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THEMATIC COLLECTION: COMMENTARIES

Infant Cortical Development and the Prospective Control of Saccadic Eye Movements

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Babies, like everyone else in this world, need to learn how to coordinate their actions with events that are not under their direct control. Response latency is an obstacle in this process, and the primary goal of sensorimotor development is to overcome it through the application of foresight (Piaget, 1937/1954). Visual exploration is where the infant first seriously confronts the problem of response latency. The infant moves his or her eye to inspect something in the periphery, only to find that when his or her eye has rotated to its final position, the object of interest may no longer be there. To solve this problem, he or she must learn to make good guesses about the future and be ready to act when, or even before, the future arrives. In other words, the baby will need to organize his or her behavior in a prospective manner. Rather than simply reacting to what happens to him or her, the baby needs to start thinking ahead. Eventually, the baby will be guided by plans, goals, anticipatory schemata, expectations, and memories of the future. By developing prospective sensorimotor control, not only will the baby become the master of his or her domain, he or she will be building a foundation

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for the higher cognitive functions that are distinctive to the human species (Canfield & Haith, 1991; Dodge, 1933; Fuster, 1997; Gancarz & Grossberg, 1999; Goldman-Rakic, 1995; Gross, Heinze, Seiler, & Stephan, 1999; Haith, Wentworth, & Canfield, 1993; Ingvar, 1985; Michel & Moore, 1995; Milner & Goodale, 1995; Neisser, 1976; Stadler & Wehner, 1982).

One aspect of prospective sensorimotor control, saccade planning, is the focus of this exciting set of articles. An explicit goal of each investigation is to link behavior and brain functioning in real time using event-related potentials (ERPs). It is significant that these three teams of investigators are not using ERPs to discover how the baby's brain responds to various types of events. That was a 20th-century question. Instead, they are asking how babies look to the future, using ERPs to discover what parts of the brain are involved.

Individually, and as a group, these articles raise important conceptual and methodological issues, and they lead to recommendations for the next phase of research in this area. Our comments focus primarily on the implications of this research for understanding the role of the prefrontal cortex (PFC) in prospective oculomotor control during early infancy. We are guided by the following questions: (a) What is a saccade plan? More specifically, how is the concept of saccade planning operationalized by these researchers? Are they talking about the same or different phenomena?; (b) Where in the brain and when in development should we find evidence of saccade planning? Are the behavioral and electrophysiological findings in these reports consistent with what is known about neuroanatomical development during early infancy?; (c) How do these studies contribute to our understanding of saccade planning and prospective motor control more generally?; and (d) What implications can be drawn from these studies to guide future research in this area? These questions and issues provide a context for understanding where these articles fit in an emerging psychobiological model of the early development of prospective sensorimotor control.

WHAT KIND OF PLAN IS A SACCADE PLAN?

What counts as a plan depends in large part on who is asked. The term has different meanings at different levels of behavioral organization. The most relevant distinction for our purposes is the one between planning as a construct in cognitive psychology and planning as a concept in motor control. From a motor control perspective, a plan (or motor program) is nothing more than

> A set of muscle commands that are structured before the motor acts begin and that can be sent to the muscles with the correct timing so that the entire sequence can be carried out in the absence of peripheral feedback. (Brooks, 1986, p. 127)

A motor plan can be thought of as a schema, but according to this definition, the schema is a passive mental structure holding information about muscle tensions and joint angles that could be accessed when a particular posture is requested from a higher level of control. In contrast, from a cognitive psychology perspective, a plan is an active mental structure organized in service of a goal. The plan may include requests for specific motor routines, but the primary functions of a plan at this level are to select constituent behaviors and organize them in time (Miller, Galanter, & Pribram, 1960). Because planning is used in a variety of ways in these articles, we try to make explicit how the term *planning* is being used and how planning is operationalized in each research protocol. In general, we use the term *expectancy-based planning* when referring specifically to the hypothetical cognitive construct.

WHERE AND WHEN SHOULD WE LOOK FOR EVIDENCE OF SACCADE PLANNING IN INFANTS?

There is little disagreement that in the adult human and nonhuman primate, expectancy-based saccade planning requires cortical eye fields in the PFC, posterior parietal cortex (PPC), or both. The functions of the PFC include working memory, movement planning, expectancy, and many other functions that rely on the temporal organization of behavior (Dias & Segraves, 1999; Fuster, 1997; Goldman-Rakic, 1995; Snyder, Batista, & Anderson, 2000). At least two major eye fields are found in the PFC; they are the frontal eye fields (FEFs) and the supplementary eye fields (SEFs). In primates, both of these eye fields are active during the execution of saccadic eye movements. Lesion data suggest that the FEFs are more specialized for eye movements, whereas some SEF neurons are involved in the control of limb movements (Tehovnik, Sommer, Chou, Slocum, & Schiller, 2000). Both FEFs and SEFs are connected with the dorsolateral prefrontal cortex (DLPC), a primary site of working memory that has also been implicated in guiding eye movements (Chafee & Goldman-Rakic, 2000; Fuster, 1997; Goldman-Rakic, 1987; Pierrot-Deseilligny, Rivaud, Gaymard, & Agid, 1991; Schiller & Chou, 2000).

Among all the cortical eye fields, the FEF is unique in at least two ways: It codes for saccades in retinocentric coordinates, and it has both direct and indirect (through superior colliculus) connections with the saccade generators in the brain stem. Because of its access to DLPC and the saccade generators, the FEF is often viewed as the most autonomous of the cortical eye fields (Findlay, 1981; Fuster, 1997; Gancarz & Grossberg, 1999; Pierrot-Deseilligny et al., 1991; Schiller, Sandell, & Maunsell, 1987; Schlag-Rey, Schlag, & Dassonville, 1992). Consistent with this view, the FEF is involved in generating all intentional saccades and plays a unique role in producing saccades in the absence of current visual information

(Bruce & Borden, 1986; Dias & Segraves, 1999; Guitton, Buchtel, & Douglas, 1985; Klostermann et al., 1994). Also called *goal-guided,* these nonvisually guided saccades are guided by memory and prediction (Braun, Weber, Mergner, & Schulte-Mönting, 1992; Bruce & Borden, 1986; Deng, Goldberg, Segraves, Ungerleider, & Mishkin, 1986; Dias & Segraves, 1999; Rivaud, Müri, Gaymard, Vermersch, & Pierrot-Deseilligny, 1994; Sommer & Tehovnik, 1997). Like neighboring centers in PFC, the FEFs are biased toward prospective information processing (Fuster, 1997; Gancarz & Grossberg, 1999; Gross et al., 1999).

The question of whether FEF plays a unique role in generating memory-guided saccades demonstrates how very subtle differences in an experimental protocol can influence saccade generation. Under some conceptualizations, frontal and posterior eye fields are thought to make independent and equal contributions to the initiation of memory-guided saccades (Chafee & Goldman-Rakic, 2000; Snyder et al., 2000). In contrast, several other studies have concluded that at least one intact FEF is necessary for generating predictive and memory-guided saccades (Braun et al., 1992; Bruce & Borden, 1986; Deng et al., 1986; Rivaud et al., 1994; Sommer & Tehovnik, 1997). The resolution of this debate involves the recognition that not all memory-guided saccades are executed alike. In the standard memory task, delay period activity in PPC and FEF cells are very closely matched (Chafee & Goldman-Rakic, 2000). However, when the task is changed so that the animal is required to make an intervening saccade before fixating the remembered location, cells in PPC became inactive, whereas FEF cells remained active (Gancarz & Grossberg, 1999; Gnadt & Andersen, 1988). An interesting implication for these studies is that evidence for FEF involvement in infant saccade planning may depend on the use of paradigms that require infants to make intervening saccades to a new location between the presentation of the cue and target in a memory or predictive saccade task. This feature is typical of most visual expectation-like procedures, but is not typical of spatial cuing procedures.

Regardless of whether it sits alone at the top of a hierarchy, FEF is normally involved in all forms of intentional guidance of saccades and visual attention. Therefore, it is important to ask when during infancy it might begin to influence oculomotor behavior.

The PFC and Infant Behavior

Little is known about the functional significance of PFC in infants younger than 6 months of age. Beginning at 6 to 7 months, when infants can be tested in reaching paradigms, PFC functions of memory and inhibitory control develop rapidly (Diamond & Doar, 1989; Diamond & Goldman-Rakic, 1986). An oculomotor delayed response task has suggested PFC functions as early as 6 months (Gilmore & Johnson, 1995).

In a synthesis of research on infant visual attention, oculomotor control, and neuroanatomical maturation, Johnson (1990; Johnson, Posner, & Rothbart, 1994) concluded that frontally mediated oculomotor control would not appear before approximately 4 to 6 months of age. Drawing from Conel's (1939–1967) studies of cortical maturation in human infants, Johnson (1990) noted that cells in the early maturing Layers 5 and 6 of primary visual cortex (V1) project only to subcortical structures, including the superior colliculus and the basal ganglia. Although cells in Layers 2 and 3 (the major origin of associative and collosal fibers in PFC) eventually project to higher cortical structures, including PFC, Conel's data suggested that cells in these layers would be insufficiently mature to contribute to information processing until infants are about 4 to 6 months of age. After corroborating this insight with existing behavioral evidence, and in the context of a more comprehensive model, Johnson (1990) posited that predictive saccades, which should rely on a functional pathway to the FEF, are unlikely to be seen before the age of 4 months.

Recent behavioral, neuroanatomical, and electrophysiological research offers an alternative perspective on the maturational status of the PFC. Indeed, some evidence suggests that PFC is sufficiently mature to support information processing in very early infancy (Canfield & Haith, 1991; Mrzljak, Uylings, Kostovic, & Van Eden, 1988, 1992; Vaughan & Kurtzberg, 1992; Wentworth & Haith, 1992).

Subsequent to the introduction of Johnson's (1990) ideas, behavioral studies using the visual expectation paradigm began reporting evidence of predictive saccades in 12- to 14-week-old infants (Canfield & Haith, 1991; Haith, Hazan, & Goodman, 1988; Haith et al., 1993; Wentworth & Haith, 1992). Indeed, infants as young as 8 to 9 weeks predicted future stimulus locations in some studies (Canfield & Haith, 1991; Canfield, Smith, Brezsnyak, & Snow, 1997; Wentworth & Haith, 1992). If the FEFs are necessary for the generation of anticipatory saccades, then these behavioral findings are suggestive of some PFC–FEF influence at a very young age.

Recent neurodevelopmental research also supports the possibility of early function in the PFC. Important among these events was a reassessment of Conel's (1939–1967) work in light of subsequent research using more modern neuroanatomical methods. In reference to Conel's studies, Vaughan and Kurtzberg (1992) noted that, "his data were somewhat deficient from a technical standpoint, and suggested a greater degree of neural immaturity at birth than has been observed in more recent studies" (p. 13). For example, in a serial Golgi study of visual cortical development from 14 weeks gestation to 6 months postnatal, Takashima, Chen, Becker, and Armstrong (1980) reported substantially earlier development of pyramidal cells in cortical Layers 2 and 3 of V1 than reported by Conel. Similarly, Mrzljak and colleagues (Mrzljak et al., 1988, 1992; Mrzljak, Uylings, Van Eden, & Judas, 1990) studied neuronal development in human fetal and neonatal PFC specimens and reported that the maturity of pyramidal cells in Layers 3 and 5 are surprisingly similar, with both showing rapid dendritic and axonal differentiation beginning at about 26 weeks gestation (Mrzljak et al., 1990). This coincident rapid growth is induced by the ingrowth of thalamocortical fibers, indicating that cells in both layers are targets for these subcortical afferents very early in development (Mrzljak et al., 1990). Growth is rapid, and by 28 weeks gestation these thalamocortical fibers are "especially densely packed at the levels of fetal layers III and V" (Mrzljak et al., 1988, p. 383). During the late prenatal and neonatal period, Layer 3 cells undergo continued rapid dendritic differentiation as their axons begin establishing connections with target cells in the opposite hemisphere (Mrzljak et al., 1988). Growth and differentiation of nonpyramidal local circuit cells was also found to be a more rapid process than was earlier believed (Mrzljak et al., 1988). Thus, although the maturation of cells in Layer 3 lags slightly behind those in Layer 5, there appears to be sufficient structural maturity in PFC to support information processing in the neonate (Burkhalter, Bernardo, & Charles, 1993).

Finally, evoked potentials in preterm infants also indicate cortical responsivity early in prenatal life. One review concluded that

> Obligatory cortical responses to sensory stimulation are present in the visual, auditory, and somatosensory modality by 26 weeks postconception, … by 3 months before term, when cortical neurons are extremely immature in their morphology … functioning synaptic connections are present not only in primary sensory cortex but in secondary and association cortex as well. (Vaughan & Kurtzberg, 1992, p. 15)

In sum, evidence from behavioral, anatomical, and electrophysiological research provides a basis for supposing that anticipatory saccades observed in very young infants involve the same prefrontal neural circuits as in the adult. However suggestive, indirect evidence of possible functional capacity from Golgi studies, possible neural mechanisms underlying specific behavioral observations of infants, and the existence of recordable scalp potentials in preterm infants do not constitute sufficient evidence to evaluate this hypothesis. These studies begin to close the loop between saccade planning and brain function during early infancy. They provide a basis for evaluating whether in the midst of widespread immaturity, neural events in PFC can be linked directly to voluntary expectancy-based oculomotor behaviors in young infants.

EVALUATING ERP EVIDENCE FROM THE STUDIES IN THIS ISSUE

Considered as a group, there is only modest consistency in the pattern of findings reported in these articles. This should come as no surprise given the many differences in how the studies were carried out. These include differences in experimental paradigms, target behaviors, ERP recording methods, dependent variables, data analytic techniques, stimulus parameters, and participant ages. Nevertheless, each study demonstrates the promise of supplementing behavioral data with ERPs to advance our understanding of infant oculomotor control. Again, our comments focus primarily on what can be learned about the role of PFC in early oculomotor behavior from these articles.

Wentworth, Haith, and Karrer

Wentworth et al. (this issue) operationalized saccade planning in terms of ERP differences between anticipatory and reactive saccades to stimuli appearing in a predictable left–right sequence. Their procedures reflected closely those used in a number of previous studies of visual expectancies in 8- to 14-week-old infants (e.g., Wentworth & Haith, 1992). Just two scalp leads, frontal midline (Fz) and vertex (Cz), were used in this study. This precludes drawing any conclusions about ERP sources within cortical regions, laterality, or hemispheric asymmetry, but makes interpreting the findings relatively straightforward. It was concluded that when 3-month-old infants make anticipatory saccades, they use the same general part of the brain as adults do, namely, the PFC.

Evidence for cortical saccade planning in 3-month-olds was found in both the response-locked and event-locked components of the ERP. The presaccadic signal showed a slowly increasing negative shift in the frontal lead, beginning about 500 msec before a saccade. This was terminated by a positive deflection 30 to 90 msec prior to saccade initiation. Both components were larger prior to anticipatory saccades than reactive saccades. For reactive saccades, these components were larger at the vertex. This signal suggests the use of PFC structures during anticipatory saccade programming.

A negative deflection was also related to the stimulus onset-locked recordings, revealing that infants were indeed coordinating their behavior with the externally controlled event. This finding suggests contingent negative variation (CNV), the expectancy wave first reported in adult participants by Walter (1967). CNV is observed only when reacting to a stimulus that has gained behavioral significance—that is, when one stimulus is predictive of a subsequent stimulus, which itself will require a motor response. This is exactly what infants were confronted with in the Wentworth et al. (this issue) paradigm. Offset of the left stimulus was a consistent predictor of the onset of the right stimulus, which itself called for a saccade (and vice versa). Like the adult CNV, the wave reported for infants was strongest over the frontal cortex, especially when the subsequent saccade anticipated the appearance of the upcoming stimulus.

When combined with single-cell recording techniques in nonhuman primates, CNV is found to reflect activity in the frontal cortex as it prepares lower levels of the motor system for an impending movement—sometimes called *motor intention* or *preparatory set* (Fuster, 1997; Snyder et al., 2000). These findings are in agreement with conclusions from many behavioral studies of visual expectation, and they are also consistent with an interpretation of recent neuroanatomical and electrophysiological findings that at least some functional capacity exists in PFC as early as 3 months of age.

Csibra, Tucker, and Johnson

More differentiated answers to questions about the cortical control of saccades in young infants require more than two recording sites. Csibra et al. demonstrated success in recording from 62 scalp electrodes while infants viewed a four-position visual expectation sequence. An explicit focus of this investigation was to compare patterns of cortical activation in 4-month-olds to the pattern expected for adult participants in a similar task. Significant presaccadic potentials over frontal scalp sites prior to anticipatory saccades would suggest planning in PFC, although parietal components were also expected.

The procedure appears to share many fundamental similarities with the Wentworth et al. (this issue) study. Infants viewed a perfectly predictable sequence of picture presentations and formed anticipatory eye movements as they looked. The psychological processes seem to be equivalent to those in the Wentworth et al. study, leading to the prediction of similar ERP findings, with the possible exception that activations prior to anticipatory and reactive saccades would be more clearly differentiated. However, evidence for frontally mediated saccade planning was equivocal in the Csibra et al. (this issue) study. Analyses of the average ERP amplitude during the 100- to 300-msec interval following the offset of one picture revealed greater frontal positivity for trials on which the infant anticipated the next picture in the sequence. This is another indication that PFC is involved in anticipatory saccade generation. Curiously, this finding was limited to electrodes over the right hemisphere; reactive saccades showed no corresponding differences between sides or hemispheres and no significant offset-related activations were observed for parietal leads.

If related to the upcoming stimulus, right frontal positivity could indicate saccade planning very early during the interstimulus interval (ISI), but this interpretation is complicated by the asymmetry of the stimulus sequence. Indeed, saccades to the left were oblique and about 30% larger in amplitude than the horizontal, right-going saccades. Because it involved greater coordination among the muscles controlling vertical and horizontal eye movements, leftward anticipations may have been more difficult to program. This could have produced greater right hemisphere activation, therefore producing an unexpected laterality finding (Brooks, 1986).

Behavioral data confirmed that anticipations to the left were more difficult. Infants made a smaller percentage of anticipations toward the left, and those anticipations occurred significantly later in the ISI. Because it took babies longer to compute the left-going anticipations, it is likely that electroencephalograms (EEGs) were sampled during an earlier stage of saccade planning than for anticipations to the right side. This asymmetry also may have affected the degree to which offset-locked signals were synchronized uniformly on each side. Choosing side-specific sampling intervals or averaging across trials with similar latencies might be informative (Vaughan & Kurtzberg, 1992).

Saccade-locked frontal ERPs showed a nearly opposite pattern of results as the event-locked potentials; that is, they were more positive prior to reactive than anticipatory saccades. Furthermore, this difference was greater over the left hemisphere. It is not clear how this finding can be integrated with those from event-locked analyses.

Discrepancies between the findings of Csibra et al. (this issue) and Wentworth et al. (this issue) seem even more unusual when considering that 3-month-olds showed greater evidence of frontal activation, and much more consistent responding overall than 4-month-olds. It is possible that the differences are due entirely to procedural differences between studies. For example, in the Csibra et al. procedure, all four stimulus locations were continuously visible during the ISI (in the form of gray windows on a dark background). This may have altered the cognitive processes taking place during the ISI by adding an element of visual guidedness to what appeared to be purely anticipatory saccades. The visible stimulus locations may also help explain the lack of significant parietal activation because of the reduced effort needed to keep a spatial map of the possible stimulus positions in active memory. Further studies using this particular paradigm will be needed to better understand these puzzling results.

The difficulty in reconciling the findings across these two studies underscores the fact that our ability to interpret brain activity depends critically on how well we understand our behavioral paradigms. Although using innovative procedures can be more interesting, progress during the early phases of research attempting to link brain and behavior is likely to benefit from using straightforward, highly standardized research protocols (Van Der Molen & Molenaar, 1994).

Richards

The concept of expectation and saccade planning is operationalized differently in Richards's (this issue) spatial cuing paradigm than in visual expectation procedures (Hood & Atkinson, 1991; Posner, 1988; Posner & Petersen, 1990). In the two previous studies, there were cross-temporal contingencies the infant could use to support expectations about where and when the next picture would appear. A stimulus in one location was a perfect predictor of where and when the next would appear. This allowed for the possibility of expectancy-based saccade planning that could activate several cortical eye fields, in addition to DLPC. However, the spatial cuing paradigm does not support the development of the same type of expectancy-based planning because the cue itself has no predictive value. Specifically, within each 15-trial block, infants saw 15 unique Trial Type × Delay combinations. A cue was presented on only 9 of these trials, and a target picture followed only 6 trials of these 9. When a cue did appear, the target was as likely to appear ipsilateral as contralateral to the cued location. Finally, even when the cue was valid, it did not predict when the target would appear (i.e., 150, 575, or 1,000 msec after cue offset). From the infant's perspective, there was no possibility of developing expectations of the type seen in the visual expectation procedures.

To the extent that the PFC may be specialized for prospective action, a reasonable prediction is that no significant frontal activation would be found in the spatial cuing paradigm. However, evidence indicated FEF involvement in some saccades. A contralateral presaccadic potential was observed over frontal leads that peaked about 50 msec before cued-exogenous saccades (ipsilateral trials). This was interpreted as evidence that these saccades resulted from activity in FEF cells "that guide saccades to specific targets in expected locations" (Richards, this issue, p. 154). The sense in which the infant could expect a target on the basis of a noncontingent cue is not altogether clear.

It was surprising that endogenous saccades were not associated with frontal activations, and this may signal a need to reconsider the relation between the analysis categories (endogenous, etc.) and the trial types (ipsilateral, etc.). For example, the endogenous category is a combination of two very different types of saccades: the endogenous saccades that anticipate the target and those from the no-target control trials that may have had extremely long shift latencies. Combining saccades generated under different stimulus conditions and with such different latency characteristics can be problematic. Longer latency responses would have gone through additional processing stages (accumulating additional random variability along the way), and thus their EEGs are likely to be very poorly synchronized with the short-latency responses. The expected result would be no identifiable components in the averaged potential (Vaughan & Kurtzberg, 1992). Separating these different behaviors appears warranted on both statistical and conceptual grounds. Finally, although the EEG was synchronized to saccade onset for all trials, the variable and unpredictable ISI values are likely to have been a source of error variance in the overall analysis of waveforms. Thus, when using the spatial cuing procedure there may be good rationale for including ISI as a factor in the analytic models as a way of enhancing synchronization, or at least controlling for desynchronization.

CONCLUSIONS

The case for cortical saccade planning in early infancy is strong. Although far from telling a uniform story, the combination of ERP and behavioral data reported in these articles shows that by the age of only 3 or 4 months, the cortical eye fields are actively involved in the prospective control of saccades and visual attention. One might even say that despite our best efforts to stimulate reflexive saccades by putting them in the dark and flashing images in their peripheral visual fields, babies planned saccades to these stimuli. ERP and behavioral evidence indicated that frontal and posterior cortical networks are an active part of this control system at an early age. Given that each of the three research teams has only just begun to address questions about the prospective organization of sensorimotor behavior, we should not be unduly discouraged by the present lack of consensus about the cognitive processes reflected by ERPs, or the brain regions responsible for various types of saccades.

There appears to be little doubt that many important questions about the development of brain, behavior, and cognition will yield to a combination of sophisticated oculomotor control research paradigms and measures of brain activity. There is even less doubt that technological improvements leading to super high-density EEG recording will be an important factor in helping answer some of them. However, it is our view that technology will not be the limiting factor in how quickly this type of research enterprise advances. Instead, progress will depend most on a deeper understanding of the behaviors we are studying. Our ability to interpret EEG recordings depends critically on understanding the meaning of the behaviors associated with them.

These articles are among the first to link brain and prospective oculomotor control in babies, and in this sense they break new ground. The stage is set for rapid progress in this area, but the rate t which we advance depends on our ability to leverage the large and more conclusive knowledge base on brain and oculomotor control in primate models. Success will require clearly focused efforts toward refining and standardizing attention and oculomotor control tasks for infants that parallel, to the extent possible, tasks currently used with monkeys. A number of investigators have been moving in this direction for several years, but broader collective efforts are needed.

We believe a valuable first step will be to design, choose, or further develop two or three simple infant tasks that have close analogs to ones used with monkeys. One possible set is (a) a version of the spatial cuing task (Hood & Atkinson, 1991; Johnson et al., 1994; Posner, 1988; Richards, 2000), (b) a version of the free-looking predictive saccade task procedure (Canfield et al., 1997; Csibra et al., this issue; Haith et al., 1993; Wentworth & Haith, 1992), and (c) a version of the individual trials predictive saccade task (Johnson, 1990; Smith, 1998). The next step may be the most important—to standardize the administration and scoring of these tasks. The use of novel target arrangements, or combining habituation or operant learning with the expectation paradigm, is certain to produce exciting insights, and it should be encouraged. However, novel tasks also introduce complexities of interpretation the field is not yet able to sort out. The Csibra et al. and Wentworth et al. (this issue) studies of visual expectations demonstrate such a case. Each study leads to numerous interesting questions about, for example, relations between dorsal and ventral stream processing and the effect of visual landmarks on parietal activity. At the end of the day, however, it is nearly impossible to synthesize the findings when such different research protocols are used. It may help to imagine the difficulty of synthesizing ERP findings in the absence of the international 10–20 system for placing electrodes. With a few tasks in hand, it will then be feasible to carry out the parametric studies that will serve as both a foundation and springboard for future discoveries. Either through informal agreements or through formal funding mechanisms, it is time to focus a portion of our research energies in this direction.

What do we stand to gain from such an approach? The answer goes back to the issue of what these oculomotor behaviors really mean. A complete response to that question is beyond the scope of this commentary, but the control of saccadic eye movements and visual attention involves the fundamental operations of sensory selective attention, working memory (encoding, retrieval, and reactivation), motor selective attention (response selection), expectation, planning, and perhaps most fundamental, the ability to identify and use cross-temporal contingencies (Fuster, 1997). These are the primary building blocks of the higher cognitive functions, including the ever popular “executive” functions. The possibility of describing how these complex cognitive functions emerge through the interaction of brain and environment during infancy has never seemed closer at hand.

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