

## Commentary on Guillaume Thierry

# *The Use of Electrophysiology in the Study of Early Development*

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Electrophysiology is a timely and important tool in the study of early cognitive development. This commentary polishes the definition of event-related potential (ERP) components; often interpreted as expressions of mental processes. Further, attention is drawn to time-frequency analysis of the electroencephalogram (EEG) which conveys much more information than the exclusive use of traditional ERP methodology. Several studies have shown that frequency bands of the EEG undergo systematic development in early childhood. EEG frequency analysis has a potential in early risk assessment. 40 Hz gamma range oscillation bursts accompany stimulus feature binding both in infants and in adults, probably indexing grouping and selection of distributed neuronal populations. Methodological concerns are noted and the need for long-term normative studies is stressed. Copyright © 2005 John Wiley & Sons, Ltd.

Guillaume Thierry's article draws attention to the importance and appropriateness of using electrophysiological (EEG) methods to investigate early cognitive processes. Focusing on event-related brain potential (ERP) studies in mainstream journals, the author primarily summarizes results regarding ERP components relevant in the development of early language functions. However, the expression 'ERP component' can be used in two ways (Näätänen and Picton, 1987). Some researchers use it in a purely functional sense, meaning the visible/measurable modulations (peaks and troughs) of the ERP curves. Others use it in the sense used by Thierry, to denote the effects that the functional changes (not activation!) in certain part(s) of the brain have on the electric potentials measurable on the human scalp.

Thierry may be too cautious in his focus on methodological issues when considering EEG studies. First, cognitive terms have been used from the outset in the explanation of psychophysiological results (e.g. Sutton *et al.*, 1965; Kutas *et al.*, 1977). Second, while the literature concerning early components (like N1, N2, MMN) goes into very subtle technical details about stimulus parameter effects, the literature exploring later components (like N4, P3, P6, LPC) has been

overwhelmingly oriented towards cognitive questions. Though Thierry's article promises to review the use of 'electrophysiology', the author in fact restricts himself to ERPs, both time and phase-locked to stimulus presentation. Only results from traditional ERP analysis (interpreting peak amplitude and latency of the ERP components) are discussed. Yet, more recently, both in general and in early cognition EEG research, more and more emphasis is allocated to detailed *time-frequency analysis* of data.

Averaging brain responses in the time-domain computes the ERP (evoked activity). This methodology considers any activity that is not phase-locked to stimulus presentation ('background activity') as noise. In contrast, frequency analysis averages data in the frequency domain. Frequency analysis can retain both phase-locked and non-phase-locked information (Kalcher and Pfurtscheller, 1995). Non-phase-locked activity may also show germane changes in response to stimulation (induced activity). While traditional ERP methodology filters out a large part of brain activity and collapses all information into a single measure (the ERP), advanced time-frequency analysis grants the researcher access to both phase-locked and non-phase-locked electric responses, with a good resolution in both the temporal and frequency domains (e.g. Makeig *et al.*, 2002). Typical measures in time-frequency analysis are (1) the EEG power (the 'strength' of certain frequency bands), (2) the phase-locking factor or intertrial-coherence (the phase difference between brain responses detected at discrete occurrences of stimuli), and (3) the cross-channel coherence (the phase difference between brain responses detected at different electrodes).

According to frequency-analysis, brain activity in the delta and theta frequency bands is not merely 'brain noise' that needs to be filtered out from the data. Several authors have highlighted the importance of these frequency bands in cognitive development, especially in the crucial area of early assessment for developmental risk. The analysis of the delta, theta, and alpha band of the EEG enable early identification of brain injury or other neural malfunctions in newborns and in infants (Watanabe *et al.*, 1999). It is probably only a question of time until a firm connection between delta and theta band disturbances and cognitive disorders is established. For example, in older children theta band abnormality has been shown in autism (Martineau *et al.*, 2004; seven children, 6–11 years old); whereas delta and theta band disturbances have been detected in children with educational problems (Gasser *et al.*, 2003; 158 normal; 47 mentally retarded, and 26 learning disabled children).

In order to enable reliable early identification of risk, it is of vital importance to build up large normal databases of infant EEG activity. Some studies have already attempted this. Data collected in sizeable populations suggests that the delta (Ktonas *et al.*, 1995; 28 subjects in total; ages: 2–6 weeks, 7–14 weeks, and 4–12 months), theta (Orekhova *et al.*, 1999; 60 infants, 8–11 month olds), and alpha (Stroganova *et al.*, 1999; 154 infants, 32–41 weeks old) bands undergo systematic development in early childhood. For example, it has been suggested that decreases in frontal theta synchronization during the first year of life may reflect the maturation of the anterior attentional system, increasing the ability to maintain anticipatory attention (Orekhova *et al.*, 1999). Although correlational data must be interpreted with caution, such patterns suggest that identifying associations between certain frequency bands of the EEG and cognitive functions is a promising endeavour.

High-frequency neuronal activity, the so-called gamma activity (25–70 Hz) is also of great importance to human brain function. Special significance has been attributed to oscillations at about 40 Hz (Tallon-Baudry *et al.*, 1996). These

oscillations appear to play a fundamental role in the 'binding' process. During binding the brain unites separately coded perceptual information into a common entity (e.g. perceiving somebody's visual appearance, scent and voice as a unique individual). Csibra *et al.* (2001) have shown that even 8-month-old infants show gamma bursts similar to those of adults when they perceive illusory objects. Perception of the illusory objects requires binding the features of spatially separate elements together (e.g. in the Kanizsa triangles). Moreover, these authors found that the frontal lobe may play an especially critical role in the development of this very central perceptual mechanism. Similarly, Kaufmann *et al.* (2003) found that gamma power over the right temporal areas of the scalp reflects the active maintenance of occluded objects in 6-month-old infants. According to most recent theories, the role of gamma oscillations is more general and it is not limited to the establishment of binding (Engel *et al.*, 2001). Coherence changes may be the means of grouping and selecting distributed neural elements (e.g. rote detectors) in order to form dynamic networks. In other words, the gamma oscillations may be the means by which the brain is able to form new associations and retrieve stored knowledge. The study of the development of this key brain process is clearly of pivotal importance.

In addition to summarizing existing work, Thierry draws attention to the methodological hardships that this new research area inevitably has to face. One plausible source of the differences between infant and adult EEG responses lies in the volume conduction principles to which the human EEG is subjected. Electric potentials are significantly distorted inside the cranium and get even more distorted when penetrating the bones of the skull. This occurs because of the different conduction properties of different tissues. As the morphology of the infant's brain and skull is constantly changing, part of the modulation of electric potentials with development is a consequence of the physical transformation of the body, not of brain function.

As Thierry proposes, the solution to overcoming methodological problems is to carry out several normative studies. Of particular importance are long-term longitudinal studies, which can link the morphology of infant and adult brain activity to each other. Probably the most rewarding research strategy would be to build-up such connections from top to bottom, i.e. first mapping brain activity in older and then in younger children (followed by 10–20 year longitudinal studies). For example, recently Hahne *et al.* (2004) found that while the N400 (related to semantic processing) and the P600 (related to syntactic processing) ERP components appeared in both 6–13-year-old children and adults, the early left anterior negativity (ELAN), also related to syntactic processing, was missing in 6-year-olds. The careful design of similar studies, tracking information about the developmental trajectory of other signature ERP responses in younger and younger populations, may enable the outstanding questions identified by Thierry to be answered. Nevertheless, an awareness of the need for reliability and rigor in this new area should not lead us to underestimate the many possibilities of asking more intuitive, explorative research questions about early cognitive development.

## REFERENCES

Csibra G, Davis G, Spartling MW, Johnson MH. 2001. Gamma oscillations and object processing in the human infant brain. *Science* **290**: 1582–1585.

- Engel AK, Fries P, Singer W. 2001. Dynamic predictions: oscillations and synchrony in top-down processing. *Nature Neuroscience* **2**: 704–716.
- Gasser T, Rousson V, Schreiter-Gasser U. 2003. EEG power and coherence in children with educational problems. *Journal of Clinical Neurophysiology* **20**: 273–282.
- Hahne A, Eckstein K, Friederici D. 2004. Brain signatures of syntactic and semantic processes during children's language development. *Journal of Cognitive Neuroscience* **16**: 1302–1318.
- Kalcher J, Pfurtscheller G. 1995. Discrimination between phase-locked and non phase-locked event-related EEG activity. *Clinical Neurophysiology* **94**: 381–384.
- Kaufmann J, Csibra G, Johnson MH. 2003. Representing occluded objects in the human infant brain. *Proceedings of the Royal Society Series B* **270**: S140–S143.
- Ktonas PY, Fagioli I, Salzarulo P. 1995. Delta and sigma EEG power dynamics throughout quiet sleep in infants. *Electroencephalography and Clinical Neurophysiology* **95**: 90–96.
- Kutas M, McCarthy G, Donchin E. 1977. Augmenting mental chronometry: the P300 as a measure of stimulus evaluation time. *Science* **197**: 792–795.
- Makeig S, Westerfield M, Jung TP, Enghoff S, Townsend J, Courchesne E, Sejnowski TJ. 2002. Dynamic brain sources of visual evoked responses. *Science* **295**: 690–694.
- Martineau J, Schmitz C, Assaiante C, Blanc R, Barthélémy C. 2004. Impairment of cortical event-related desynchronization during a bimanual load-lifting task in children with autistic disorder. *Neuroscience Letters* **367**: 298–303.
- Näätänen R, Picton TW. 1987. The N1 wave of the human electric and magnetic response to sound: a review and analysis of the component structure. *Psychophysiology* **24**: 375–425.
- Orekhova EV, Stroganova TA, Posikera IN. 1999. Theta synchronization during sustained anticipatory attention in infants over the second half of the first year of life. *International Journal of Psychophysiology* **32**: 151–172.
- Stroganova TA, Orekhova EV, Posikera IN. 1999. EEG alpha rhythm in infants. *Clinical Neurophysiology* **110**: 997–1012.
- Sutton S, Braren M, Zubin J, John ER. 1965. Evoked potential correlates of stimulus uncertainty. *Science* **150**: 1187–1188.
- Tallon-Baudry C, Bertrand O, Delpuech C, Pernier J. 1996. Stimulus-specificity of phase-locked and non-phase-locked 40 Hz visual responses in human. *Journal of Neuroscience* **16**: 4240.
- Watanabe K, Hayakawa F, Okumura A. 1999. Neonatal EEG: a powerful tool in the assessment of brain damage in preterm infants. *Brain and Development* **21**: 361–372.