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AUTISM
THE MOVEMENT-SENSING PERSPECTIVE

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7 ADOS
The Physiology Approach to Assess Social Skills and Communication in Autism Spectrum Disorder

Caroline Whyatt and Elizabeth B. Torres

CONTENTS

This section of the book has provided an outline of research aimed at exploring the development and refinement of social skills, social cognition, and communication—a core area of inquiry of autism research. Yet, as noted, an individual's background and training will guide research—in terms of both the questions posed and the approaches adopted for analyses, the inferences made, and the interpretation of data. This chapter aims to provide a concrete working example of social dynamics in autism spectrum disorder as decomposed and considered from the perspective of a physiologist and computational neuroscientist. In particular, this chapter illustrates the role of dyadic exchange within the framework of closed feedback loops, which consider reentrant information from sensations of self-generated motion—an element currently missing from the working conceptualization of social exchange. Further, the exchange of volitional and spontaneously co-occurring social motions across a dyad will be objectively quantified, and examined as evolving levels of entrainment. Through this new multidisciplinary movement sensing perspective, we demonstrate the potential utility of such metrics to inform and reshape a diagnostic tool—the Autism Diagnostic Observation Schedule (Lord et al. 2000, 2012), from a *monologue* to a *social dyad*.

INTRODUCTION

Clinically defined and characterized by "classical" behavioral symptomatology, autism spectrum disorder (ASD) (APA 2013) continues to be largely classified as a psychological or psychiatric disorder (see Chapter 2). This classification, prominent across academic, clinical, and public arenas, is reflected in *definitions*—that draw on broad symptomatology, including impaired social and communicative ability, and restricted and repetitive behaviors—and methods of *diagnosis*. Within this framework—and as part of the coarse symptomatology of ASD—social skills play a critical role.

Specifically, easily identified through observational techniques, and a core feature of ASD, social skills provide an intuitive step toward diagnosis, and offer insight into underlying psychological processes and neurological underpinnings (e.g., see Chapter 5). However, our approach to the use of, and understanding of, such higher-level skills is dependent on the perspective that we adopt (see Chapter 4). One's research background and training will inevitably shape our conceptualization and understanding of what social skills are, and thus how these may be harnessed, quantified, and remedied. This chapter aims to illustrate the benefit of each perspective while highlighting the potential of a multidisciplinary lens to reshape our often modular, one-sided, or isolated conceptualization.

DEFINITION AND WORKING CONCEPTUALIZATION OF SOCIAL SKILLS

Encompassing concepts such as social reciprocity or interaction, and language or communication skills, the underlying construct of social skills is largely conceptualized as the ability of an individual to engage in a meaningful interpersonal interaction within a dyad (or larger) setting. Traditionally conceived of as verbal in nature, social skills and communication exist on a continuum of *both* verbal and nonverbal interactions. Further, as outlined in Chapter 5, through these verbal and nonverbal interactions, members of a dyad influence each other at two levels—*content* and *temporal* interdependence at both *micro-* and *macrolevels*. This multilayered deconstruction of social skills and communication provides initial insight into the complexity of these higher-level dynamics. However, the level of examination—and thus how these are harnessed—varies.

From the *psychological perspective*, social skills are core to infant development, and remain prominent in adult existence, facilitating the building of cultural beliefs and shared understanding, and the development of stable relationships. Seminal work empirically deconstructing this early dyadic exchange demonstrates subtle levels of content and temporal entrainment across the infant–caregiver dyad in the macrolevel feeding patterns of new mothers and microlevel suck-burst patterns of infants (Kaye 1977, Schaffer 1996), cycled infant–caregiver gaze on–off patterns (Beebe, Jaffe et al. 2010), and early "vocal" exchanges (Wolff 1969, Schaffer and Liddell 1984). Illustrative of the first levels of sociocommunication skills, this work demonstrates macrolevel behavioral organization of dyadic exchange by profiling the microlevel temporal entrainment, that is, the underlying periodicity of exchange (Schaffer 1977, Kaye and Fogel 1980, Lester, Hoffman et al. 1985, Cohn and Tronick 1987). Yet, despite the pivotal role of social dynamics—particularly during development—quantifying social skills and interpersonal relationships within the psychological or psychiatric remit is arguably limited. Indeed, current standardized psychological and psychiatric methods designed to profile social interaction rely heavily on observational assessment tools, such as the Coding Interactive Behavior (Feldman 1998, Feldman 2003) and the Infant and Maternal Regulatory Scoring Systems (IRSS and MRSS) (Tronick and Weinberg 1990). Although designed to consider the *bidirectional* relationship—that is, both members of the dyad—on behavioral outcomes, such tools are reliant on descriptive methods, via the use of visual quantification of macrolevel observed behaviors by trained coders or examiners. Indeed, despite employing analytical methods to examine the bidirectionality of early dyadic interactions through time and frequency metrics, and the isolation of stochastic versus periodic cycles of exchange e.g. Cohn and Tronick (1987), such seminal work relies on the primary quantification of exchange through subjective measures—via the monadic phases manual (Tronick 1987). This reliance on visual metrics restricts our interpretation of microdynamics to those that are at a substantial level so as to be observed.

The *physiologist* may aim to provide a more concrete, objective method to record and profile levels of social skills, social cognition, and communication, by making precise recordings of physiological (bodily) control. A growing area of inquiry, perhaps in part due to advances in technology, this is akin to the initial level of a motor or movement perspective. Indeed, studies have employed eye-tracking technology in an attempt to further quantify traditionally psychological metrics of social dynamics, such as early infant–caregiver joint attention, through an examination of synchronized and sustained fixation on joint regions of interest (ROIs) (e.g. Yu and Smith 2013). Furthermore, by recording physiological landmarks of members of a dyad (or larger), attempts to deconstruct the internal dynamics for social synchronization and coordination—that is, temporal interdependence—have been made. As discussed in Chapter 5, this field of "coordination dynamics" utilizes high-speed motion capture technology, and draws prominently from recurrent analytical techniques, to objectively profile the potency of joint action coordination and entrainment (Kugler, Kelso et al. 1982, Turvey, Fitch et al. 1982, Kelso 1984; Schmidt, Fitzpatrick et al. 2011). However, despite providing evidence of coordination dynamics at an underlying temporal level that can impact macrolevel behaviors, such work is limited to artificial paradigms (Schmidt, Christianson et al. 1994; Amazeen, Schmidt et al. 1995; Amazeen, Amazeen et al. 1998; Richardson, Marsh et al. 2005; Richardson, Marsh et al. 2007; Schmidt, Fitzpatrick et al. 2011) (also see Chapter 5). Indeed, in more naturalistic contexts such physiologist perspectives revert back to a reliance on underlying psychological coding techniques of entrainment to guide the analytical methods (Schmidt et al. 2011). Thus, despite attempts to provide impartial, objective metrics to quantify macro- and microlevels of social dyadic exchange, the physiological perspective faces a number of inherent limitations, including an inability to extrapolate findings generalizable to a broader naturalistic contextual setting.

Building from the physiologist methodology, the *neuroscience perspective* aims to isolate areas of the brain that are responsible for social cognition and thus social skills. Neurological areas vital in the identification of socially relevant facial stimuli and characteristics (e.g. Morris, Frith et al. 1996, Phillips, Young et al. 1997, Winston, O'Doherty et al. 2007), the detection and utilization of biologically relevant motion information (e.g. Allison, Puce et al. 2000), and action understanding (e.g. Rizzolatti 2005) have been isolated. Yet, despite advances in brain imaging techniques, such metrics are restricted to an artificial examination during an experimental—or medically—restricted scan. Such an approach constrains our understanding to considering the impact of socially relevant information on an *individual*—that is, a unidirectional approach—rather than a neurological conceptualization of bidirectional interaction. Further, movement—an inherent part of dyadic exchange, particularly at the nonverbal level—is a well-documented limiting factor in the use of modern brain imaging and scanning technology, including functional magnetic resonance imaging (fMRI) and electroencephalogram (EEG), and even ocular (Friston, Williams et al. 1996, Croft and Barry 2000, Gwin, Gramann et al. 2010). Thus, current *computational neuroscience* models of social cognition, skills, and communication focus heavily on the level of the central nervous system (CNS), as characterized by underlying neural activity. However, as discussed throughout this book, this arguably restricted interpretation—artificially removing contributions of movement as a form of sensing and the role of the *peripheral nervous system* (PNS)—from computational models, limits our understanding of the global social environment, including the impact of motor control and sensory processing. Attempts to integrate motor control and social interaction have been made in recent years (Frith and Wolpert 2003), yet difficulties extrapolating such information to a broader context remain. Indeed, despite drawing heavily on forward planning models of action control, such theoretical constructs place an assumption of a priori information in one's ability to "decode" such socially and biologically relevant information. Potential limitations of such an approach have been discussed in Chapter 5, demonstrating the complexity of this "dark matter" of neuroscience (Schilbach, Timmermans et al. 2013).

Combined, the psychological, physiological, and computational neuroscience perspectives, although informative, are arguably restricted in their approach. Indeed, the challenge posed by a "second person of neuroscience"—the dark matter of neuroscience today (Schilbach, Timmermans et al. 2013)—has been repeatedly raised in an attempt to open dialogue regarding methodology and assumptions. Despite this, inherent limitations and preconceived conceptualizations based on one's background and field of study pose a tangible barrier. Indeed, reflecting the complexity of natural human behaviors, particularly those such as social exchange, we argue that this modular approach is outdated. Rather, we propose a multilayered, multidisciplinary approach to quantify, examine, and thus understand social exchange in *complex systems* (Figure 7.1). In our inquiry, we

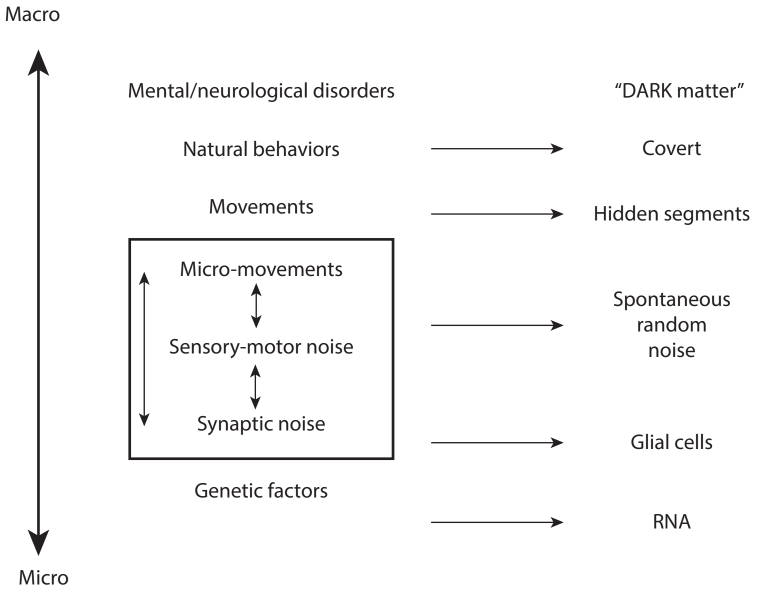

FIGURE 7.1 Multilayered system of inquiry from macro- to microlevels—inevitably, information is neglected at each level, information that falls largely beneath our awareness. For example, observational metrics that rely on the description of behavior focus on overt aspects, while the study of movements that make up such behaviors omit incidental segments that supplement goal-directed actions (Torres, 2011). Further, traditional kinematics-parameter averaging removes minute fluctuations within the amplitude and timing of movements as "noise"—information that may contain important signals (Brincker and Torres, 2013; Torres et al. 2013). Finally, recent discoveries regarding the underlying role of glial cells and RNA are also examples of data that were previously omitted.

will incorporate new elements of behavior at the macro- and microlevels across different spatial and temporal scales. As noted, these components of the social exchange have been traditionally overlooked due to both limitations in observational (psychological and physiological) metrics, and the a priori assumptions placed on such complex phenomena in an attempt to simplify, or reduce, the research condition. The remainder of this chapter thus presents an overview of a multilayered approach to examining social dynamics. This model integrates new elements—previously overlooked due to a priori assumptions—in an attempt to objectively quantify the "social dance" for a population with known social difficulties: ASD.

MULTILAYERED, BIDIRECTIONAL APPROACH TO SOCIAL DYNAMICS IN AUTISM SPECTRUM DISORDER

Current psychological and psychiatric tools for the diagnosis and characterization of ASD draw heavily on the role of social skills as a fundamental axis of symptomatology (APA, 2013). The Autism Diagnostic Observation Schedule (ADOS[*]) (Lord et al. 2012) is considered the "gold standard" assessment tool currently available to assist in diagnosis[†] (Ozonoff, Goodlin-Jones et al. 2005, Kanne, Randolph et al. 2008). The ADOS is thus equipped with a range of measures to assess the quality of *spontaneous* socialization in ASD, including the use of communicative gestures, joint attention, and quality of response to the examiner. Drawing on these traditionally *psychological* metrics that tap into

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[*] ADOS will be used to refer to all versions of the ADOS, including the generic and second edition.

[†] The ADOS is typically used in conjunction with additional tools for contextual information, such as the Autism Diagnostic Interview–Revised (ADI-R) (Lord, C., et al. 1994).

the diagnostic conceptualization of ASD, the ADOS provides a unique opportunity to measure social cognition and skills from the broader macrolevel from the standpoint of an observer. Specifically, the ADOS provides a structured, controlled social environment, and *attempts* to simultaneously harness naturalistic—spontaneous—*bidirectional* dyadic exchange. However, upon closer examination, the metrics extracted from this observational psychological model rely on a *unidirectional* approach. Indeed, through the use of a semistructured controlled social environment, the ADOS targets a range of symptomatic features of ASD, with an examiner using a number of social "presses" to illicit a response from the individual through age-appropriate play-like behaviors. The quality of social response, or lack thereof, provides an insight into aspects of autism, which is used to assess the presence and severity of symptoms. Yet, no information is recorded as to the potential impact of the clinician on the outcomes of this social exchange—a cornerstone of a dyad—artificially restricting outcome metrics to the "performance" of the participant or examinee. Further, such observational scoring metrics face inherent limitations with subjective coder bias and error, and exist on ordinal scales that neglect subtle aspects of behavior occurring at timescales beyond conscious awareness (Figure 7.1). In particular, the observer or clinician is explicitly looking for spontaneous overtures —in response to the social presses that they present. Combined, such a platform results in potential levels of confirmation bias, and an artificial restriction to the inclusion of discrete behaviors that exist at an observational level so as to be "coded." As such, we need to (1) adopt an approach that examines the social *dyad* rather than the child in isolation (a dyadic ADOS rather than an ADOS monologue); (2) integrate an "objective neutral observer" provided by data-driven methods and statistical frameworks that can span across, and integrate between, the multiple macro- and microlevels of inquiry to include "hidden" movement classes; and (3) provide metrics that can encapsulate the *continuous flow* of evolving social dyadic exchange between both members of the dyad to examine entrainment and synchronicity. By coupling this standardized psychological tool with in-depth objective methods to quantify microlevel coordination, higher-level psychological metrics of social interaction may be sequentially deconstructed, proving a model and method to address these limitations. Further, drawing on core principles founded in mathematics, this objective exploration may facilitate a computational modeling approach—vital in the autism endeavor.

COMBINING THE PSYCHOLOGICAL AND PHYSIOLOGICAL PERSPECTIVES: AN OBJECTIVE EXPLORATION INTO THE SOCIAL DYAD

The following provides an overview of an ongoing research study currently being completed at the Sensory-Motor Integration Laboratory of Rutgers University—funded by the New Jersey Governors Council for Medical Research and Treatment of Autism.

This project initially draws on the concrete and controlled environment of the ADOS platform, to examine constructs defining social skills, cognition, and communication from a macropsychological level. As such, the ADOS is administered and scored according to a standardized protocol by a trained clinical team member. Outcome metrics using ordinal data are scored for subsequent consideration, yet of most importance, the order and controlled administration of social presses is tracked, for subsequent targeted analysis and decomposition. Through this sequential deconstruction, the project aims to examine the relationship between higher-macro-level observed psychological constructs of social dynamics and underlying microlevel forms of temporal and content interdependence as measured using objective metrics. Indeed, through this method, the project aims to isolate and identify tasks presented within the global psychological tool that are particularly informative of underlying dyadic exchange and social skills. To incorporate this nuanced understanding of social dynamics, and at the level of dyadic interaction, high-end wireless motion capture technology is integrated. Specifically, lightweight inertial measurement units (IMUs) (APDM) are positioned on key anatomical landmarks of *both* the clinician and the examinee or participant—six positioned on each member, as demonstrated in Figure 7.2.

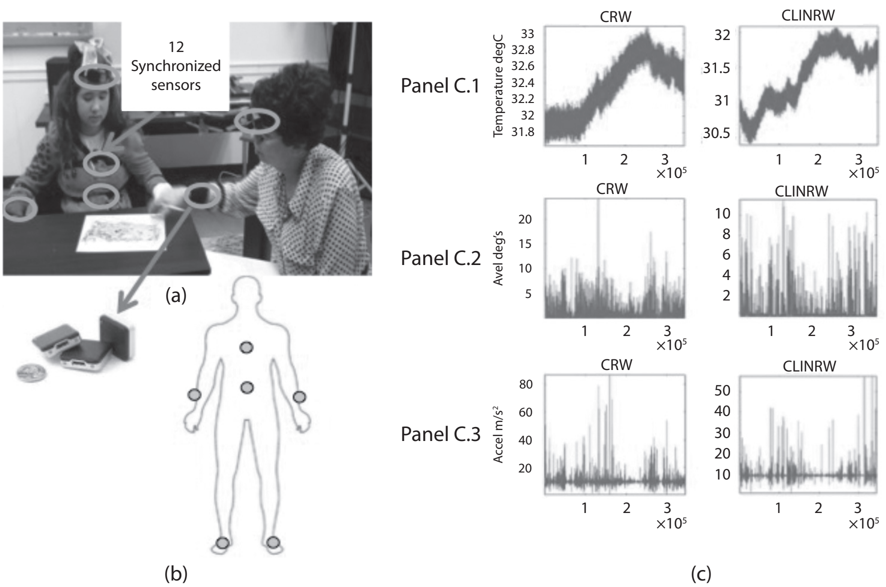

FIGURE 7.2 Experimental setup with sensors and example data. (a) Image of a typical paradigm for the administration of the ADOS, whereby a clinician creates a standardized social environment to elicit a spontaneous response. As indicated, 12 IMUs are strategically positioned across the dyad—6 on each member—at key anatomical landmarks, as demonstrated in (b). (c) Synchronously sampling at 128 Hz, these IMUs provide temperature (c.1), angular velocity (c.2), and acceleration (c.3) metrics, on which underlying kinematic analysis can be performed.

Sampling at 128 Hz, these sensors provide *synchronized* measurements of temperature, angular velocity, and acceleration from across *both* members of the dyad. These synchronized signals, harnessed from the output of the nervous systems, are subsequently examined at the microlevel of somatic sociomotor coordination. Specifically, recorded motor output is also considered within the framework of reentrant kinesthetic sensory input—"kinesthetic reafference" (Holst and Mittelstaedt 1950). As discussed below, the lead–lag information of each body part of each member of the dyad is considered to understand how the motoric biorhythm of one system guides the other—that is, levels of entrainment and temporal interdependence—during the ADOS exchange. Mirroring the multilayered approach of Figure 7.1 to the study of social interactions, kinematic research in the specific area of autism also exists on a layered continuum of analysis (e.g., Torres et al. 2013; Torres 2011)—as such, the first question to consider is what form of kinematic analysis is most informative?

In the case of individuals with ASD, higher macrolevel observations of kinematic control imply a general level of motor difficulty (Green, Charman et al. 2009, Whyatt and Craig 2012), which has been objectively profiled using standard microlevel kinematic methods to confirm levels of motoric irregularity that can be directly linked to macrolevel behavioral outcomes (Whyatt and Craig 2013). However, both of these "traditional" levels of kinematic, physiological analysis rely on the examination of goal-directed behaviors across discrete timescales (an epoch) to examine specific overt behaviors at the expense of larger timescales—that is, those of continuous, evolving motor output. Indeed, similar to the difficulties encountered by the examination of unfolding coordination dynamics (e.g. Schmidt, Christianson et al. 1994, Amazeen, Schmidt et al. 1995), the longitudinal profiling of evolving nonlinear motor control, a characteristic of continuous social interaction, negates the use of handpicked epochs in discrete methods of analysis.

Consider, for example, the complex sports routines of boxing (jab, cross, hook, and uppercut) (Figure 7.3). The hand trajectories and speed profiles derived from these complex motions reveal hidden segments that the athlete is unaware of. For each alternating hand punch, the athlete focuses on

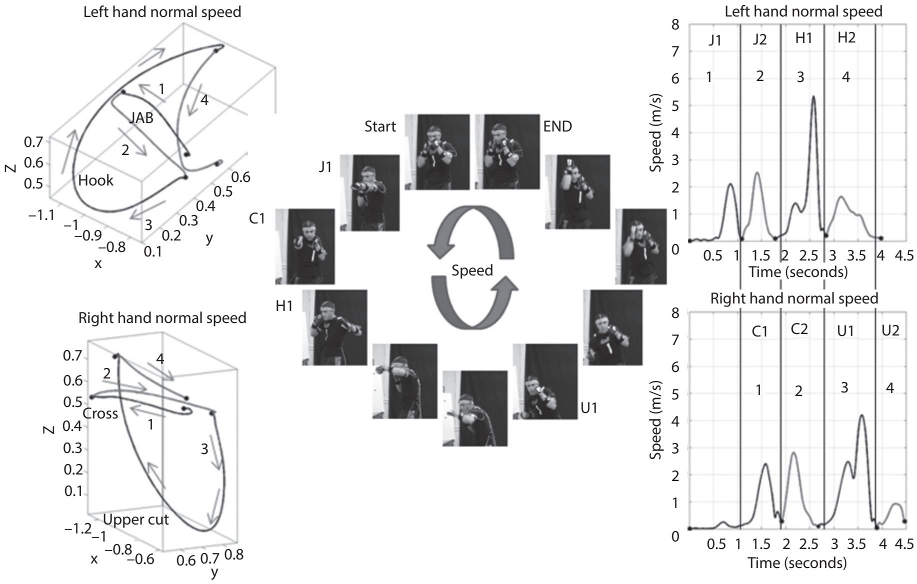

FIGURE 7.3 Hidden movement segments of boxing behavior. The jab–cross–hook–uppercut routine is decomposed here for the right and left hand (end points of the upper-body kinematic linkage). The center picture shows the athlete from start to end performing the routine at variable speeds on command (fast or slow called at random by a computer program). The traces correspond to a slow-motion case. (a) Trajectories with the segments delineating the start and end of each subroutine in the order in which they occurred, marked by arrows. (b) Temporal speed profiles of the positional trajectories shown in (a). The J2, H2, C2 and U2 marks the hidden movement segments of this complex boxing behavior. While the athlete attends to the forward punches with one hand (J1, H1, C1 and U1), the other hand is simultaneously retracting. These supplementary (incidental) motions co-occurring with the staged (deliberate) ones the athlete directs to a goal (the opponent) are the hidden segments that "glue" our complex behaviors along a continuum and make the fluid. The supporting role of these actions was previously unknown, as we had not yet quantified them and had no way to distinguish them from the goal-directed (forward) ones. The athlete was also unaware of them. The experimenter was therefore surprised by the resulting plots of these motions (see Figure 7.4). (Reproduced from Torres, E. B. *Exp Brain Res* 215 (3–4):269–83, 2011. With permission.)

the forward, goal-directed segment of the hand aiming at the opponent, while the retracting segment of the other hand is co-occurring. Despite overt focus on the forward movement, the athlete's nervous systems also attend to these "hidden" segments, such as the retraction. Yet, an external observer "coding" the dyadic behavior between the athlete and his opponent may only "see" overt segments of the action—those directed to the very dynamically moving target (opponent). When empirically quantified at a high resolution, this example from sports science illustrates the additional layers of complexity embedded within our actions—with different "classes" of hidden movements isolated (Torres 2011). Utilizing a third "neutral objective observer," a quantitative approach can be adopted that automatically separates the effect of changes in motion dynamics (e.g., speed) from the geometry of the motion trajectory (Figure 7.4). A computational model (Torres 2002) guided by a mathematical equation can then be harnessed to identify levels of intent from the signatures of deliberateness, or spontaneity, in the motions (Torres 2011). Interestingly, this distinction which is obvious in neuro-typical systems does not occur, or is less obvious in systems with ASD (Figure 7.5). Namely, this approach detected the presence of the memoryless exponential distribution, denoting a "here and now" statistical code characterizing ASD—a code with no certainty in the reliance of past events to predict future events (Figure 7.5). In other words, the peripheral signal that is echoed back to the brain bears information on the moment, yet each moment is experienced anew. This discovery can be appreciated in

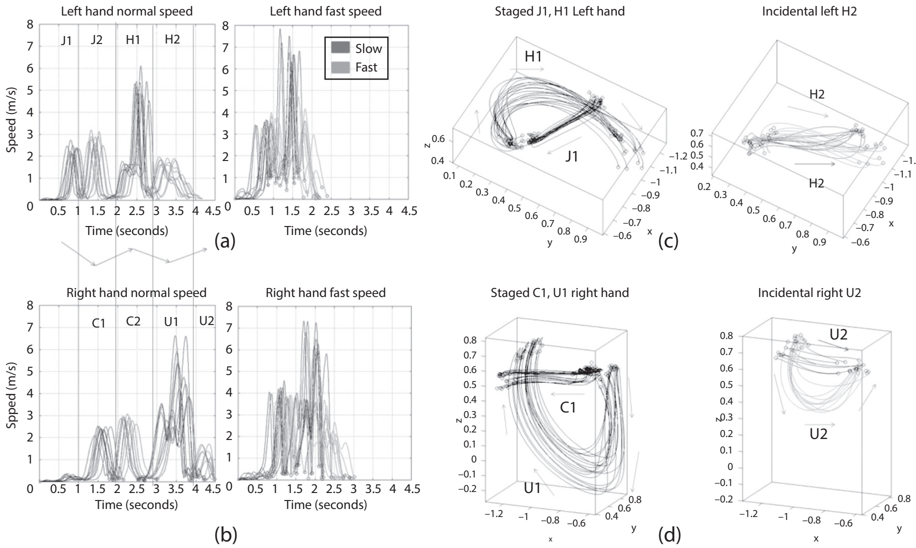

FIGURE 7.4 Automatic distinction of staged (deliberate) and incidental (spontaneous) movement classes coexisting in complex behaviors performed by systems with redundant degrees of freedom (DoF). (a, b) Speed profiles of the left- and right-hand trajectories alternating staged and incidental motions from the full boxing routine performed many times along a continuous flow. The athlete followed the random call of "slow" or "fast." The trials are then grouped by speed, with the lighter segments denoting the hidden movements and black segments denoting the ones the athlete and the experimenter were attending to. Note that the speed profiles remain similar in structure while contracting in time. (c, d) This time contraction does not affect the geometry of the staged-segment trajectories of each subroutine. However, it changes the geometry of the incidental segments. For example, take the incidental uppercut U2 and compare it with the staged uppercut U1. While the fast U2 follows a rather curved trajectory, the slow U2 follows a nearly straight one. Keep in mind that these segments were performed in randomly called order. This speed invariance in the geometry of staged behavioral segments is a signature of deliberateness that contrasts with the variations in spontaneous behavioral segments escaping the naked eye. (Reproduced from Torres, E. B. *Experimental brain research*, 215(3-4), 269-283, 2011. With permission.)

Figure 7.5, which further explores the boxing routines of Figure 7.3 in an adolescent individual with ASD (e.g., Torres 2011).

This example further illustrates levels of trial-to-trial variation in the amplitude and timing of kinematics—parameters that are extracted from the supplementary and goal-directed segments, and that can be further assessed using the statistical platform for individualized behavioral analysis (SPIBA). It is this overarching methodology that can be translated to empirically examine social dyadic interactions in the clinical arena.

SPIBA AND THE MICROMOVEMENT DATA TYPE

The micromovement perspective, introduced by Torres and colleagues, provides a new level of kinematic analysis, whereby minute fluctuations within the sensory-motor signature are captured to characterize neurophysiological control (Torres et al. 2013). Within this framework, the continuous profiling of behaviors is endorsed and the stochastic signature of variation within this signature is empirically estimated (Figure 7.4).

This method serves as a departure from traditional methodologies that rely on discrete metrics, and thus lends itself to the precise profiling of naturalistic (continuously flowing) social interactions. Further, as discussed throughout this book, the use of underlying variability within this signal (micromovements) can be empirically profiled at the individual level, providing insight into the predictability (or likely future "states") of the system, based on prior registered states. Importantly, as

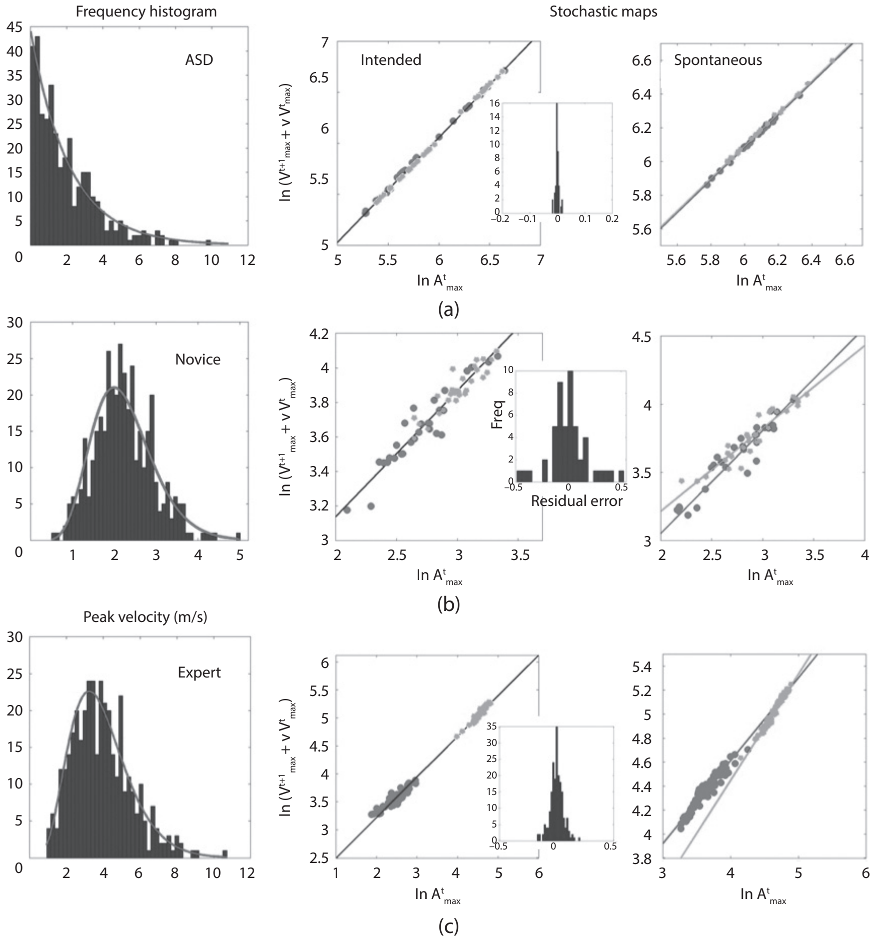

FIGURE 7.5 Signatures of intended and spontaneous behaviors differ between participants with ASD and neurotypical controls. (a) Linear speed micromovements from the peak velocity along the hand trajectories of the jab segments (in Figures 7.3 and 7.4) manifest an exponential-like distribution in ASD, while controls (b, c) are skewed to symmetric. Stochastic maps from a first-order rule that anticipates the variations in future speed from the combination of variations in past speed and acceleration differ between ASD and neurotypical controls in very precise ways. Notably, the intended segments do not distinguish the different speeds, and unlike controls, the ASD's spontaneous movement segments lack the variations to predict the motion dynamics. The memoryless exponential distribution of their variations suggests that the movements are performed in the here and now, in marked contrast to the anticipatory signature of the neurotypical performance.

noted above, the micromovement approach has uncovered a "special" stochastic signature present across multiple biorhythms of ASD motions. Such results illuminate the potential difficulties of "movement sensing" in autism—thus the movement sensing perspective.

The central tenet of the new methodology proposed here is to examine levels of coherence across the bodily rhythms of participants within a dyad in search for entrainment and synergies within (Figure 7.6a) and across (Figure 7.6b) the bodies in motion. As such, this method can provide insight into, *first*, the underlying state of the sensory-motor system of each individual. Through this method, the state of the sensory-motor system can be empirically profiled along a continuum of predictive states: from those with a low noise-to-signal ratio (as characterized by a symmetric distribution with low dispersion) through to a highly variable state with a high noise-to-signal ratio and

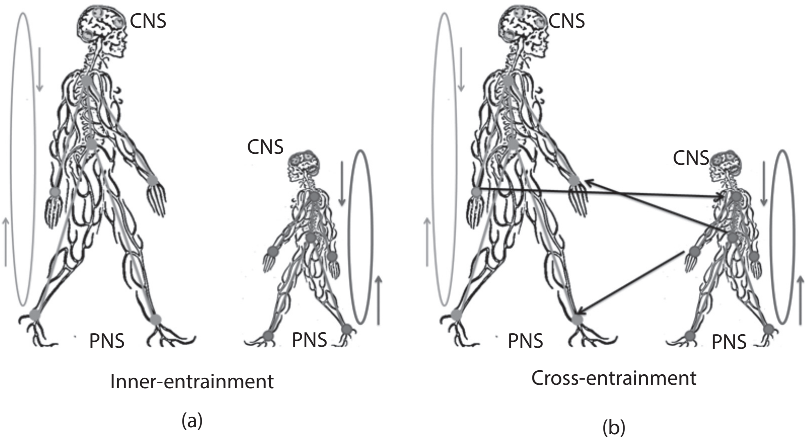

FIGURE 7.6 Schematic representation of the dyadic networks and their coupled activities across CNS-PNS interactions. (a) Intranetwork activity of each dyad participant for one state configuration per unit time. (b) Cross-network coupling with lead–lag network coherence state configuration per unit time. Colored arrows denote the closed-loop intranetwork activity for each dyad participant, while black arrows denote the coupled activity across the two networks. In a dynamic setting, these configurations change (activities evolve as in a movie). As such, they provide a temporal profile of the networks' states. Each contributing node of the overall dyad network provides biorhythms for the continuous tracking of the PNS activity as dictated by the CNS.

randomness (the latter characterized by the memoryless exponential distribution). By empirically estimating the state of an individual's system, SPIBA provides an objective characterization of an individual's neurophysiological control of self-generated movements.

To achieve this level of precision, bundled somatic motor information is collated, minute by minute, from each IMU for a participant (and clinician) across each session. Underlying variability or micro-movements (Torres et al. 2013)—moments of maximal deviation—within the acceleration signal are extracted and normalized to control for allometric variation, providing a time series or "spike train" of underlying kinematic fluctuations. This normalized time series is subsequently profiled, empirically establishing the probability distribution function that best characterizes this stochastic process—with four moments utilized (mean, variance, skewness, and kurtosis). This level of processing provides insight into the underlying level of neurophysiological control (Torres et al. 2016)—a level that can be subsequently considered in light of further outcome metrics (see below and Figure 7.8).

Second, this framework can facilitate precise examination of nonlinear evolving synchronicity across the social network—that is, members of the dyad. Information exchange is thus examined within the synergistic coordination of individual anatomical landmarks across each member of the dyad, but also extended to the interconnected synergies across the dyad as a whole. As such, the bodily nodes of both participants (i.e., sensors on anatomical landmarks) are treated as interconnected nodes of a large network (analogous to a network of nerves (Figure 7.6), given that the data readout from the peripheral bodily network is controlled by the central networks of the brain). Then mathematical tools from network analyses are adapted to the analyses of the dyad elements in isolation, and of those in tandem (see Whyatt & Torres 2017 for methodological information). Figure 7.6 provides a schematic representation of these networks, while Figure 7.7 provides an example of network connectivity metrics extracted across the network recorded during an ADOS session. Specifically, these metrics (Figure 7.7) provide information regarding the direction of the interaction—that is, who leads the interaction and when considered in the global framework of the controlled ADOS administration—for what tasks (Figure 7.7b). For instance, despite administration of the ADOS taking (on average) 30–50 minutes to complete per session, core metrics draw heavily on key tasks and critical moments of exchange. Viewing this objective underlying metric of dyadic synergy or entrainment, one can

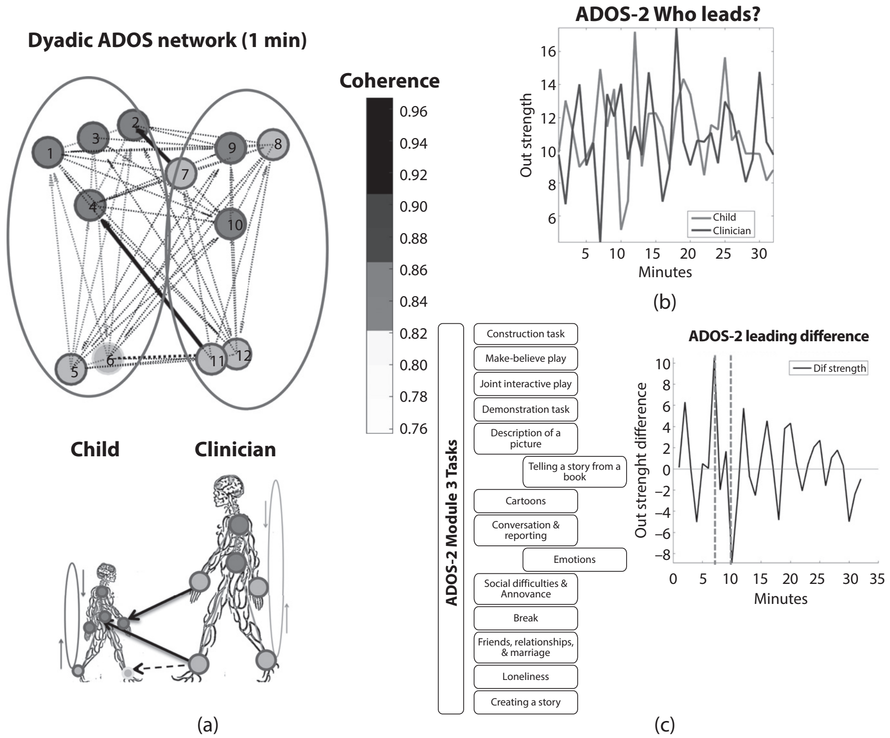

FIGURE 7.7 Dyadic ADOS network and its dynamic temporal profiles. (a) Network analyses of the two dyad participants for 1 minute (out of 40 minutes) of the dyadic ADOS exchange. Different colors of the circles denote different modules denoting cross-network coupled synergies, while the circles' "edge" denotes the coherence level of the nodes connected to other nodes in the network. Arrows denote the connection and the direction of leading activity according to phase lead profiles. Black arrows are internetworks' coupled activity denoting cross-entrainment levels. (b) Illustrative example of leading information across the ADOS-2 administration. Specifically, leading information derived from a pairwise cross coherence analysis across the dyad is summed to result in node-out strength for each member across the session. (c) The difference in out-strength between each member of the dyad is subsequently calculated, and isolated within the framework of the ADOS-2 administration - highlighting the importance of the Telling a Story (TS) task and Emotion (EMO) competent.

blindly isolate elements of the ADOS administration in which the clinician or participant or child was leading the exchange. As demonstrated in Figure 7.7b and c, the weight of outgoing leading information across all nodes (i.e., sensors) for each member of the dyad can be summed to provide a total metric (outstrength metric; see Figure 7.7b). This can be profiled across the course of the session —and the difference between the outstrength of both member of the dyad examined in light of overarching ADOS tasks. This examination can thus illustrate who out of the dyad is leading the exchange for each task (see Figure 7.7c), and which are most informative.

AFFECT VERSUS MOTOR CONTROL?

The leading–lagging profiles, and their critical points, can provide information regarding important differences in task demands, differences that may not be obvious to the most experienced examiner, or even to the designers of the observational tools, such as the ADOS. Indeed, examination of critical points of difference in the strength of leading information for both the clinician and participants - isolate two core tasks: the Telling-a-story (TS) task and the Emotional component (EMO). While the design and requirements of the tell-a-story (TS) task denote a motorically demanding activity, the

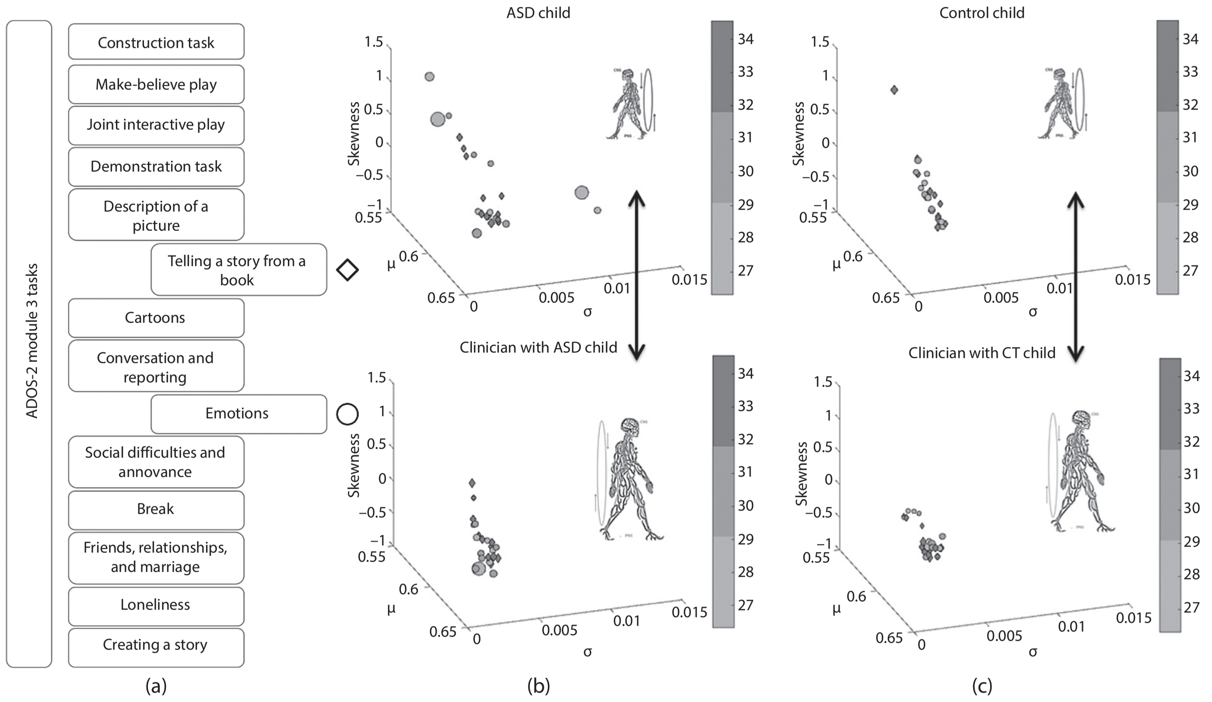

FIGURE 7.8 Affect versus motor control? Quantifying marked differences in the signatures of micromovements during the EMO and TS tasks. Using the aforementioned method, critical points in leading information during the administration of the ADOS were examined – blindly isolating two primary tasks: Telling a story, and the Emotion Component (Panel A). Automatic distinction between the motoric demands of each task is evident in the estimated gamma moments and the temperature profiles (Panel B). The EMO outcome measure shows high levels of involuntary micromovements (lighter circles), defined by the lower-temperature profiles of the motions during the emotionally demanding task. In marked contrast, the motorically demanding TS task outputs more activity (darker diamonds) with a higher-temperature profile from higher battery drainage during actively self-generated voluntary motions (see color bar). The ASD profile (top left panel) is also more variable and differs in the shapes of the estimated probability distribution functions (skewness and kurtosis moments denoted by the *z*-axis and the size of the marker, respectively).

emotional (EMO) task lacks this motor element. Specifically, the former requires the child to enact and tell a story to the examiner—a form of social exchange, while the latter requires the participant to answer a range of emotionally salient questions—targeting elements such as loneliness, relationships, and emotions. The amount of uncertainty and emotional distress such questions elicited in each child (see also Chapter 26 on bullying) is reflected in a very different stochastic landscape in ASD than that uncovered in the typically developing age- and sex-matched controls (CT). This unexpected signature of an increase in the spontaneous involuntary micromovements served to characterize this emotional component. While the constituent components of the EMO task would imply no involvement of motion, the sensor technology has output a level of lower-temperature motion (implying involuntary actions) statistically different from that of the TS task. Figure 7.8 provides this contrast in results for representative children, with both ASD and age-matched control participants (completing the same ADOS module). Further, as performance is examined in a truly dyadic nature, the examiner's or clinician's motions are also profiled per session (in the corresponding bottom panels). The ASD population demonstrates a spread of the gamma moments in space, particularly for the circles that represent motions across the body recorded during the EMO task. These parameters clearly contrast with those of the control population, but also with those of the examiner in both contexts. Indeed, the motoric demands of the TS task and the affect demands of the EMO task are automatically uncovered in the stochastic profile of the micromovements extracted from these bodily rhythms.

The results raise the question—have these metrics tapped into a level of affect that is currently beyond the scope of traditional psychological tools? As noted, the emotional component contains a range of questions that are designed to target emotional constructs, such as loneliness, friendships, and sadness. Although often stereotyped as experiencing difficulties with emotional regulation, expression, and empathy (Cohn and Tronick 1987)—largely a by-product of the psychological perspective interpretation of social skills and cognition—such work may give voice to those feelings. Currently being examined at a larger group level, and considered in light of psychological outcomes, these underlying microlevel metrics may provide novel insight into the underlying coping systems of individuals with ASD and may speak to a level of empathy—or discomfort—beyond our current scope.

CONCLUSION: WHAT CAN THIS TELL US?

Combined, this multilayered approach to the deconstruction of social skills demonstrates the importance of considering microlevels of exchange—a level currently beyond psychological metrics alone. Indeed, by coupling standardized psychological tools with objective, precise kinematic measurements of physiological control, novel insight into levels of dyadic entrainment may be achieved. Such objectives, informative in a variety of arenas, are particularly useful for individuals and populations living under the stereotype of poor social skills, social cognition, and communication. With the ADOS adopted as a framework, this model has provided a controlled social environment in which to deconstruct complex naturalistic social dynamics, while maintaining direct links to clinically relevant behavioral metrics, and simultaneously illustrating perceived difficulties with such restricted tools. Through the use of objective metrics, connections beyond the macrolevel—that is, subtle attempts to engage—may be identified. If so, such tools may demonstrate that rather than characterizing individuals with ASD as unable to communicate and engage, it may be time to consider how such an interpretation may be artificially enforced by *our inability* to perceive such attempts. By viewing performance during the ADOS through an alternative lens, we may identify the impact of the clinician on this dyadic process, and consider the possibility that we are simply out of step with individuals on the autism spectrum. Indeed, it may be argued that the ADOS of today is merely an instrument that serves to highlight the child's social deficits (arguably as induced, in part, by the examiner's style of prompting). It gives us a one-sided account of the severity of the problem, but social exchange is not one-sided. Under the sensory and somatic motor umbrella, the ADOS of tomorrow could be an instrument that serves a different purpose—to highlight the potential and best capabilities of the child in a truly dyadic context.

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