

## Through the looking glass: ERPs in an MBE world

With apologies to Alice, sometimes I feel as though I live – at least partly – in some wondrous alternate world. In that world, it is not uncommon to hold a discussion in an undergraduate education class in which the phrases “posterior superior temporal gyrus” and “differentiated instruction” are both used fluently. In that world, having both the *Journal of Cognitive Neuroscience* and *Educational Leadership* waiting to be read on one’s desk is not peculiar. In that world, classroom experiences can generate hypotheses to be tested and peer-reviewed articles from scientific journals provide a knowledge base for discussion of educational issues. In that world, “biology” does not mean “destiny,” and plasticity – that is, change, not fixedness – is recognized as one of the most breathtaking and educationally relevant principles from neuroscience. And in that world, the word “education” is not synonymous with the word “teaching,” but encompasses a wider meaning that includes concepts and theories of a science of learning and development in sociocultural context. This alternate world is actually, in part, the interdisciplinary, MBE world in which I would like to spend most of my time; unfortunately, a good amount of my time is spent in a world in which I receive student evaluations with comments like “too much brain stuff... this was supposed to be an education class.”

So where are the disconnects? Why do some students see only their own reflections in the looking glass? One of the primary issues hindering students from making connections between education and neuroscience may be the technical nature of much of the neuroscientific literature. Methodologically, neuroscience can be difficult. Brain-related findings are relatively useless without the scientific literacy skills to understand and meaningfully interpret neuroscience data – a statement that should not be interpreted to mean that I believe that educators should be trained as neuroscientists, but rather that I believe that education students should have a basic familiarity with neuroscience methods so as to be capable of carefully considering and evaluating neuroscience findings for their own purposes. Indeed, with newspapers and weekly newsmagazines increasingly reporting on neuroscience findings, basic neuroscience literacy is becoming required of all consumers of popular culture. Who has not been dazzled by a four-color positron emission tomography (PET) or functional magnetic resonance imaging (fMRI) picture accompanied by a headline like “Neuroscientists identify the brain area for X”? And yet, most probably, that picture is in fact a statistical plot of brain areas that showed greater blood flow in one condition as compared to another. Knowing that, surely the modular interpretation can change at least slightly.

My own research, which uses the event-related potential (ERP) technique, comes with its own share of technical limitations, not the least of which is that my data generally consist of squiggly lines – perhaps a sort of awkward country cousin to the sophisticated and stylish saturated color plots of fMRI and PET. To understand, meaningfully interpret, and potentially decide to use the information represented by those squiggly lines (that is, to make brain-education connections), it is important to know a little bit about where those lines come from and what they represent. ERPs are a derivative of the electroencephalogram (EEG). The EEG is a direct measure of cortical function recorded from electrodes placed non-invasively on the scalp and reflects the net electrical activity of millions of neurons that are synchronously active (Nunez & Srinivasan,

2006, p. 3). If one presents a stimulus while recording the EEG, an epoch of EEG that is time-locked to stimulus presentation can be defined; within this epoch, neural voltage changes specifically related to the brain's response to that stimulus event can be identified – that is, the event-related potential (e.g., see Coles & Rugg, 1995; Luck, 2005).

The voltage changes related to a specific stimulus as reflected in the ERP recording are on the order of microvolts – one microvolt is 1/1,000,000<sup>th</sup> of one volt – while the ongoing EEG is on the order of tens of microvolts. To extract the tiny ERP signal from the unrelated background EEG, one must present multiple instances of a stimulus and average across the epochs of EEG time-locked to stimulus presentations, which yields an average ERP response. This foundational aspect of ERP recording – the necessity to present numerous instances of a stimulus class of interest, enough instances to average together to create a clean ERP waveform – is a technical limitation and can be particularly challenging in ERP studies with children: the more stimuli presented, the more repetitive (and boring) the task can become, the longer the recording session can extend, and the less cooperation and attention can be maintained. Designing tasks that can be appealing and engaging for children is crucial to collection of decent developmental ERP data. Sometimes this can be as simple as modifying a paradigm successful with adults (Armstrong, Neville, Hillyard, & Mitchell, 2002) by limiting the number of conditions and consciously choosing child-friendly target stimuli (Coch, Skendzel, Grossi, & Neville, 2005), and sometimes this can be as simple as carefully providing short wiggle breaks and encouragement with M&Ms and Goldfish – but most of the time, this is a difficult design issue.

Thus, the ERP method provides a direct measure of neural activity: the squiggly lines are a visual representation of biological, electrophysiological activity. However, because the brain is a volume conductor, electrophysiological activity recorded at any given electrode site does not necessarily come from brain regions in close proximity to that site. Therefore, the ERP method does not provide specific information about *where* in the brain stimulus-related processing is occurring; that is, it has relatively poor spatial resolution, in contrast to PET and fMRI. But the ERP method does provide very specific information about *when* stimulus-related processing is occurring, on the order of milliseconds (one millisecond is 1/1,000<sup>th</sup> of one second).

It follows that the ERP method is best suited to addressing questions about the timing of neurocognitive processing. This, I think, is particularly important in terms of measuring *process* as opposed to *product*. For example, consider a simple rhyming study in which pairs of stimuli (prime-target) are presented and participants are asked to press a button after presentation of each target to indicate whether the stimuli in the pair rhymed or did not rhyme. If this were a purely behavioral study, the only data would be the button press measures (perhaps reaction time and accuracy) reflecting the final decisions of the participants – an outcome or product measure. If this were, in addition, an ERP study, we could gather electrophysiological data reflecting processing of the primes and processing of the targets and we could compare processing of rhyming and nonrhyming targets – indexing key parts of the *process* of performing the rhyme task in addition to gathering data regarding the final *product*. Each of the component parts of the rhyme task may have different developmental time courses or may be differentially compromised in populations with rhyming deficits. A student who “can’t rhyme” may not be encoding the prime in memory, may not be segmenting off the ending sounds (rimes) of the prime and target, may not be comparing those ending sounds, or may not be answering

accurately. A simple ERP rhyming paradigm with a behavioral response can index many of the aspects of this rhyming process and suggest at what point there may be failure.

This example begins to illustrate what neuroscience can add to education. In my view, findings from neuroscience should not necessarily dictate how to teach in a classroom – there is nothing, inherently, in a pattern of brain activation alone that can indicate how to teach; the promise of neuroscience is not in “telling educators what to do.” In my view, part of the promise of neuroscience is in encouraging educators to think about the learning and development occurring in the children in their classrooms in new ways, considering evidence both from their own experiences and from the multidisciplinary literature on child development. Moreover, I do not envision neuroscientists at the top of some knowledge hierarchy, handing down truths to educators at the bottom. (In fact, I find this model, often implicit, repugnant for a number of reasons – not the least of which is that it severely devalues the professionalism of educators.) Instead, I envision collaboration between educators and neuroscientists, each group having unique insight into and experience with learning and development and thus each group bringing valuable information to the dialogue.

I recognize that this vision of an MBE world is not easy to achieve – some of my students never see through the looking glass, and sometimes I seem to get only tantalizing glimpses myself. In both my research and my teaching I have struggled to build the foundations and support the difficult critical thinking that leads to making useful connections across disciplines. For example, a local fourth-grade teacher is a member of my lab; over time, she has learned the procedures related to running an ERP study and has participated in ongoing studies. In her classroom, she has noticed that some students who are poor readers seem to read better when written materials are placed on slant boards on their desks. We have talked about this observation, basically a finding from action research, in terms of the roles of attention and various aspects of the visual system in reading and poor reading. We have delved into the relevant scientific literature – across psychology, neuroscience, and education – and have developed some specific hypotheses. We are in the process of designing ERP paradigms that will test these hypotheses. To get to this point has taken nearly two years; basic logistical constraints involving time, scheduling, availability of funding, and full-time jobs have seriously impeded our progress.

Note that this is but one example; as I mentioned above, my contention is not that educators need to become trained neuroscientists as part of a science of MBE. Local educators have also toured my lab, participated in experiments, attended workshops and discussions, and audited my classes – all attempts to begin building the dialogue and interdisciplinary knowledge base that are fundamental to MBE. In addition, I have the opportunity to teach teachers- and researchers-in-training and involve these students in ERP research. This I see as a chance to develop scientific literacy and engender transdisciplinary thinking *from the beginning*, making synthesis and integration across evidence from various disciplines a habit of mind and consideration from multiple perspectives second nature. I believe that activities such as these, beyond the research itself, are crucial to making brain-education links.

In my ERP research, the brain-education link, for me, is in the content: am I investigating something that will better help me to understand some aspect of learning and development that is relevant in an educational context? Using the ERP technique in an MBE world requires me to

think critically about an educationally relevant, astoundingly complex process such as reading; carefully consider the possible contributing component processes and subprocesses by culling across educational, psychological, and neuroscientific literatures; design electrophysiological experiments to selectively target, index, and explore them; begin to chart their developmental course at the neural level; and consider the implications of the findings in a broader context. In my view, electrophysiological recordings can provide a unique neurobiological perspective on aspects of learning and development that are relevant in educational context, such as the phonological skills crucial to reading development.

As an illustration, consider an ongoing series of ERP rhyming studies using a simple prime-target with response paradigm. In the original developmental studies with real word pairs (*juice-moose*, *juice-chair*), subjects from age 7 to 23 participated in both an auditory (Coch, Grossi, Coffey-Corina, Holcomb, & Neville, 2002) and visual (Grossi, Coch, Coffey-Corina, Holcomb, & Neville, 2001) version of the task. Within each modality, we reported an ERP rhyming effect to targets that was similar across age groups. The onset of the ERP rhyming effect indicated very early differentiation of rhyming from nonrhyming targets across age groups: by 100-150 milliseconds after target presentation in the auditory modality and by 250-300 milliseconds in the visual modality.<sup>1</sup> These findings suggested that the phonological processing networks indexed by this task are relatively well established and have an adult-like organization at least by the age of 7. Interestingly, the standard behavioral button-press data were seemingly at odds with the ERP findings (e.g., Coch et al., 2002): reaction time and accuracy improved with age, suggesting change over time in the studied age range. How to reconcile these sources of information? One possibility is that the behavioral measure revealed more about button pressing than it did about rhyming, while the ERP measure more clearly reflected rhyme processing; in this view, without the constraint of the brain data, the behavioral data might have suggested marked development where there was little.

These were some of the first studies to begin to chart the developmental course of the ERP rhyming effect, and were striking in their indication that the neurocognitive systems indexed by a simple word rhyming task appear similar in typically developing 7-year-olds and adults. Given these foundational developmental ERP findings, it is now possible to investigate whether children with atypically developing language and reading skills demonstrate a similar ERP rhyming effect with similar onset timing and whether this effect is influenced by behavioral remediation techniques. Such findings will add a temporal dimension to the fMRI literature showing changes in the spatial distribution of activation during a rhyme task after targeted remediation in children with dyslexia (e.g., Shaywitz et al., 2004, Temple et al., 2003) and can begin to address questions of *how* and *why* targeted educational interventions work or do not work.

In a subsequent study further investigating the ERP rhyming effect to targets, we used auditory, made-up (nonword) stimuli (*nin-rin*, *ked-voo*) with college students and 6- to 8-year-old participants (Coch, Grossi, Skendzel, & Neville, 2005). We found an ERP rhyming effect similar to that for real words, suggesting that the effect is not particularly sensitive to semantics. In the

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<sup>1</sup> The later onset timing in the visual modality might be expected hypothetically given the additional orthographic-to-phonological mapping that must occur in this condition but not necessarily in the purely auditory condition.

children, we also measured phonological awareness using a standardized behavioral test (Wagner, Torgesen, & Rashotte, 1999). We divided the 54 child participants into two groups based on a median split of their phonological awareness scores. Behaviorally, the groups differed significantly in terms of phonological awareness but not in terms of age. Electrophysiologically, the onset of the ERP rhyming effect was comparatively 80 milliseconds later in the group with poorer phonological awareness (or 80 milliseconds earlier in the group with better phonological awareness). This is a striking pattern: 80 milliseconds in real time is less than the blink of an eye, but in neural processing time is a significant epoch (recall that rhyming and nonrhyming auditory real words were differentiated within just 150 milliseconds of stimulus onset). It is important to note that all children scored within normal limits on the standardized behavioral test: all of the participants had adequate and age-appropriate phonological awareness skills and all were able to perform the ERP rhyme task at greater than 87% accuracy. However, the ERPs revealed that phonological rhyme information was being processed on a different timetable in the two groups. Once again, brain and behavior provide different sources of evidence at different levels of analysis, mutually constraining interpretation of a pattern of findings with educational implications.

In a recent study in this series, we showed that visually presented single letter stimuli (*b-c, b-a*) elicit the typical ERP rhyming effect to targets in college students (Coch, Hart, & Mitra, in press). Letter stimuli are of particular interest developmentally because numerous behavioral studies have shown that phonological awareness and letter identification skills are the best predictors of ease of learning to read (e.g., Adams, 1990; Scarborough, 2005; Treiman, 2000). Thus, a simple paradigm that directly indexes both phonological skills and letter names, such as a letter rhyming paradigm, could potentially provide insights into brain-behavior relations in reading in participants who are, in fact, not yet reading, who are just beginning to read, or who are struggling to learn to read – participants for whom word or nonword stimuli might be confoundingly difficult. Provocatively, even in college students with no history of language or reading disorders, the size of the ERP letter rhyming effect was correlated with standardized measures of vocabulary and orthographic-to-phonological analysis skills (Woodcock, 1987)<sup>2</sup> – once again suggesting brain-behavior connections for phonological processing skills central to reading and learning to read in a classroom context.

Indeed, it is the combination, comparison, and contrast among findings from different methods and approaches that I believe will be most powerful in building a sustainable interdisciplinary science of MBE. I think that the ability to synthesize and integrate across multiple levels of explanation and multiple perspectives – including the electrophysiological – is one of the key characteristics of practitioners of MBE (e.g., Ansari & Coch, 2006). In this view, one can move beyond the technical details of the methods and begin to engage critically with findings across disciplines, creating meaningful connections and building understanding across evidence from various sources. And this, I believe, is how one begins, finally, to see through the looking glass to the wondrous world beyond.

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<sup>2</sup> The mean amplitude of the ERP rhyming effect to letter targets, measured at right hemisphere, medial, posterior sites C4, P4, and O2 (where the effects were largest), was correlated with scores on the WRMT-R Word Identification ( $r = -.398, p < .05$ ) and Word Attack ( $r = -.396, p < .05$ ) subtests.

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