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AUTISM

The Movement-Sensing Perspective

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FRONTIERS IN NEUROSCIENCE

Concluding Remarks to Section I

Top-Down versus Bottom-Up Approaches to Connect Cognition and Somatic Motor Sensations

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Chapter 3 highlighted the contributions of cognitive theories to autism research. The cognitivist ideas reviewed in the chapter provide a *top-down* approach to the possible relations between cognition and movements. Despite its relevance to help us formulate questions regarding motor control differences in autism spectrum disorder (ASD), the top-down approach tends to obstruct our ability to bridge cognition and action in neurodevelopment. This is, in part, due to a reliance on descriptions of a system that, although still young and growing, has already reached a steady-state rate of development. The system of a 5-year-old child or that of a young adolescent is physically growing at a steadier pace than that of a newborn baby. Indeed, the steady-state growth of a child stands in stark contrast to the rapid rate of growth of the nascent nervous systems of a newborn baby. The latter is changing on a daily basis at highly accelerated rates (Figure I.1). To better appreciate this difference, consider, for example, the rate of physical growth of a newborn baby. In 30 days, the body gains weight at a nonlinear rate of change that varies from 0.02 kg/day to nearly no change to actual weight loss in the first week (Figure I.1). If we were to apply such rates to the body of a 5-year-old child, the changes would be, even overnight, so appreciable to the child's brain that a total "recalibration" of all bodily and sensory maps would be required for that brain to be able to control that body from one day to the next. Indeed, Figure I.1c shows that the typical 5-year-old child (1825 days) changes weight at a rather slower rate per day in relation to the newborn baby.

None of the theoretical cognitive attempts to describe motor coordination, motor sequencing, or any type of inference about the actions of the child used to guess his or her mental states or the mental states of others (i.e., as in theory of mind [Baron-Cohen et al. 1985]) would work in this rapidly changing physical body scenario. Cognitive theories merely describe the observer's perception of a physical body in motion (i.e., producing behavior) without considering the evolution of the physical parameters that intervene in motor control and the sensations that their consequences produce. They describe an intermediate final end product of a body that reaches some stable configuration before it goes on to another major physiological change (e.g., puberty). This semisteady state of being is only a local window into more global developmental phenomena along the human life span. Zooming out of this local window (as in Figure I.1 examining the changes in weight and their rates of change for the first 5 years of life) underscores the fact that the cognitivist description needs to reconsider longitudinal change using a nonlinear, stochastic lens, rather than a locally linear, static, deterministic one.

The cognitivist researcher describes the individual performing a socially oriented or purposeful behavior that has already matured to some extent. The top-down inferences that cognitive theories make about the functioning of the mind are not based on evolving physical bodies with embedded evolving nervous systems, developing from the bottom up (Figure I.2). As such, the cognitivist could never see the need for understanding the mechanisms necessary to control a body in motion as basic ingredients required to construct predictive behavior underlying the description of the (presumed) mental intentions of others and their social consequences.

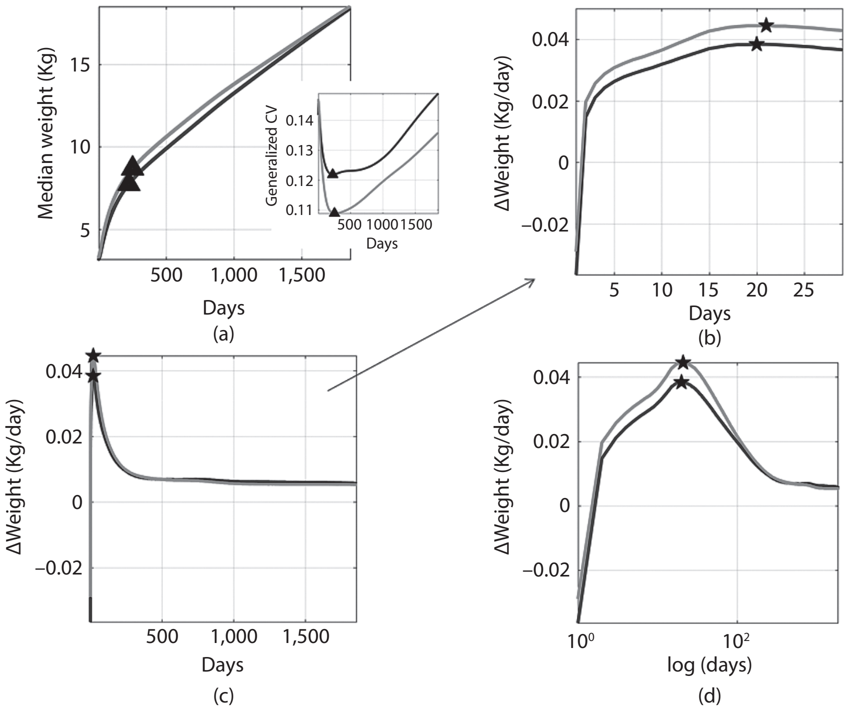

FIGURE I.1 The rate of change in weight is much more accelerated in the early days of the neonate than at 5 years of age. (a) The course of daily weight gain and its variability (inset) during the first 5 years of life show the marked nonlinear nature of these processes. The body steadily gains weight around 5 years of age, but in the first year of life the changes are accelerated. (b) Indeed, the baby gains an average of 0.5–1 kg/month for the first 6 months, but this rate slows down after 5 years (c and d). (d) Similar plot as (c) in log scale for better visualization. The stars mark a critical point of change from positive to negative slope in the gain (rate). The triangles mark a critical point of change in the generalized coefficient of variation (the estimated ratio of mean weight to variance) separating males (cyan) reaching the point at 252 days from females (magenta) reaching the point at 224 days (almost a month earlier). (Data obtained from 26,985 breast-fed babies per summary point [13,623 females and 13,362 males] available from public records accompanying the methods to produce the World Health Organization and Centers for Disease Control growth charts (Reproduced with permission from Torres et al., *Front Pediatr* 4(121):1–15, 2016.)

The rather disembodied approach of the cognitivists' theories fails to consider that the rapid physical changes that a newborn baby experiences while gaining autonomy over the body are also characterized by changes in the rates of growth of the peripheral nerves innervating the face, trunk, and limbs (Figure I.2). Such nerves ought to establish proper synapses to build networks that effectively communicate activity from the end effectors back to the also fast-growing brain. This brain will eventually have to develop deliberate autonomy over the body. Without this closed loop properly in placed between the peripheral nervous systems (PNSs) and the central nervous systems (CNSs), it will be very hard for the baby's nascent nervous systems to self-discover controllable change, i.e., to self-discover a self-corrective code that enables the prediction of sensory consequences from self-directed actions, i.e., beyond simpler stimulus–response associations.

Indeed, the error in the current conceptualization of cognitivist approaches is the disembodied notion of cognition understood as an information processing digital machine (more recently attempting to predict or anticipate the future using, e.g., Bayesian inference and other machine learning methods [e.g., Yufick and Friston 2016] to try to define intelligence). The fact that self-produced movements continuously affect our ongoing sensations is used by other contemporary approaches that have partly emerged in response to the impossibility of the cognitivist theories to connect body and mind. The new approaches (e.g., enacted cognition or embodied cognition [Varela et al. 2016]) try to bridge abstract thoughts to

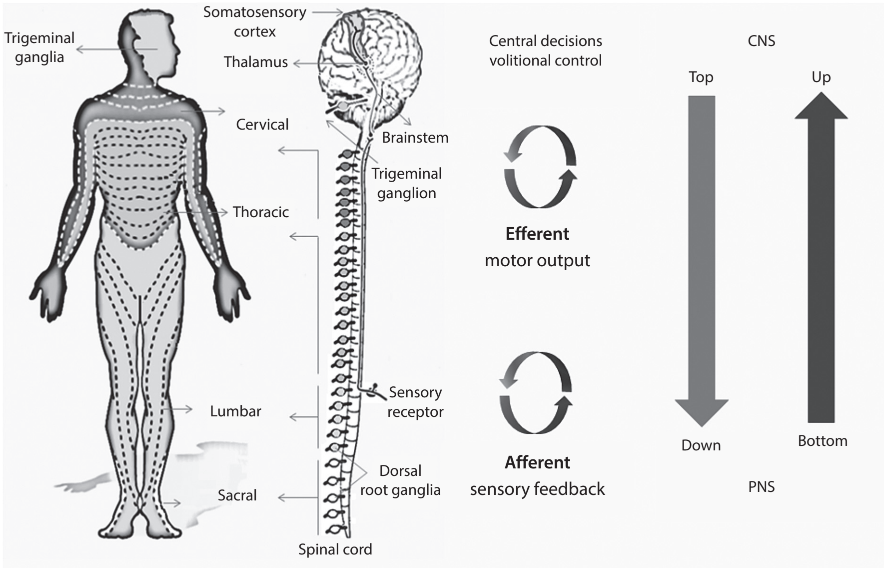

FIGURE I.2 Sensory-motor maps, nerves, and ganglia across the body and face project to cortical maps. The development of these underlying systems scaffold bottom-up and top-down interactions that enable subsequent cognitive decisions and sociomotor behaviors.

physical action. Yet these views tend to operate in the "here and now," whereby the sensory-motor loops are conceived as directly dependent on each other's currently experienced or enacted activity: the organism senses its self-produced motions and the self-produced motions affect the organism's sensations. The overall idea is in tune with the original principle of reafference by Von Holst (Von Holst and Mittelstaedt 1950), which we mentioned in Chapter 1: "Voluntary movements show themselves to be dependent on the returning stream of afference which they themselves cause." Without a doubt, the concept is a powerful one, but to direct the sensory organs to optimally sample the external world for successful purposeful and social behaviors, and to integrate that information in a timely manner with the continuous internal flow of somatic motor information, the organism will necessarily have to be a step ahead of the self-produced and self-sensed movements. Internal sensory-motor transduction and transmission delays vary with the stimuli. These variations forcedly require anticipating the sensory-motor consequences of impending actions, decisions, and thoughts. Compensating for such delays are among the tenets of contemporary internal models for action (IMAs) (e.g., Kawato and Wolpert 1998; Wolpert et al. 1998). However, such models have yet to provide appropriate statistical frameworks to track the unfolding of these processes in real time, and to account for their neurodevelopmental evolution (as discussed in Torres 2016). As in the above-mentioned cognitive approaches, the proposition of the IMA refers to the by-product of a maturation process, a process already taking place within a steady-state system. This formulation of the problem leaves out an avenue for the discovery of self-emergent phenomena in the nascent nervous systems of the newborn infant, developing adaptable interfaces to connect the fast-changing brain and body.

Throughout this book, we will introduce the notion of measuring, through the multilayered historicity of self-produced biophysical rhythms, the very sensory consequences that impending activity may have on the organism's experience of the world. It is our proposition that the evolving balance between this uncertainty of predicted consequences and the self-confirmation the developing organism attains over time is what forms the self-discovered notion of cause and effect. This important notion in turn leads to body ownership and agency, required ingredients to bridge physical volition to the type of mental intent that the above-mentioned cognitivist, enacted cognition, and neuromotor control approaches already take for granted.

The emergence of motor intent and its mental formulation require a maturation process that we can witness surfacing in the neurodevelopmental arena of a newborn infant (Torres et al. 2016). Part of this process includes attaining a proper balance between the actual consequences of the actions and those that the organism learns to predict from both spontaneous activity and active trial-and-error statistical sampling. When successful, these processes are then conducive of neurodevelopment oriented to embed the social medium in the organism's nervous systems and to project the organism's nervous systems' signatures onto the social medium. Such a mapping, when attained, leads to social life, whereby the organism becomes an integral part of the collective and the collective embraces the organism as one of its kind. When these evolving processes fail to occur, or when they derail, we come to witness impairments in social interactions between the organism's nervous systems and the social environment, but such impairments (as in the case of ASD) develop as well between the social environment and the organism's nervous systems, which the social medium fails to embrace.

We close this section of the book with the proposition that a *bottom-up* approach to neurodevelopment at the early stages may be more appropriate to capture the dynamic and variable nature of the nervous systems in transition to deliberate autonomy of the brain over the body (Figure I.2). Indeed, the emergence of an intentional brain that finds a way to deliberately control the body at will, a body that it gradually learns to own, may be better captured with methods that first track this emergent property from the periphery (Torres et al. 2013, 2016; Brincker and Torres 2013). The question then is how the autonomic nervous systems contribute in the early stages of life to the eventual maturation of the cognitive systems that these *top-down* cognitivist theories make reference to? How are affect, emotion, and logical reasoning gradually acquired, maintained, and modified through sensory, somatic motor loops?

To begin this line of inquiry, we need tools, and new data types, to quantify *change*, its rate, and the relationship between physical growth and the emergence of the balance between autonomous and voluntary neuromotor control (e.g., Torres et al. 2016). The quantification of such change in the organism as part of a group, and of the group as a whole operating organismic entity, is a new challenge for the social sciences to explore. In the next sections, we invite some thoughts along these lines in view of the critical need for early detection of stunting of neurodevelopment at large and of the consequences this may have for social exchange.

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