal scales demanding different strata of physical and mental dynamics with dynamically shifting priorities during the potential brief exchange to take place.

Designing models of motor control to simulate the motions of one single person has been an extremely difficult problem in computational motor neuroscience. Designing models of dyadic social exchange will surely be much more difficult. And yet, some aspects of sensory-motor transformations and the continuous internal dynamics of bodily actions may necessarily transfer to the dance of the social dyad. In particular, an attempt has been made to translate the notions of internal models for action (IMAs) from an individual system to a dyadic interaction setting (Wolpert et al. 2003), but the oversimplifications and assumptions of that proposed model are much too stringent to allow for a realistic outcome in typical scenarios, much less to capture critical aspects of atypical social exchanges.

INTEGRATING ALL THREE ACCOUNTS TO EXPLORE DEEPER LAYERS OF DETAIL

In an ideal world, the behaviorist, the physiologist, and the computational neuroscientist would join forces and try to integrate all three accounts under some unifying framework. Interdisciplinary collaboration is not always easy, though. More often than not, each body of knowledge is built independently. Integration of knowledge may be a challenge when an atypical nervous system is under study. It may take some time before multiple disciplines can unanimously agree on how to gather data to form a normative model. Then it may be even more challenging to gather data conducive of automatically unveiling systematic differences from normative data and to propose logical explanations based on first principles.

This section of the book provides different accounts from a behavioral-psychological perspective, a physiological characterization of behavior, and a computational approach to simple problems embedded in social exchange. These accounts are by no means exhaustive. They serve as mere illustration of the formidable complexity we scientists face when studying social phenomena.

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