Consciousness and Cognition 20 (2011) 109–119

Contents lists available at ScienceDirect

Consciousness and Cognition

journal homepage: www.elsevier.com/locate/concog

The self as phenotype

Philippe Rochat *

Department of Psychology, Emory University, 36 Eagle Row, Atlanta, GA 30322, USA

A R T I C L E I N F O

Article history:
Available online 8 December 2010

Keywords:
Self-awareness
Infant and child development
Brain development

A B S T R A C T

Self-awareness is viewed here as the phenotypic expression of an interaction between genes and the environment. Brain and behavioral development of fetuses and newborn infants are a rich source of information regarding what might constitute minimal self-awareness. Research indicates that newborns have feeling (subjective) experience. Unlike automata, they do not just sense and respond to proximal stimulations. In light of the explosive brain growth that takes place inside and outside of the womb, first signs of feeling as opposed to sensing experience are discussed. Feeling experience is considered as the necessary condition for having minimal self-awareness. Both would co-emerge in development. However, minimal self-awareness is rapidly supplemented with an awareness that is not just perceptual, but also conceptual and ethical, primarily defined in relation to and by others.

1. Introduction

What is a self and what qualifies for self-awareness? Much can be gained by addressing these questions in the light of ontogeny and the dynamic of changes. Development is too often forgotten in the debate on the nature and origins of self. Here, I want to re-visit these questions from a developmental perspective, in relation to both behavior and brain growth.

As a general framework, I propose to think of the self as a *phenotype*, in the literal sense of an *organism emerging from the interaction of the genotype and the environment.* At the origins, and at a basic level, it is perceived as something that has form and unity, a Gestalt that is more than the sum of its parts. The self is indeed an organism, in the dictionary sense of "a form of life composed of mutually interdependent parts that maintain various vital processes" or "a complex system having properties and functions determined not only by the properties and relations of its individual parts, but by the character of the whole that they compose and by the relations of the parts to the whole" (Random House, Unabridged Dictionary).

Here, the goal is to consider the origins of self-awareness in the light of the fast, highly programmed development of brain and behavior, within the maternal womb and beyond. We are interested in the predictable maturation of the nervous system's anatomy and functions that accompanies and supports less predictable, more open-ended behavioral development. Taking a developmental stance and parallel look at brain and behavior from conception to the point where children start expressing shame and self-consciousness, helps pondering the question of what qualifies for self-awareness and what changes in the course of early development. A developmental approach helps capturing the self as phenotype: an emerging and changing expression, rather than a static and disembodied form. This is the bet.

I will start discussing the basic criteria for having self-awareness. To capture the origins of such criteria, I try to link behavior and brain during the pre- and neonatal period of development. For the rest of the article, I review important transitions in the development of self-awareness, leading the child to become eventually self-conscious, ultimately *conscientious* (ethical) toward others from approximately 3 years of age. I consider some of the structural and functional brain changes

* Fax: +1 404 727 0372.
E-mail address: psypr@emory.edu

1053-8100/$ - see front matter © 2010 Elsevier Inc. All rights reserved.
doi:10.1016/j.concog.2010.09.012

that might be implicated in such development leading children toward becoming "free" (autonomous) moral agents. I view the phenotypic emergence of "conscientiousness" as a moral kind of self-awareness, the ultimate finality of child development demanded by all cultures.

2. Criteria for having self-awareness

It is common to link self-awareness to higher order cognitive processes associated with late developing cortical structures. From this perspective, one should not attribute any self- or other kinds of awareness to creatures that are not, or not yet endowed with higher cortical structures, namely a *mammalian forebrain*. But this view is challenged by empirical evidence of goal-directed, purposive behaviors in decorticated animals and anencephalic children (children born without cortex, see Merker (2007) for a cogent review). In general, it appears that self-awareness does not have to be explicit and mediated by higher symbolic processes like language. Infants as well as most animals could be endowed with the potential for self-awareness, depending on what criteria are used.

In his argument in support of a consciousness without cortex, Merker (2007) proposes that in "the most basic and general sense" what qualifies for consciousness (here by extension awareness and self-awareness), is "the state or condition presupposed by any experience whatsoever" (p. 63). This would mean that only "experiencing" creatures could be self-aware: those who are capable of having subjective "what it is like" experience. Such proposal, however, begs the question of what qualifies for having "any experience whatsoever?" In particular, what is having experience vs. not having experience?

I submit that to have experience is to have an affective life that is made of perceived values (or qualities) such as pain, pleasure or cravings. Having experience, hence having an affective life, should transcend the mere recording of raw sensations as "signals" by an organism. Inversely, not having experience is to sense the world by simply recording raw sensory signals that trigger automatic, predictable responses like in the output behaviors of computers or thermostats. These automata sense but do not feel. One entails minimal subjective experience (feelings), not the other, even though output behaviors might be homologous for third party observers (e.g., fleeing of a cockroach vs. the fleeing of a foot soldier under attack).

Feelings as opposed to raw sensory signals are expressed in emotions via particular bodily movements (e.g., facial expressions; particular dynamic of motion or signaling like in screaming). It is the affective life revealed in emotions that distinguishes sentient creatures from mere machines and automata. The former feel and are potentially conscious, the latter are not. Feeling experience adds values to an organism's encounter with the world. More importantly, in relation to self-awareness, it gives *purpose* and *orientation* to the actions performed by that organism.

This, I will suggest, is the constitutive element of any form of what we refer as consciousness (the state or condition presupposed by experience), and by extension the necessary pre-requisite of minimal self-awareness. We will see, for example, that it is in the feeling experience of purpose and orientation that infants from birth express an early ecological "feeling experience" of themselves as differentiated, situated, substantial, and eventually by 2 months as agent entities among other "distal" entities in the world.

Affectivity and emotions guide actions and elevate behaviors above the register of mere automatic and mechanistic responses. Automata respond, they do not act proper. Contrary to sentient (feeling) organisms, they respond like thermostats do in relation to temperature fluctuations within a pre-set, calibrated range. Thermostats do not act to avoid hot or cold, nor are they oriented toward a gain of comfort (pleasure or good feelings maintenance). Machines have however the superior power to find and apply algorithms to resolve complex problems with reliable success (see the chess match between I.B.M. Deep Blue machine and Garry Kasparov). Machines can, in some cold sense, think and resolve problems, but they cannot feel and for this reason have no potential for self-awareness, except maybe in science fictions (e.g., computer HAL 9000 experiencing "fear" in Clarke and Kubrick "2001 Space Odyssey").

The necessary qualifier for having minimal self-awareness is, accordingly, the feeling experience that elevates organisms from mere responders to volitional actors (goal oriented and purposeful beings in a world made of affective values: pleasures, pains, envies). Self-awareness would co-emerge with feeling experience, both mutually necessary and co-defining.

Self-awareness is therefore affective and emotional at the origin, rather than cognitive in the etymological sense of consciousness ("*con-scientia*" or "with-knowledge"). If self-awareness has anything to do with knowledge or cognition, it is with "hot", not cold cognition: what feels good or bad, what is pleasurable or not, ultimately what feels right and what feels wrong.

Children in their development, as I will try to show, demonstrate that the explicit conscious "content" of the self (explicit and conceptual awareness of Me) rests upon and is eventually added to this basic pre-reflective and implicit affective process that distinguishes us from machines. But this implies major steps in brain and behavior development.

Within this theoretical framework, the question is: when can we say that an organism has feeling experiences, hence fills the criteria for having minimal self-awareness? Do cockroaches feel? Are cold blood species (fish, octopus, reptiles) and those who did not evolve a mammalian brain precluded from having self-awareness? Do birds feel? What about human fetuses or young infants? When do we start to feel, hence have the potential to be self-aware?

Looking at the brain, isolating neural networks and brain structures that are predictably associated in time with feeling experiences can help determining whether an organism "feels" something and might be endowed with subjective experience, therefore qualifies for potential self-awareness. Inversely, just looking at behavior and emotional expressions that are predictably associated with feeling experiences (e.g., pain) can do the same. But first, "peripheral" receptor systems (e.g., pain, auditory, vestibular, light, olfactory, or gustatory sensitivity) have to be functional and connected (projecting) to some higher centers of the nervous system for further processing and motor/vegetative responses.

A rich body of evidence points to the fact that, in humans, the potential for self-awareness might already be expressed at birth, possibly even during the last weeks of gestation. This is rather revolutionary considering that not so long ago, the idea of feeling-less infants (i.e., non verbal children) was the default assumption. The Zeitgeist was to deny infants any form of worthwhile feeling experience (phenomenal awareness). Proof of it is that in the 1940s and 1950s, surgery without anesthesia was routinely performed on infants and young children. Modern surgeons conveniently paralyzed squirming infants by injection of Curare or similar paralytic agents. Under such circumstances, adults recalled excruciating pain during surgery. But patients were not believed and the practice went on for 20 years. As pointed out by Dennett (1981): "The fact that most of the patients were infants and small children may explain this credibility gap" (p. 201). Even today, local anesthetics are not routine in painful procedures on newborns such as heel prick and circumcision, even by pediatricians practicing in state of the art maternity hospitals. The Zeitgeist continues to be that infants have either no feelings, less feelings, or that feeling experience at this early stage might not be as consequential for lack of memory (infantile amnesia). Such rationale raises questions when looking at the brain and behavior in pre- and post-natal development.

3. Great momentum of brain growth

The basic facts about brain development that I briefly present are meant to remind us of the great biological momentum, epigenetic force and programming behind brain growth. What might correspond to the basic, necessary neurological pre-requisites for feeling experiences, is put in place only 8 weeks after conception. Here are some cardinal facts.

It takes only 4 weeks from conception for the neural tube to be formed from layers of cells on the embryonic disc (Hepper, 2002). Only one extra week is needed for the basic five parts structure of the brain to be anatomically differentiated and clearly visible (i.e., Telecephalon and Diencephalon of the Forebrain, Midbrain, Hindbrain and the Spinal cord) (Carlson, 1994). By 11 weeks, Medulla, Cerebellum, Inferior and Superior colliculus, as well as both Cerebral hemispheres covering the Diencephalon are also clearly visible.

From then on and for a few years, both hemispheres grow in surface areas via folding grooves and convolutions. This growth reflects rapid and exponential connection network among synapses as well as myelination of axons providing insulation (fatty "white matter") for better transmission of electrochemical nerve impulses. By 2 years of age, the child's brain weighs already 80% of its lifetime maximum weight (Kretschmann, Kammradt, Krauthausen, Sauer, & Wingert, 1986).

In terms of neural growth, between 10 and 26 weeks gestational age, neurons are produced at a rate of 250′000 a minute, leading to overproduction. Beyond 26 weeks, more than half of the produced nerve cells are selectively pruned and die. The surviving 100 billions will eventually form the adult brain (Oppenheim, 1991).

Regarding connection between cells, there is also an overproduction of synapses that continues beyond birth, with peaking periods that vary across brain regions (Rakic, 1972). Synaptogenesis continuing after birth is not homogeneous and synchronous across brain regions. For example, post mortem data indicate that synaptic density peaks earlier in the auditory cortex (3 months) compared to the middle frontal gyrus (15 months, Huttenlocher & Dabholkar, 1997). This kind of growth asynchrony is reflected, for example, in the sequential development of sense modalities in the womb and beyond (i.e., vision lag).

In short, these facts remind us that brain emergence is remarkably fast and programmed, literally an explosive growth. This development puts in place within 8 weeks the potential for fetuses to sense the world, eventually by the end of gestation also to feel it, hence to have the potential for minimal self-awareness. However, feeling experience rests on the pre-requisite of an ability to sense the world via systems that are in place and functional, the basis for primary sensitivity.

4. Emerging fetal sensitivity

Fetal sensitivity matures sequentially depending on the modality (Lecanuet & Schaal, 1996), recapitulating the evolutionary order of the main sensory systems (Gottlieb, 1971). Somesthetic sensitivity (skin and body feelings) matures first. This sensitivity corresponds to tactile (skin pressure), vestibular (posture and balance), and pain stimulation (tissue damage, see Merskey & Bogduk, 1994). It is followed by the maturation of chemosensory sensitivity that combines olfaction and gustation (i.e., smell and taste), followed by audition (pitch, amplitude, and phrasing of sounds), and finally by vision (light and optic array). Below are some relevant facts on the emergence of each sensory system, in the order of their functional emergence in pre-natal development.

4.1. Skin and body

Tactile and somatic sensitivity is already expressed by 8 weeks gestational age. Eight week-old, externalized fetuses display head movements away from an object touching their lips (Hooker, 1952). Nociceptive (pain) receptors appear first in and around the mouth area at around 7 weeks post conception. They rapidly extend to the palmar surface of the hands by 11 weeks, and the rest of the skin and mucosal surfaces by 20 weeks (Brusseau & Mashour, 2007; Smith, 1996).

4.2. Taste and smell

Fetuses are documented swallowing amniotic fluid by 12 weeks of gestation when chemo-receptors already pave the inside of the nose and the oral cavity. Chemo-sensation (sense of taste and smell combined) is evident when a sweet substance (sugar) is injected into the amniotic fluid, swallowing increases. It decreases with the injection of a "noxious" (iodinated poppy seed) substance (Schaal, Orgeur, & Rognon, 1995).

In multiple studies, Marlier and collaborators (Marlier, Schaal, & Soussignan, 1998a, 1998b) demonstrate that newborns manifest not only taste and smell discrimination, but also chemosensory *preferences* (preferential postural orientation of nose and mouth) that have been learned in the womb (e.g., smell of maternal amniotic fluid), a preference that perseverates days after birth.

4.3. Sounds and voices

Fetuses display bodily movements in response to sounds from 22 to 24 months. These movements reflect a complex auditory sensitivity to variations of sound's frequency, intensity, as well as duration (Hepper & Shahidullah, 1994). From 30 weeks gestational age, fetuses display heart rate acceleration at the onset of external airborne sounds they hear through the uterine wall, as well as vibroacoustic stimulations applied against the mother's abdomen (Kisilevsky & Hains, 2010; Lecanuet, Granier-Deferre, & Busnel, 1988). Based on habituation/dishabituation paradigms with extra-uterine speakers placed close to the mother, fetuses learn from approximately 32 weeks to discriminate structure characteristics of speech sounds. Changes in the order of two syllables composing a word like "babi" and "biba" are correlated with heart rate deceleration indexing an orienting response of the fetus (Lecanuet et al., 1987, 1988).

The womb is not sound proof, sounds travel through the amniotic fluid with the voice of the mother particularly amplified. In their niche, fetuses learn and develop preferences for familiar noise configurations. Based on an operant sucking paradigm, few hour old newborns are shown to discriminate and actively prefer to hear their mother's voice compared to another female's uttering the same phrases with the same intensity. This preferential discrimination is based on what infants heard and eventually learned in-Utero regarding their mother's voice characteristics (DeCasper & Fifer, 1980).

4.4. Light and dark

Light experience being greatly limited in the darkness of the womb explains the maturational delay of vision. However, fetal eye activities are recorded from 13 weeks gestational age, starting with downward movements of both eyes (12.5 weeks), slow eye movements (16 weeks), eye closing (20 weeks), rapid eye movements (23 weeks) and conjugate lateral eye movements by 24 weeks (deVries, Visser, & Prechtl, 1985). From approximately 26 weeks, change in heart rate and overall bodily movements are recorded in the fetus when a bright light is flashed on the mother's abdomen (Hepper, 2002).

Compared to audition, which is almost adult-like at birth, vision is noticeably poor in comparison. Babies are born with poor visual acuity and contrast sensitivity, in need of the rich illumination and much larger view outside of the womb to develop. Vision improves dramatically in the weeks following birth and within 6 months becomes close to adult-like, with detection of colors' full spectrum, sensitivity to movement parallax, contrast sensitivity, convergence and accommodation for objects at far distances (Kellman & Arterberry, 2006).

5. Pre-natal signs of feeling experience

By 30 weeks gestational age, fetuses display marked changes in their habituation to acoustic vibrations, coupling of movement to heart rate, as well as some indications that they might begin experiencing pain (Anand & Hickey, 1987). Such changes suggest a budding minimal experience of "what it is like" or phenomenal (P) consciousness (Block, 2007).

We read pleasure and pain in others, perceiving as well as eventually inferring feeling states. We do so primarily by perceiving organized patterns of outward bodily movements (e.g., facial expressions), either directly or linking them to perceived circumstances or events in the environment such as loud sound = startle = fear; needle prick = cry = pain; or tickle = giggle = pleasure. Animals evolved patterns of such recognizable bodily movements (emotions) rendering their feeling states public, accessible to others in communication (Darwin, 1872/1965). There is indeed an inherited equation between particular feeling experience and the expression of specific bodily patterns. This equation is directly perceived in communication (e.g., threat or fear bodily expressions as signs of aggressive or avoidant feeling states), but can also be inferred and made explicit in conversation at more advanced stages of development (e.g., the typical content of gossips and other folk theories that furnish our social lives).

In relation to issue of the self in development and within the proposed framework, the question is when do emotional patterns that are readily perceivable as standing for particular feeling states emerge in epigenesis? What might be the actual origins of emotional patterns that we perceive as standing for particular feeling states like pain, fatigue, or pleasure, all of which could be linked to minimal self-awareness? Newborns do cry when unmistakably in pain and smile when satiated, but what about fetuses?

New technological progress in real-time sonographic imaging of fetuses (2D-4D ultrasound, Hata, Dai, & Marumo, 2010) allow to study with great precision facial expressions that are universally recognized as standing for basic mental states. Ultrasonic imaging demonstrate that from *30 weeks* gestational age, fetuses display highly organized facial expressions that stand unambiguously for what we perceive as experiences of pleasure (smiling), displeasure (scowling), and fatigue (yawning). These patterns of emotional expressions are also readily observable immediately after birth.

When newborns fuss before feeding or smile away following a feed, we can assume that they are feeling either pain or intense pleasure, not just ''on or off'' hunger sensations that would set off some sort of thermostatic responses. Mental states and affective values most likely motivate newborns' behaviors, not just sensation as I will try to show next. Newborns do experience the world, including themselves, beyond the raw ''proximal'' sensations transducted on the surface of the sense receptors. They are not *just* stimulus-bound.

If clear, unambiguous emotional expressions can be detected in fetuses in the same way that they are readily observable in newborns, the inference of feeling states is not too far fetched, particularly in light of the abundance of data showing the remarkable behavioral continuity of pre-natal and post-natal development (Prechtl, 1984).

Recent use of fine grain 4-D ultrasonographic recordings confirm that no movements observed in the fetus during the last trimester of pregnancy (from at least 30 weeks) are not also expressed by neonates (deVries et al., 1985; Hepper, 2002; Prechtl, 1984). These include also, aside of unambiguous smiling and scowling, isolated eye-blinking, hand and finger movements, tongue protrusion, and all reflex responses displayed by newborns with the exception of the Moro reflex that requires space for the spreading of arms (Andonotopo & Kurjak, 2006; Andonotopo, Stanojevic, Kurjak, Azumendi, & Carrera, 2004).

Furthermore, by 36 weeks fetuses also show four well-defined grouping of behaviors (Sleep-Wake behavioral states) that would correspond to distinct levels of consciousness (levels of ''feeling'' experience). These patterns are stable and show clear transitions, respectively: *Quiet Sleep* (stable heart beat, no eye movements); *Active Sleep* (eye movements, body movements with heart rate acceleration); *Quiet Awake* (eye movements, stable heart rate), *Active Awake* (eye movements, unstable heart rate and bouts of tachycardia) (Hepper, 2002; Nijhuis, Prechtl, Martin, & Bots, 1982; Prechtl, 1977).

These patterns of behavioral states are observed in newborns and beyond via applicable electro-encephalographic (EEG) recordings. Starting a trend that will continue beyond birth, the proportion of time fetuses spend in an *Active Alert state* augments significantly during the last 4 weeks of gestation (from 6% to 9% of the time, Hepper, 2002; Prechtl, 1977). This developmental trend continues in the weeks following birth, infants spending an increasing amount of time in an active and awake behavioral ''feeling'' state (Wolff, 1987).

Finally, sensory evoked potential recorded in infants born premature, 10 week before term, indicates that minimal level of phenomenal consciousness might be present already by 30 weeks of gestational age as thalamo-cortical connections become functional (Klimach & Cooke, 1988), although continuing to develop markedly through adulthood with documented changes in childhood and adolescence (Fair et al., 2010).

As suggested by Fair et al., cortical-subcortical interactions must play a role in ''the shift from reflexive, stimulus-bound behavior in childhood, to the goal-directed and more flexible functioning found in adulthood'' (Fair et al., 2010, p. 2). However, cortico-subcortical interactions remain scarcely mapped in the perspective of fetal and infant development. However, as we will see next, early behavioral signs of such shift clearly exist in infancy, with precursor signs possibly manifested already by 32 weeks gestational age (see discussion above).

In this context, noteworthy is the observation that the significant increase of full range emotional expressions and facial movements observed in the fetus from 32 weeks of gestation is associated with a decrease of overall movements (Kurjak et al., 2006; Andonotopo et al., 2004; Hata et al., 2010). This growing expressive specificity is consistent with the normal neurological development of the fetus (Prechtl, 1997).

In summary, recent progress in fetal psychology research suggests that there are pre-natal signs of feeling experience. The well organized emotional expressions combined with the remarkable continuity of pre-natal and post-natal development supports the idea that first feeling experience, therefore the potential for minimal self-awareness, might emerge 8–10 weeks before birth (30–32 weeks gestational age). Keeping in mind the striking continuity of behaviors observed during the last 10 weeks of gestation and what can be readily observed and tested after birth (Prechtl, 1984), what can be seen in the newborn could stand also for what is not readily testable in the womb, from at least 32 weeks when fetal behaviors show all the aspects of what is observed after birth. I now turn to such demonstration.

6. Newborn feeling experience

Infancy research of the past four decades changed our views on the starting state of mental life, namely what is it like to be a newborn. Until then, developmental theorists tended to endorse the view, in their own ways, of an initial state of confusion with the environment, the famous initial ''blooming buzzing confusion'' proposed by James (1890). Neonates were presented as stimulus-bound, sensing but not feeling the world, their behavior primitively reduced to ready-made, evolved automatisms (reflexes or pulsions). Newborns' were thought to experience a world that was not yet objectified or differentiated, subjectivity and objectivity confounded and in need of progressive integration through experience (e.g., cognitive distancing and construction in the case of Piaget (1952, 1955), Ego development in the case of Freud's pulsion theory (Freud, 1905/2000).

More recent research shows that, in fact, healthy newborns do perceive the world objectively and are not in a state of subject–object confusion. From birth they express a difference between what pertains to their own body and what pertains to the world "out there". Within the proposed framework, infants at birth do not just sense and respond based on reflex-like mechanisms. More than thermostats functioning on the basis of on/off close-loop feedback, they also feel and act on objects that they experience as differentiated, distal, and situated in relation to them. This research demonstrates that infants from birth are capable of "feeling" not just "sensing" the world, demonstrating the potential for minimal embodied self-awareness. For sake of space, only a few evidence are reviewed here (for more, see Rochat (2001, 2010b)).

Although babies are born with poor contrast sensitivity and grating acuity (Banks & Shannon, 1993; Kellman & Banks, 1997), infancy researchers investigating newborn vision demonstrate that despite the obvious developmental lag of the modality, active perceptual processing does take place at birth. For example and relevant to our discussion, using habituation and novelty preference paradigms researchers have established that newborn infants, only a few hours old, when awake and alert, perceive the real (distal) size of objects, not the varying (proximal) sizes projected onto the retina. Newborns perceive size constancy of objects (Granrud, 1987; Slater, Mattock, & Brown, 1990), most likely via visuo-proprioceptive convergence cues from both eyes as they line their gazes and focus onto the distal object (Kellman & Arterberry, 2006).

What is particularly relevant to our discussion is that this kind of empirical evidence suggests that newborn infants have feeling experience, and are not just limited to sensing what is recorded at the proximal level of the receptors (i.e., the retina). But what does it say about self-awareness? If feeling experience is required for minimal self-awareness, what kind of evidence is there that newborns actually express such awareness?

Research shows that infants from birth are capable of perceiving their own body as an entity among other entities. An entity that has unity, is differentiated, occupies space, and is substantial. In addition, from at least 2 months of age, there is good evidence that infants have a sense of their own agency on objects, aware of themselves as embodied agent in the world (Rochat, 2001).

For example, we were able to show that newborn infants do discriminate between self-stimulation and stimulations coming from the outside world, suggesting that they are not in a state of confusion with the world outside. They root (i.e. orient head and mouth) significantly more toward the finger of an experimenter touching their cheek than their own hand spontaneously brought in contact with the peri-oral region of the face (Rochat & Hespos, 1997). We also showed that 2 month-olds are attentive and systematically explore the auditory consequences of their own action while sucking on a sound-producing pacifier (Rochat & Striano, 1999). They differentiate between sounds that are perfectly contingent but that are either analog or non-analog to the physical pressures they apply on the pacifier. In the context of our research, from 2 months of age (not at birth) infants show clear signs that they perceive themselves as agent of what they hear.

Other empirical observations demonstrate further the minimal self-awareness of neonates who seem to experience the world with an implicit differentiated sense of themselves as embodied perceivers. In their behavior, newborns confirm J.J. Gibson's (1979) idea that perceiving the world is co-perceiving the self. For example, there is some evidence that from birth infants differentiate movements of the own body (ego motions), from movements of objects and things in the world that occur independently of the self (allo motions). Newborns pick up visual information that specifies ego-motion or movements of their own body while they, in fact, remain stationary. These studies indicate that neonates experience an illusion of moving, adjusting their bodily posture according to changes in direction of an optical flow that is presented on TV monitors in the periphery of their visual field (Jouen & Gapenne, 1995). This kind of observations point to the fact that from birth, infants are endowed with the perceptual, qua inter-modal capacity to pick up and process meaningfully *self-specifying* information.

Other research indicates that neonates and young infants display an a priori proprioceptive sense of their own body in the way they act and orient to meaningful affordances of the environment (Ball & Tronick, 1971; Carroll & Gibson, 1981; E.J. Gibson, 1995; Van der Meer & Lee, 1995) as well as in the way they detect visual information that specifies ego motion, adjusting their posture appropriately in direction and amplitude to compensate for surreptitious changes in gravitational forces (Butterworth, 1992; Butterworth & Hicks, 1977).

In summary, newborns demonstrate minimal, implicit self-awareness in relation to physical objects, what Neisser (1988, 1991) first coined as the ecological self. Empirical research indicate that infants are born with a sense of themselves as differentiated and situated entities among other entities in the world they perceive as distal and distinct from the feeling experience of their embodied self. By 2 months, correlated with a sudden increase in the proportion of time spent awake and alert (Wolff, 1987), infants also manifest a sense of their own agency on both physical objects and people, what I view as indexing the "two month-revolution" (Rochat, 2001). This important transition has been identified and correlated with brain maturation, in particular the transition from the dominant control of behaviors by subcortical systems, to higher order cortical systems (McGraw, 1942). A major index of the two-month revolution is the emergence of a more contemplative stance taken by infants in their attention to events and things, together with (and not the least), the emergence of socially elicited smiling in relation to people (Wolff, 1987; Rochat, 2001).

However, the implicit minimal self-awareness changes rapidly, from the time it is expressed by neonates, and possibly even older fetuses during the last 10–8 weeks of gestation. It is supplemented with an awareness of self that becomes explicit and conceptual. We now turn to this development.

7. Emerging idea of Me

From around 18 months, parallel to the emergence of grammatically articulated language as well as the explosion of a children's vocabulary (including personal pronouns and adjective like "Me" and "Mine!" (Bates, 1990; Tomasello, 1998), children start to express much more than implicit (minimal) self-awareness. They become explicitly *self-conscious*. They are newly capable of re-cognizing themselves for themselves, inclined to work on their self-presentation with others in mind, hence begin to manifest radically novel feeling experiences that are determined by what children now perceive and construe of the evaluative eyes of others onto themselves (Rochat, 2009). They show first explicit signs of self-conscious emotions such as embarrassment, but also shame, pride, contempt, guilt, even hubris and contempt (Kagan, 1981; Lewis, 1992).

From this point on, minimal self-awareness is not simply replaced and does not disappear as a kind of feeling experience. It remains implied in perceptions and actions that are not under explicit conscious control, which is the case for most perceptions and acts that are ritualized, automatic, and routinely performed all through the lifetime. However, from the middle of the second year, minimal self-awareness is supplemented, and often in competition with a self-awareness that is explicit and conceptual, what James (1890) referred to as the distinct idea of *Me* that he contrasted with the implicit sense of *I*, here referred as minimal self-awareness.

From the point of view of brain growth, there is a developmental synchrony between emerging meta-cognitive abilities around 2–3 years of age, potentially turned toward the self, and the documented ontogenetic maturation of the rostrolateral region of the prefrontal cortex. The growth of this region would correlate with the development of new levels of consciousness, in particular the transition from minimal to meta-cognitive levels of self-consciousness (Bunge & Zelazo, 2006; Zelazo, Hong Gao, & Todd, 2007).

Likewise, and in a related fashion, same prefrontal regions of the cortex that come on line in development are correlated with progress in the cognitive control underlying "executive function": the ability to pause and reflect before a decision to act, the capacity inhibit first impulse for action.

Similar models exist in the animal literature in relation to the search of hidden objects by rhesus monkeys and young infants in the context of object permanence and the famous A-Not-B error first described by Piaget (Diamond & Goldman-Rakic, 1989; Piaget, 1936/1952). These prefrontal cortex regions are known to develop steadily, but at different rates, coming chronologically on-line through childhood (see Gogtay et al., 2004). Each of these prefrontal cortex regions would be linked to particular levels of cognitive control achieved by the child (Zelazo, 2004; Zelazo et al., 2007).

Bunge and Zelazo (2006) distinguish four types of rules in a sorting card game they use to test children (from simple stimulus-reward to complex higher order "meta" rules), indexing various levels of cognitive control children achieve in early development. These levels of cognitive control would, for these authors, correspond to levels of self-awareness as they are directly linked to children's executive functioning when for example they try to resolve a problem or anticipate events.

Children would develop self-consciousness and recursive consciousness by "the iterative reprocessing of the contents of consciousness via thalamocortical circuits involving regions of prefrontal cortex" (Zelazo et al., 2007, p. 224). Each reprocessing of the content of consciousness, starting with minimal consciousness and self-consciousness at birth, would require the recruitment and "excitability" of yet another region of the prefrontal cortex (Rochat, 2010a).

Four cortical regions are identified as maturing in succession by Zelazo et al. (2007): the orbitofrontal, ventrolateral, dorsolateral, and the rostrolateral regions of the prefrontal cortex. Based on both developmental neuroscience (EEG, PET), animal models, and neurological case studies, each of these regions would control for particular levels of executive functioning and rule use, extended to the development of self-awareness: from simple to more complex, eventually reflective and evaluative self-awareness**,** the latter particularly linked to the maturation of the rostrolateral region of the prefrontal cortex (Bunge, 2004; Bunge & Zelazo, 2006).

The development of self-consciousness and bodily awareness, like the development of the ability to use rules to inhibit inappropriate behaviors at higher levels of complexity, would "mirror the protracted developmental course of the prefrontal cortex" (Zelazo et al., 2007, p. 412).

An important aspect of the proposed brain-based model of developing self-consciousness is that such development starts off with the innate prescription of a minimal level consciousness**.** In relation to the own body and self-consciousness in general, such development does not start from scratch, but rather rests on the primary requirement of a minimal experiential awareness of the embodied self that would be already signified prenatally (Rochat, 2010a).

At a behavioral level, the mirror mark test (self-directed behaviors toward a mark surreptitiously put on the face and discovered in the mirror) established some 40 years ago by (Amsterdam, 1968, 1972; and Gallup, 1970) continue to be viewed as the "acid acid test" of self-consciousness in both the developmental and the comparative literature (see Gallup, 1970; Lewis, 1995). In general, the rationale is that self-directed behavior toward the mark would presuppose some form of explicit and conceptualized self-awareness (but see the recent critic of such purely cognitive view in Rochat and Zahavi (2010)). A majority of children are documented passing the mirror mark test from around 21 months (Amsterdam, 1972; Lewis & Brooks-Gunn, 1979), although recent findings suggest that it might greatly vary depending on the cultural and developmental niche of the child (Broesch, Callaghan, Henrich, & Rochat, 2010). In her pioneer study of children's reaction to the mirror in the context of the mark test, Amsterdam (1968, 1972) describes four developmental phases emerging in succession between 3 and 24 months. In a first period extending from 3 to 11 months, children treat their own image as a playmate, expressing mainly social invitations toward the specular image. In a second period (11–12 months) children start to explore the mirror proper, its surface and texture, often searching behind it. By 13 months, children begin to show marked increase in withdrawal behaviors, avoiding looking at the mirror, hiding from it and even sometime crying. From 14 months and peeking by 20 months, children show unmistakable signs of embarrassment and coy glances toward the specular image. These observations point to the complex cognitive and affective aspects of children's developing reactions to their own mirror reflection (Amsterdam & Greenberg, 1977; Amsterdam & Levitt, 1980). In particular, the generalized embarrassment children express by either by hiding from or clowning in front of the mirror (two opposite forms of explicit self-consciousness) demonstrate the growing social connotation of mirror self-experience: the fear or weariness of being ultimately judged (Rochat & Zahavi, 2010).

It appears that the evaluative gaze of others begin to weigh heavily on the child's mind, indexing genuine emergence of self-consciousness, in the literal English sense of being aware and weary of how others perceive and represent the self. From the middle of the second year, children begin to show signs that they care about reputation, a uniquely exacerbated human trait and a major determinant of self-awareness beyond infancy and through the lifetime (Rochat, 2009).

The social dimension of self-consciousness is unmistakable in the fact that as children begin to show explicit self-concept using personal pronouns, engaging in pretense, covering up, putting up faces, or working on self-presentation, they also display a growing sense of rules and norms, the way things "ought to be" (Kagan, 1981). By the time children begin to recognize themselves in mirrors (21 months), they also tend to assert their own territory and possession over things, stating that "it's Mine!", implying "... it's not yours!" (Rochat, in press). This development is significant and marks what can be viewed as an ultimate step: an awareness of self that is situated in a moral space made of shared values.

8. Emergence of moral self-awareness by 3–5 years

Charles Taylor (1989) makes the point that developing self-awareness is ultimately becoming conscientious and mindful of self in relation to others: "What we are constantly losing from sight (...) is that being a self is inseparable from existing in a space of moral issues, to do with identity and how one ought to be. It is being able to find one's standpoint in this space, being able to occupy a perspective in it" (Taylor, 1989, p. 112). This aspect might be an ultimate achievement and a primary goal of children's socialization that constrains them to share, reciprocate, and to tame a natural inclination toward selfishness.

From 5 years of age, children start to factor the perspectives of others on the world, their mind states, and motives, allowing them to predict for example whether they hold correct or false beliefs (Wellman & Liu, 2004). This development is universal (Callaghan et al., 2005) and continues beyond 5 years of age with increased expression of inequity aversion (Fehr, Bernhard, & Rockenbach, 2008) as well as more complex considerations of what constitutes equity and relative sacrifice in sharing (McCrink, Bloom, & Santos, 2009).

Parallel to the emergence of explicit theories of mind between 3 and 5 years, children develop an ethical stance and become "principled", ready to sacrifice some of their own resources to make a "moral" point (Robbins & Rochat, 2010). The ethical stance taken by children from 5 years of age indexes a new kind of self-awareness that emerges from the ethical feeling experience of what feels right and what feels wrong relative to others.

Moral self-awareness and the taking of an ethical stance by which one acts "principled" depends on some control over selfish propensities: the propensity to maximize gains for self and to be primarily centered on one's own motives and perspectives. In relation to the brain, such development is likely to be linked to the growing ability in executive functioning, in particular the ability to inhibit basic "selfish" propensities and immediate self-gratification to consider the motives, mind states, and perspectives of others, a "mentalizing" ability that is lacking in autism (Frith & Frith, 2003).

In the context of theories of mind and false belief understanding, research indicates that such executive functioning and mentalizing process are linked to prefrontal regions of the brain that would presumably come on-line at around 5 years of age in the healthy child (Gallagher & Frith, 2003). Such regions include the medial prefrontal cortex, once again a late maturing brain system linked to higher order processing of neural signals (Gallagher & Frith, 2003; but see also Saxe & Kanwisher, 2003; Saxe, Moan, Scholz, & Gabrieli, 2006).

9. Summary and conclusions

Infancy and fetal psychology research supports the idea that minimal self-awareness is deeply rooted in epigenesis, possibly manifested already by 30–32 weeks gestational age. I proposed that such embodied awareness co-emerge with the ability of an organism to have "feeling" experience. Research points to the fact that newborns, and possibly older fetuses are more than automata. They do not just sense the world by responding to proximal stimulation hitting their receptors. Aside from reflexes, they perceive and act toward distal objects and events that are not confounded with their own subjective experience. Self-world differentiation is indeed an early fact of life.

Such evidence needs to be considered in light of the explosive brain growth that takes place from the embryo stage of child development, as part of a powerful epigenetic momentum. Self-awareness needs to be construed as the phenotypic expression of such momentum, exacerbated and protracted in humans beyond birth (Konner, 2010). Minimal awareness of the body as a differentiated, situated, and substantial entity among other entities (implicit ecological self) expressed at birth is rapidly supplemented with an implicit awareness of the self as agent in the world.

By 2 months, infants explore systematically the perceptual consequences of their own actions. They adopt a contemplative stance toward objects and people. A cardinal index of this new stance is the emergence of socially elicited smiling, aside from significantly more time spent in an alert and awake state. This ''two-month revolution'' has been linked to the maturation of thalamo-cortical connections, allowing greater cortical control of behaviors. By 18 months, self-awareness develops to become conceptual in addition to being perceptual. Children start to demonstrate explicit recognition and signs of embarrassment (self-consciousness) when viewing themselves in mirrors, in parallel to first uses of personal pronouns and adjectives like ''Me'' and ''Mine''. Increasingly, they appear to behave with others in mind, construing how others might represent and evaluate them. Self-consciousness is associated with the maturation and the coming on-line of various regions of the prefrontal cortex that continues to mature up to 5 years of age and probably beyond.

As children become self-conscious, they begin to care about reputation and demonstrate growing concerns regarding norms, rules, and regulations. As part of such growing concerns, children become also proactive in asserting their own entitlement to things (i.e., claimed possessions). This creates a rich soil for the ultimate development of the moral self-awareness emerging between 3 and 5 years as children show first signs of taking an ethical stance. They become *conscientious* of others in addition to being self-conscious and self-assertive. They show first signs of becoming ''autonomous or free'' moral agents.

From then on, children start the lifelong quest of finding a perspective in a space of moral values that is shared and recognized by others. In development, the moral self is an ultimate expression of the interaction between genes and the environment, an expression demanded by all human cultures.

So, what is a self and what qualifies for self-awareness? I tried to show that it is helpful to consider these perennial questions in the perspective of early, even pre-natal development as organisms grow from just sensing to actually feeling the world. Feeling experience would give any organism the potential for being minimally self-aware, something that appears to be readily demonstrated by neonates. The question of how minimal self-awareness (''I'') relates to later developing conceptual and moral self (''Me'') remains an open question that should guide future research. What is certain is that much can be gained from considering how brain, body, and environment interact to produce the self as phenotype.

Acknowledgments

Gratitude is expressed (by alphabetical order) to Michel Heller, Claudia Passos-Ferreira, and Erin Robbins for their constructive criticisms and feedback on an earlier version of this article.

References

Amsterdam, B. K. (1968). Mirror behavior in children under two years of age doctoral dissertation. Univ. North Carolina. Order no. 6901569; University Microfilms, Ann Arbor, MI. 48106.

Amsterdam, B. (1972). Mirror self-image reactions before age two. *Developmental Psychobiology, 5*, 297–305.

Amsterdam, B. K., & Greenberg, L. G. (1977). Self-conscious behavior of infants. *Developmental Psychobiology, 10*, 1–6.

Amsterdam, B. K., & Levitt, M. (1980). Consciousness of self and painful self-consciousness. *Psychoanalytic Study of the Child, 35*, 67–83.

Anand, K. J. S., & Hickey, P. R. (1987). Pain and its effects in the human neonate and fetus. *New England Journal of Medicine, 317*, 1321–1329.

Andonotopo, W., & Kurjak, A. (2006). The assessment of fetal behavior of growth restricted fetuses by 4D sonography. *Journal of Perinatal Medicine, 34*, 471–478.

Andonotopo, W., Stanojevic, M., Kurjak, A., Azumendi, G., & Carrera, J. M. (2004). Assessment of fetal behavior and general movements by four-dimensional sonography. *Ultrasound Review of Obstetrics and Gynecology, 4*, 103–114.

Ball, W., & Tronick, E. (1971). Infant responses to impending collision: Optical and real. *Science, 171*, 818–820.

Banks, M. S., & Shannon, E. S. (1993). Spatial and chromatic visual efficiency in human neonates. In C. E. Granrud (Ed.), *Carnegie-Mellon symposium on cognitive psychology* (pp. 1–46). Hillsdale, NJ: Erlbaum.

Bates, E. (1990). Language about me and you: Pronominal reference and the emerging concept of self. In D. Cicchetti & M. Beeghly (Eds.), *The self in transition: Infancy to childhood* (pp. 165–182). Chicago: University of Chicago Press.

Block, N. (2007). Consciousness, accessibility, and the mesh between psychology and neuroscience. *Brain and Behavioral Sciences, 30*, 481–548.

Broesch, T., Callaghan, T., Henrich, J., & Rochat, P. (2010). Cultural variations in children's mirror self-recognition. *Journal of Cross-Cultural Psychology*, in press.

Brusseau, R. R., & Mashour, G. A. (2007). Subcortical consciousness: Implications for fetal anesthesia and analgesia. *Behavioral and Brain Sciences, 30*(1), 86–87.

Bunge, S. A. (2004). How we use rules to select actions: A review of evidence from cognitive neuroscience. *Cognitive, Affective, and Behavioral Neuroscience, 4*, 564–579.

Bunge, S. A., & Zelazo, P. D. (2006). A brainbased account of the development of rule use in childhood. *Current Directions in Psychological Science, 15*, 118–121.

Butterworth, G. (1992). Origins of self-perception in infancy. *Psychological Inquiry, 3*(2), 103–111.

Butterworth, G., & Hicks, L. (1977). Visual proprioception and postural stability in infancy: A developmental study. *Perception, 6*, 255–262.

Callaghan, T., Rochat, P., Lillard, A., Claux, M. L., Odden, H., Itakura, S., et al (2005). Synchrony in the onset of mental-state reasoning: Evidence from five cultures. *Psychological Science, 16*(5), 378–384.

Carlson, B. M. (1994). *Human embryology and developmental biology*. St. Louis: Mosby.

Carroll, J. J., & Gibson, E. J. (1981). Differentiation of an aperture from an obstacle under conditions of motion by 3-month-old infants. In Paper presented at the meetings of the society for research in child development, Boston, MA.

Darwin, C. (1872/1965). *The expression of the emotions in man and animals*. Chicago: Chicago University Press.

DeCasper, A. J., & Fifer, W. P. (1980). Of human bonding: Newborns prefer their mother's voices. *Science, 208*, 1174–1176.

Dennett, D. C. (1981). *Brainstorms: Philosophical essays on mind and psychology*. Cambridge, MA: M.I.T. Press Bradford Books Series.

deVries, J. I. P., Visser, G. H. A., & Prechtl, H. F. R. (1985). The emergence of fetal behavior: II. Quantitative aspects. *Early Human Development, 12*, 99–120.

Diamond, A., & Goldman-Rakic, P. S. (1989). Comparison of human infants and rhesus monkeys on Piaget's A not B task: Evidence for dependence on dorsolateral prefrontal cortex. *Experimental Brain Research, 74*, 271–294.

Fair, D. A., Bathula, D., Mills, K. L., Costa Dias, T. G., Blythe, M. S., Zhang, D., et al (2010). Maturing thalamocortical functional connectivity across development. *Frontiers in Systems Neuroscience, 4*(10), 1–10.

Fehr, E., Bernhard, H., & Rockenbach, B. (2008). Egalitarianism in young children. *Nature, 454*, 1079–1084.

Freud, S. (1905/2000). *Three essays on the theory of sexuality*. NY: Basic Books Classics series.

Frith, U., & Frith, C. D. (2003). Development and neurophysiology of mentalizing. *Philosophical Transactions of the Royal Society of London Series B – Biological Sciences, 358*(1431), 459–473.

Gallagher, H. L., & Frith, C. D. (2003). Functional imaging of 'theory of mind'. *Trends in Cognitive Sciences, 7*(2), 77–83.

Gallup, G. G. (1970). Chimpanzees: Self-recognition. *Science, 167*, 86–87.

Gibson, J. J. (1979). *The ecological approach to visual perception*. Boston: Houghton Mifflin.

Gibson, E. J. (1995). Are we automata? In P. Rochat (Ed.), *The self in infancy: Theory and research* (pp. 1–23). Amsterdam: North-Holland/Elsevier Science.

Gogtay, N., Giedd, J. N., Lusk, L., Hayashi, K. M., Greenstein, D., Vaituzis, A. C., et al (2004). Dynamic mapping of human cortical development during childhood through early adulthood. *Proceedings of the National Academy of Sciences USA, 101*, 8174–8179.

Gottlieb, G. (1971). Ontogenesis of sensory functions in birds and mammals. In A. Tobach, L. R. Aronson, & E. Shaw (Eds.), *The biopsychology of development* (pp. 67–128). NY: Academic Press.

Granrud, C. E. (1987). Size constancy in newborn human infants. *Investigative Opthalmology and Visual Science, 28*(Suppl.), 5.

Hata, T., Dai, S. Y., & Marumo, G. (2010). Ultrasound for evaluation of fetal neurobehavioural development: From 2-D to 4-D ultrasound. *Infant and Child Development, 19*(1), 99–118. Special issue: Towards a fetal psychology.

Hepper, P. G. (2002). Prenatal development. In A. Slater & M. Lewis (Eds.), *Introduction to infant development*. NY: Oxford University Press.

Hepper, P. G., & Shahidullah, S. (1994). Development of fetal hearing. *Fetal and Maternal Medicine Review, 6*, 167–179.

Hooker, D. (1952). *The prenatal origin of behavior*. Kansas: University of Kansas Press.

Huttenlocher, P. R., & Dabholkar, A. S. (1997). Regional differences in synaptogenesis in human cerebral cortex. *Journal of Comparative Neurology, 387*(2), 167–178.

James, W. (1890). *The principles of psychology*. NY: Henry Holt & Company.

Jouen, F., & Gapenne, O. (1995). Interactions between the vestibular and visual systems in the neonate. In P. Rochat (Ed.), *The self in infancy: Theory and research* (pp. 277–302). Amsterdam: North-Holland/Elsevier Science.

Kagan, J. (1981). *The second year: The emergence of self-awareness*. Harvard University Press.

Kellman, P. J., & Arterberry, M. E. (2006). Infant visual perception. In D. Kuhn, R. S. Siegler, W. Damon, & R. M. Lerner (Eds.), *Handbook of child psychology* (6th ed.. *Cognition, perception, and language* (Vol. 2, pp. 109–160). Hoboken, NJ: Wiley.

Kellman, P., & Banks, M. S. (1997). Infant visual perception. In R. Siegler & D. Kuhn (Eds.), *Handbook of child development* (5th ed.. *Cognition, perception, and language* (Vol. 2, pp. 103–146). New York: Wiley.

Kisilevsky, B. S., & Hains, S. M. J. (2010). Exploring the relationship between fetal heart rate and cognition. *Infant and Child Development, 19*(1), 60–75. Special issue: Towards a fetal psychology.

Klimach, V. J., & Cooke, R. W. (1988). Maturation of the neonatal somatosensory evoked response in preterm infants. *Developmental Medicine and Child Neurology, 30*(2), 208–214.

Konner, M. (2010). *The evolution of childhood*. Cambridge, MA: Harvard University Press.

Kretschmann, H. J., Kammradt, G., Krauthausen, I., Sauer, B., & Wingert, F. (1986). Brain growth in man. *Bibliotheca Anatomica, 28*, 1–26.

Kurjak, A., Andonotopo, W., Hafner, T., Salihagic-Kadic, A., Stanojevic, M., Azumendi, G., Ahmed, B., Carrera, J. M., & Troyano, J. M. (2006). Normal standards for fetal neurobehavioral developments – longitudinal quantification by four-dimensional sonography. *Journal of Perinatal Medicine, 34*, 56–65.

Lecanuet, J.-P., Granier-Deferre, C., & Busnel, M.-C. (1988). Fetal cardiac and motor responses to octave-band noises as a function of central frequency, intensity and heart rate variability. *Early Human Development, 18*, 81–93.

Lecanuet, J.-P., Granier-Deferre, C., DeCasper, A. J., Maugeais, R., Andrieu, A.-J., & Busnel, M.-C. (1987). Perception et discrimination foetales de stimuli langagiers, mise en évidence à partir de la réactivité cardiaque, résultants préliminaires. *Compte-Rendus de l'Académie des Sciences, Paris (III), 305*, 161–164.

Lecanuet, J. P., & Schaal, B. (1996). Fetal sensory competencies. *European Journal of Obstetrics & Gynecology and Reproductive Biology, 68*, 1–23.

Lewis, M. (1992). *Shame: The exposed self*. New York: Free Press.

Lewis, M. (1995). Aspects of the self: From systems to ideas. In P. Rochat (Ed.), *The self in infancy: Theory and research* (pp. 95–116). Amsterdam: North-Holland, Elsevier Publishers.

Lewis, M., & Brooks-Gunn, J. (1979). *Social cognition and the acquisition of self*. New York: Plenum Press.

Marlier, L., Schaal, B., & Soussignan, R. (1998). Neonatal responsiveness to the odor of amniotic and lacteal fluids: A test of perinatal chemosensory continuity. *Child Development, 69*(3), 611–623.

Marlier, L., Schaal, B., & Soussignan, R. (1998b). Bottle-fed neonates prefer an odor experienced in utero to an odor experienced postnatally in the feeding context. *Developmental Psychobiology, 33*, 133–145.

McCrink, K., Bloom, P., & Santos, L. R. (2009). Children's and adults judgments of equitable resource distributions. *Developmental Science, 13*, 37–45.

McGraw, M. B. (1942). *The neuromuscular maturation of the human infant*. NY: Columbia University Press.

Merskey, H., & Bogduk, N. (Eds.). (1994). *Classification of chronic pain: Descriptions of chronic pain syndromes and definitions of pain terms* (pp. 209–214). NY: IASP Press.

Merker, B. (2007). Consciousness without a cerebral cortex: A challenge for neuroscience and medicine. *Behavioral and Brain Sciences, 30*, 63–134.

Neisser, U. (1988). Five kinds of self-knowledge. *Philosophical Psychology, 1*, 35–59.

Neisser, U. (1991). Two perceptually given aspects of the self and their development. *Developmental Review, 11*(3), 197–209.

Nijhuis, J. G., Prechtl, H. F. R., Martin, C. B., & Bots, R. (1982). Are there behavioral states in the human fetus? *Early Human Development, 6*, 177–195.

Oppenheim, R. W. (1991). Cell death during development of the nervous system. *Annual Review of Neuroscience, 14*, 453–501.

Piaget, J. (1936/1952). *The origins of intelligence in children*. New York: International Universities Press.

Piaget, J. (1938/1955). *The construction of reality in the child*. New York: Routledge and Kegan Paul.

Prechtl, H. F. R. (1977). Assessment and significance of behavioural states. In S. R. Berenberg (Ed.), *Brain, fetal and infant: Current research on normal and abnormal development* (pp. 79–90). Den Haag: Martinus Nijhoff.

Prechtl, H. F. R. (Ed.). (1984). *Continuity of neural functions: From prenatal to postnatal life*. Oxford: Blackwell Scientific Publications.

Prechtl, H. F. (1997). Is neurological assessment of the fetus possible? *European Journal of Obstetrics and Gynecology and Reproductive Biology, 75*, 81–84.

Rakic, P. (1972). Model of cell migration to the superficial layers of the fetal monkey neocortex. *Journal of Comparative Neurology, 145*, 61–84.

Robbins, E., & Rochat, P. (2010). Emerging signs of strong reciprocity in human ontogeny, submitted for publication.

Rochat, P. (2001). *The infant's world*. Cambridge: Harvard University Press.

Rochat, P. (2009). *Others in mind: Social origins of self-consciousness*. NY: Cambridge University Press.

Rochat, P. (2010a). The innate sense of the body develops to become a public affair by 2–3 years. *Neuropsychologia, 48*(3), 738–745.

Rochat, P. (2010b). Emerging self-concept. In J. G. Bremner & T. D. Wachs (Eds.), *Blackwell handbook of infant development* (2nd ed.). London: Blackwell Publishers.

Rochat, P. (in press). Possession and morality in early development. *New Directions in Child and Adolescent Development*.

Rochat, P., & Zahavi, D. (2010). The uncanny mirror: A re-framing of mirror self-experience. *Consciousness & Cognition*, in press.

Rochat, P., & Hespos, S. J. (1997). Differential rooting response by neonates: Evidence of an early sense of self. *Early Development and Parenting, 6*(3-4), 105–112.

Rochat, P., & Striano (1999). Emerging self-exploration by 2 month-old infants. *Developmental Science, 2*(2), 206–218.

Saxe, R., & Kanwisher, N. (2003). People thinking about thinking people: The role of the temporo-parietal junction in 'theory of mind'. *NeuroImage, 19*, 1835–1842.

Saxe, R., Moan, J. M., Scholz, J., & Gabrieli, J. (2006). Overlapping and non-overlapping brain regions for theory of mind and self reflection in individual subjects. *Social Cognitive and Affective Neuroscience, 1*(3), 229–234.

Schaal, B., Orgeur, P., & Rognon, C. (1995). Odor sensing in the human fetus: Anatomical, functional, and chemio-ecological bases. In J.-P. Lecanuet, W. P. Fifer, N. A. Krasnegor, & W. P. Smotherman (Eds.), *Fetal development: A psychobiological perspective* (pp. 205–237). Hillsdale, NJ: Lawrence Erlbaum Associates.

Slater, A., Mattock, A., & Brown, E. (1990). Size constancy at birth: Newborn infants' responses to retinal and real size. *Journal of Experimental Child Psychology, 49*, 314–322.

Smith, S. (1996). Commission of inquiry into fetal sentience. CARE.

Taylor, C. (1989). *Sources of the self: The making of modern identity*. Cambridge: Harvard University Press.

Tomasello, M. (1998). One child early talk about possession. In J. Newman (Ed.), *The linguistic of giving*. Amsterdam: John Benjamins.

Van der Meer, A., & Lee, D. (1995). The functional significance of arm movements in neonates. *Science, 267*, 693–695.

Wellman, H. M., & Liu, D. (2004). Scaling of theory-of-mind tasks. *Child Development, 75*(2), 523–541.

Wolff, P. H. (1987). *The development of behavioral states and the expression of emotions in early infancy*. Chicago: University of Chicago Press.

Zelazo, P. D. (2004). The development of conscious control in childhood. *Trends in Cognitive Sciences, 8*, 12–17.

Zelazo, P. D., Hong Gao, H., & Todd, R. (2007). The development of consciousness. In *Cambridge handbook of consciousness*. NY: Cambridge University Press.