12-31-2000

# Studies of Brain Activity Correlates of Behavior in Individuals with and without Developmental Disabilities

Amanda DiFiore
*University of Massachusetts Medical School*

William V. Dube
*University of Massachusetts Medical School*, William.Dube@umassmed.edu

Stephen Oross III
*University of Massachusetts Medical School*

***See next page for additional authors***

# *RESEARCH IN PROGRESS*

## *STUDIES OF BRAIN ACTIVITY CORRELATES OF BEHAVIOR IN INDIVIDUALS WITH AND WITHOUT DEVELOPMENTAL DISABILITIES*

Amanda DiFiore, William V. Dube, Stephen Oross III, Krista Wilkinson, Curtis K. Deutsch, and William J. McIlvane

UNIVERSITY OF MASSACHUSETTS MEDICAL SCHOOL - SHRIVER CENTER

Traditionally, behavior analysts have sought to develop a science of behavior that is independent of, yet complementary to, the brain sciences. Variables of interest include not only those environmental events that can be explicitly arranged and manipulated by experimenter/teachers but also the so-called "private events" that are of interest to radical behaviorists (Skinner, 1974). The study of private events is only in its infancy. Yet there is a rich assortment of brain imaging methodologies that permits evaluation of the covert events that are necessary to complete a comprehensive account of behavior (see Skinner [1989] for discussion of the natural roles of behavior analysts and brain scientists and Deutsch, Oross, DiFiore, & McIlvane, this issue, for an overview). Among the latter methodologies, our laboratories have begun to explore event-related potential (ERP) research to complement traditional behavior analysis. ERPs are averaged segments of EEG that are time-locked to a specific type of stimulus. The waveforms, or components, that emerge following the averaging procedure represent the brain activity associated only with the time-locked stimulus (i.e., neural behavior under stimulus control). Thus, ERPs allow us to examine neural events that occur between the onset of a stimulus and the execution of a response (one of the two inescapable gaps identified by Skinner [1989] in any nonbiologically-oriented behavioral analysis). Although it is difficult to identify the sole source of neural activity associated with these waveforms, we are able to look at the summed activity of the brain with timing on the order of milliseconds.

Within the ERP literature, it has become common practice to dissociate *early* components of the ERP from *late* components in an attempt to identify neural behavior associated with stimulus processing. ERP components (waveform peaks or troughs) that occur within the first 200 ms of stimulus onset have been correlated with the physical attributes of a stimulus (so-called *exogenous* components). By contrast, *endogenous* components, occurring after 200 ms, have been correlated with conceptual behavior. Early processing deficits could indicate sensory system impairments (e.g., inability to detect features of a complex stimulus). Given such sensory deficits, a behavioral intervention could target these impairments. Indeed, some research on perceptual learning would suggest that early deficits could be remediated by training (Ball & Sekuler, 1987; Karni & Sagi, 1993; Zohary, Celebrini, Britten, & Newsome, 1994). If the perceptual learning interventions prove unsuccessful, alternate compensatory strategies may be pursued. Late processing deficits would indicate that higher-order systems (e.g., those subsuming attending and language) are not operating in a manner consistent with the development of stimulus control. Under these circumstances, training might try to engage or tune the relevant neural systems.

We have used two well-investigated ERP components: (1) the P300 and (2) the N400. The P300 is a positive ERP component peaking at 300-600 ms following stimulus onset. Its amplitude has been correlated with attending and other effortful activity. The N400 component is negative and peaks at 350-600 ms. An N400 component is often observed when members of different semantic classes are juxtaposed. What follows are three examples of how behavior analysts are working jointly with cognitive neuroscientists to study subject matter that is of interest to both disciplines.

**Stimulus overselectivity (restricted stimulus control).** For many years, behavior analysts have studied stimulus overselectivity in populations with developmental limitations. In discrimination learning situations, some individuals with mental retardation routinely exhibit control by an atypically restricted range of features of complex stimuli (e.g., Dube & McIlvane, 1997; Lovaas, Koegel, & Schreibman, 1979). That is, certain stimulus features present during discrimination training may independently occasion the behavior of interest whereas other features do not. With complementary ERP assessment, we are beginning to ask questions about overselectivity that are

This report is based upon work supported by the National Institute of Child Health and Development under Grant P01HD25995.

difficult or impossible to answer via behavior analysis alone (Dinsmoor, 1985).

First, we are asking whether overselectivity is an early or late processing deficit, the answer to which will help determine behavioral intervention. Second, we are attempting to identify the neural correlates, or ERP components, associated with improved performance following training, and thus help pin down what the training actually accomplished. For example, if improved performance following training were accompanied by a larger P300 (one of the most heavily researched late components, cf. Donchin et al., 1986), then this would indicate that attending was somehow modified. Absent a change in P300 amplitude, improvement could be manifest in other ERP components or could be masked by overlapping neural events. Given these possibilities, an alternative experimental protocol could help identify the specific neural marker associated with improved behavioral performance. Thus, ERP methodology may prove useful in narrowing the range of candidate variables that must be analyzed in order to understand the overselectivity phenomenon.

Thus far, we have collected data from 10 nonclinical pilot subjects (who would not be expected to exhibit restricted stimulus control) responding to stimulus arrays that do occasion restricted control in individuals with developmental limitations. Using the *oddball* paradigm, successive blocks of trials present arrays of 1, 2, 3, and 4 stimuli. Within each block, the stimuli are the same on most of the trials (i.e., standard trials which occur with a stimulus probability of 80%). A reliable P300 is produced when one of the familiar stimuli in an array is replaced by a different stimulus (i.e., oddball trials occur 20% of the time). In follow-up work, we are conducting similar studies of individuals with mental retardation to determine whether there are differences in the P300 component.

**Discrimination of emotional content in faces.** It is well documented that some individuals with mental retardation do not exhibit typical control by facial stimuli associated with emotional expression (Rojahn, Lederer, & Tassé, 1995). One of our goals is to investigate and understand this phenomenon. Do individuals exhibit atypical control merely because of a generalized deficit in detecting the relevant stimulus differences or are there emotion-specific information-processing deficits that are selectively impaired? With ERPs, we can begin to answer this question. Furthermore, we will be able to examine both typical and atypical neural signals when there is behavioral evidence of an impairment. In addition to the aforementioned goals, this protocol is also designed to evaluate neural activity in the absence of an overt behavioral response. Thus, we will be able to test individuals with motor disorders (e.g., cerebral palsy, profound mental retardation, etc.) who are not able physically to make a response. The P300 component is a reliable indicator of discrimination even if the task does not involve overt behavior (Iwanami, Kamijima, & Yoshizawa, 1996).

We have collected data from 12 nonclinical pilot subjects under two experimental conditions. In the first *identity* condition, one face (the standard) is presented on 80% of trials while a different face (the rare stimulus) is randomly intermixed among the standard on 20% of trials. A P300 to the latter indicates that the subject is able to detect identity differences between the faces. In the second *emotion* condition, all trials present the same person's face. Interspersed within the 80% of trials that display a standard emotion (e.g., happiness) is a rare stimulus (e.g., sadness). Preliminary results indicate that the P300 component reliably differentiates both the identity and emotion displays, thus setting the stage for similar studies with clinical populations.

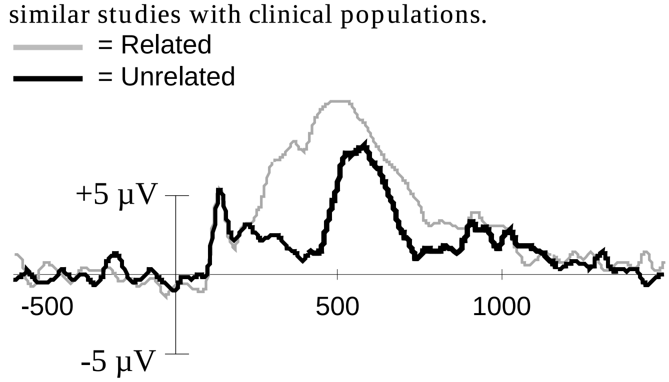


**Figure 1**

**Stimulus equivalence.** Sidman's paradigm has been used to model many aspects of semantic category development (e.g., Sidman, 1994), and such categorical processing can be evaluated using ERP methods. Extensive work of this type is now being conducted in our laboratories. In one ongoing study, for example, we have established three six-member arbitrary stimulus classes in a matching-to-sample procedure. Twelve subjects have served thus far. Following baseline training but before the equivalence tests, we (1) presented pairs of stimuli that either were or were not to be related on the tests and (2) recorded another late component, this one termed the N400 (Kutas & Hillyard, 1980) after the second stimulus of the pair had been presented. Notably, the N400 reliably discriminated between related and unrelated pairs on the equivalence tests. Data of this type are relevant to the issue of whether or not exposure to test trials is a necessary prerequisite for stimulus equivalence (McIlvane & Dube, 1990). That is, at the neural level one can detect evidence of equivalence class formation even prior to the tests. More generally, our ERP studies have shown that the N400 can be obtained with arbitrary experimentally established stimulus classes. Prior cognitive neuroscience N400 work has studied classes that were established extra-experimentally (Holcomb & Anderson, 1993; Kutas, 1993). Our ERP lab has replicated these findings. Figure 1 illustrates grand-mean ERPs to related and unrelated word pairs. The x-axis represents time (ms) and the y-axis represents amplitude (microvolts). The vertical bar designates stimulus onset. The N400 waveform is elicited by two successively presented words that are not semantically related. Successive presentation of two related word-pairs does not evoke this phenomenon. The fact that intra- and extra-experimentally defined classes share the same "neural signature" may be important data in arguing that Sidman equivalence is indeed a valid model of the semantic categories that have been of continuing interest to developmental and cognitive psychologists.

REFERENCES

Ball, K., & Sekuler, R. (1987). Direction-specific improvement in motion discrimination. *Vision Research,* **27,** 953-965.

Dinsmoor, J. A. (1985). The role of observing and attention in establishing stimulus control. *Journal of the Experimental Analysis of Behavior,* **43,** 365-382.

Donchin, E., Karis, D., Bashore, T. R., Coles, M. G. H., & Gratton, G. (1986). Cognitive psychophysiology and human information processing. In M. G. H. Coles, E. Donchin, & S. W. Porges (Eds.), *Psychophysiology: Systems, processes and applications.* New York: Guilford Press.

Dube, W. & McIlvane, W. (1997). Reinforcer frequency and restricted stimulus control. *Journal of the Experimental Analysis of Behavior,* **68,** 303-316.

Holcomb, P. J. & Anderson, J. E. (1993). Cross-modal semantic priming: A time-course analysis using event-related brain potentials. *Language and Cognitive Processes,* **8**(4), 379-411.

Iwanami, A., Kamijima, K., & Yoshizawa, J. (1996). P300 component of event-related potentials in passive tasks. *International Journal of Neuroscience,* **84,** 121-126.

Karni, A., & Sagi, D. (1993). The time course of learning a visual skill. *Nature,* **365,** 250-252.

Kutas, M. (1993). In the company of other words: Electrophysiological evidence for single-word and sentence effects. *Language and Cognitive Processes,* **8**(4), 533-572.

Kutas, M. & Hillyard, S. A. (1980). Reading senseless sentences: Brain potentials reflect semantic incongruity. *Science,* **207**(11), 203-205.

Lovaas, O. I., Koegel, R. L., & Schreibman, L. (1979). Stimulus overselectivity in autism: A review of research. *Psychological Bulletin,* **86,** 1236-1254.

McIlvane, W. J., & Dube, W. V. (1990). Do stimulus classes exist before they are tested? *Analysis of Verbal Behavior,* **8,** 13-17.

Rojahn, J., Lederer, M., & Tassé, M. J. (1995). Facial emotion recognition by persons with mental retardation: A review of the experimental literature. *Research in Developmental Disabilities,* **16,** 393-414.

Sidman, M. (1994). *Equivalence relations and behavior: A research story.* Boston: Authors Cooperative.

Skinner, B.F. (1974). *About behaviorism.* New York: Knopf.

Skinner, B.F. (1989). The origin of cognitive theory. *American Psychologist,* **44,** 13-18.

Zohary, E., Celebrini, S., Britten, K.H., & Newsome, W.T. (1994). Neuronal plasticity that underlies improvement in perceptual performance. *Science,* **263,** 1289-1292.