Running Head: ERPs in Social Neuroscience

Using Event-related Brain Potentials in Social Psychological Research:

A Brief Review and Tutorial

Bruce D. Bartholow

University of Missouri

David M. Amodio

New York University

Contact information:
Bruce D. Bartholow
Department of Psychological Sciences
210 McAlester Hall
University of Missouri
Columbia, MO 65211

Tel: 573-882-1805
Email: BartholowB@missouri.edu

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The crowning achievement of the human mind is, arguably, its ability to negotiate the vast complexities of the social world. The current surge of interest in social neuroscience reflects the fascination that scientists from a wide range of disciplines have with the neurocognitive mechanisms that give rise to social behavior (e.g., Cacioppo, Visser, & Pickett, 2005; Harmon-Jones & Winkeilman, 2007). Of particular interest are questions such as: How is information about social targets perceived? How does one manage conflicts between personal desires and social norms? What can functional neuroanatomy tell us about the social mind? What can an understanding of social cognition and motivation tell us about neural function? Social neuroscience research integrates theories and methods of the heretofore disparate approaches of social psychology, cognitive science, and cognitive/affective neuroscience, to address these and related core questions about the relationship between the brain and the social mind.

The present volume features methodological approaches used to measure activity of the brain in order to probe functions of the social mind. The focus of this chapter is on the event-related potential (ERP), a prominent method for observing patterns of brain activity associated with psychological events. ERPs are notable for their ability to assess rapid changes in neural processing, and they are the only noninvasive neuroimaging method that provides a direct measure of neural firing. Other prominent methods, such as functional magnetic resonance imaging (fMRI), provide indirect measures of neural activity by assessing, for example, the flow of oxygenated blood to neural tissue. Whereas traditional research on social cognition and motivation has had to infer the activity of underlying cognitive mechanisms only by the proxy of behavioral expressions (e.g., on reaction-time tasks), ERPs and other neuroimaging methods allow researchers direct access to the cognitive machinery that drives social behavior, thereby providing a powerful tool for testing theories of social cognitive and motivational processes.

We begin this chapter with a brief overview of the theory and methods of the ERP (for a more thorough treatment, see Fabiani, Gratton, & Federmeier, 2007; or Luck, 2005). We then describe some of the ways in which ERPs have been used to address a range of questions concerning social perception, social cognition, and self-regulation. We conclude with some advice concerning experimental design and a discussion of the advantages and disadvantages of the ERP, relative to traditional behavioral measures and to other measures of brain function.

What is the ERP?

The ERP is an index of brain activity derived from measures of electricity generated by the firing of cortical neurons. Although the existence of bioelectrical potentials in the brain had been established previously (e.g., R. Bartholow, 1882), Hans Berger (1929) first demonstrated that it is possible to measure electrical activity generated from within the living human brain, know as the electroencephalogram or EEG, using two large, saline-soaked sponges held to the scalp and connected to a differential amplifier. The technology of EEG recording has advanced considerably since Berger's time, and modern methods permit high-quality measurement of scalp voltages from multiple scalp sites (Davidson, Jackson, & Larson, 2000). The continuous recording of EEG (e.g., during a psychological task) indexes changes in patterns of brain voltage over time, the amplitude of which normally ranges from approximately -100 to +100 microvolts (μV) (for more information on the EEG, see Harmon-Jones, this volume). When measured in the context of an experimental task involving specific events (e.g., stimuli or responses), it becomes possible to examine epochs of the EEG that reflect neural processes uniquely associated with the event. This event-related EEG response is called the ERP.

Physiologically, ERPs represent the summation of post-synaptic potentials from populations of synchronously active, primarily cortical neurons (see Allison, Wood, & McCarthy, 1986; Coles & Rugg, 1995). The columnar structure of cortical neurons aligns the electrical field orientation of their potentials, creating a summated signal that is strong enough to be detected at the scalp. The ERP reflects one end of the electrical dipole produced by firing neurons. The contrapolar dipole is oriented in the opposite direction (i.e., away from the scalp), and therefore typically is not measured. Not all neural signals are picked up by EEG; only those that produce dipoles oriented toward scalp electrodes are recorded. In addition, opposing dipoles from two or more generators (i.e., dipoles of opposite polarity that are oriented toward each other) can cancel each other out so that neither is detected at the scalp.

A particular voltage deflection recorded at the scalp may comprise the activity of one or multiple sources located in different regions of the brain. Because the contours of the cerebral cortex are highly corrugated, there is substantial variability in the orientation of cortical neurons. As a result, the relative position of a neural source and the location at which it is detected at the scalp is also variable. For example, depending on the neuronal orientation, an ERP from activity in a similar region may be most pronounced at very different locations on the scalp. Finally, neural structures that are not organized in columns (e.g., subcortical structures like the amygdala) do not produce large summated dipoles that are evident at the scalp, and so activity from these neural regions cannot be assessed using ERPs.

Psychologically, ERPs represent neural manifestations of specific information processing activities associated with a stimulus or response event. The ERP waveform is typically comprised of a series of positive and negative voltage deflections, often referred to as components (see Figure 1). Specific ERP components often are associated with a particular information-processing operation or set of operations (see Fabiani et al., 2007); though it is quite likely that any given component represents numerous simultaneously occurring processes (see Coles & Rugg, 1995). In general, the amplitude of a given ERP component represents the extent to which those operations are engaged by a stimulus or response event, and the latency at which the component peaks is thought to index the time at which those operations have been completed (see Fabiani et al., 2007).

Measuring ERPs

ERPs can be measured noninvasively using electrodes placed on the surface of the scalp, typically according to standard placement guidelines (see American Encephalographic Society, 1994) and often embedded in a stretch-nylon cap that can be worn by the participant. Electrodes used to record ERPs typically are small disks of metal, 4-8 mm in diameter, made either of tin or of silver with a coating of silver chloride (Ag/AgCl), as these materials are highly conductive and resist polarization. These electrodes are connected to a set of preamplifiers, which in turn are connected to amplifiers that magnify the very weak electrical signals emitted by the neurons by a factor of 10,000 to 50,000 so they can be measured accurately. These analog signals are digitally sampled at a frequency ranging from 100 to around 10,000 Hz (samples per second) and stored to a computer hard drive. Sampling rates of 250 to 1,000 Hz are common, and in principle should be at least twice as large as the largest waveform of interest (i.e., the Nyquist frequency) to avoid aliasing, a type of sampling artifact (see Gratton, 2000). The amplified signal produces a waveform that appears as a continuous voltage waveform unfolding over time. The extent to which this “digitized” recording faithfully reproduces the original analog signal depends on the sampling rate, amplifier gain and filtering parameters (see Luck, 2005 for more details).

Reducing noise in ERP measures

As with any measure used in psychological research, it is critical to limit measurement error as much as possible when recording EEG. Some important sources of error variance can be reduced by proper preparation of participants for electrophysiological recording (for details on preparation of participants for EEG recording, see Harmon-Jones, this volume), and by ensuring that the recording environment is free from sources of electrical interference, such as motors and unshielded power cables and computer monitors. EEG laboratories typically include two separate rooms, with computers and amplifiers located in a control room that is separate from the participant chamber. As an extra precaution, the participant chamber may be electrically-shielded and soundproofed. Furthermore, the participant must be coached to remain still and focused on the experimental task during EEG recordings in order to reduce movement artifacts (such as electromyographical activity) and distractions that can cause excessive eye movement artifacts.

Assuming that EEG data are recorded cleanly, steps must be taken to extract the relatively small ERP signal (a few microvolts) from the higher-amplitude background EEG (upwards of 50 microvolts). The most common methods for extracting ERP “signal” from background EEG “noise” include filtering and averaging. Filtering involves passing the analog signal through a combination of capacitors and resistors designed to allow only signal within a particular range to pass through; a combination of high- and low-pass filters can be applied to narrow the range of frequencies recorded and to “filter out” signals that are not of interest (see Marshall-Goodell, Tassinary, & Cacioppo, 1990, for a review of bioelectrical measurement). For example, most components related to psychologically-significant events tend to have a frequency range of about 0.5 to 30 Hz (see Fabiani et al., 2007; Luck, 2005). Thus, at the time of recording or later during data processing, digital or analog filter settings can be used to attenuate frequencies falling outside this range (however, for cautionary notes concerning excess use of filtering, see Luck, 2005). As a rule of thumb, most researchers record EEG from a relatively wide bandwidth (e.g., .01 to 100 Hz) using online analog filters and then, in later offline processing, focus in on a narrower bandwidth capturing ERPs of interest using digital filters.

The averaging process capitalizes on the principle that EEG signals unrelated to a particular event will vary randomly across samples and, after one centers the data in each epoch (typically, by defining a pre-event baseline period), these randomly-varying aspects of the background EEG noise will average to zero. Meanwhile, aspects of the EEG that correspond to the event of interest will emerge as signal. In general, the inclusion of more samples will yield a better signal-to-noise ratio (but see Fabiani et al., 2007; and Luck, 2005, for qualifications). Figure 2 illustrates the concept of averaging. The ERP waveforms illustrated in Figure 2 were measured from 4 participants during an auditory discrimination task. For each of these 4 participants, four individual trial waveforms (first column), representing the response to 4 presentations of a particular stimulus, are averaged to form individual participant average waveforms (second column), which, in turn, are averaged to form a grand average waveform (third column) representing the average response to this stimulus across these participants. Note, too, that adding more participants' responses (or more responses per participant) results in a cleaner ERP signal with less random EEG noise (fourth column).

Quantifying ERPs

Once an averaged waveform is computed for each participant, it can be scored for analysis using inferential statistics. The most common method of scoring is to determine the peak amplitude of the ERP component of interest, often defined as the minimum or maximum voltage within a predefined time window in which that component emerges. As an alternative, researchers will sometimes compute the average voltage within that time window. Whether peaks or means are used can depend upon the specific questions being asked, the manner in which the EEG was measured and filtered, and to some extent on which components are being examined (see Fabiani, Gratton, Karis, & Donchin, 1987). Researchers may also be interested in the latency of an ERP component, in which case they would determine the timepoint at which the component reaches its peak value (for alternatives to peak and mean component amplitude measures, see Fabiani et al., 2007; Gratton, 2000). ERP scoring can be accomplished using most commercially-available ERP analysis software packages, which in turn will output the scores to a text (ASCII) file to be imported into a spreadsheet for statistical analysis. Alternatively, whole waveform data may be exported as text into spreadsheets in statistical programs (e.g., SPSS), and scoring and analysis can be accomplished using user-created batch files.

Interpreting ERP Data

The functional significance of different ERP components is inferred by a combination of factors, including the nature of the task used to elicit them, the timing, scalp location and putative neural source(s) of components, as well as a researcher’s particular theoretical perspective. In this section, we describe some commonly-examined ERP components and discuss the types of questions that each class of ERP components are commonly used to address. These components include stimulus-locked, response-locked, and anticipatory ERP waves. This classification refers to the way that epochs of EEG are combined during the averaging process. One method is to align all epochs of EEG to the time of stimulus onset, thereby rendering a stimulus-locked waveform. Alternatively, one may align EEG epochs to the moment when a task response is made (i.e., a response-locked waveform). Finally, EEG epochs may be aligned to a signal that indicates an upcoming stimulus, which we refer to as an anticipatory waveform. The method of averaging depends on the type of questions one wishes to ask and the nature of one’s experimental task design. Note, too, that the following list is incomplete, as the catalog of ERP components associated with specific processes continues to expand.

Stimulus-locked components

Stimulus-locked ERP components are generally associated with the engagement of attention toward a noteworthy stimulus and most pronounced over posterior scalp regions. Larger stimulus-locked ERP amplitudes are typically interpreted as reflecting a stronger psychological response to the stimulus. Because ERPs can assess changes in such processes occurring on the order of milliseconds, and because they do not depend on verbal self-report, ERPs are very useful for measuring rapid and potentially implicit perceptual responses to a broad range of stimuli. Naming conventions for stimulus-locked ERPs typically refer to the polarity (positive or negative) and either the ordinal position following the event (e.g., the first positive-going deflection following stimulus onset is P1, then N1, then P2, etc.) or the approximate time at which the wave peaks (P100, N100, P200), as illustrated in Figure 1.

Early components. Researchers interested in the extent to which attention is directed to a stimulus early in processing often focus on the amplitude of a set of early endogenous components. In particular, the N1 and the P1 have been linked to attentional processes (see Fabiani et al., 2007), in that increased amplitude of these components is thought to reflect increased direction of selective attention to stimulus processing (see Hillyard, Vogel, & Luck, 1998; Hopfinger & Mangun, 2001; Mangun, Hillyard, & Luck, 1993). The amplitude of the N2 component has also been associated with biased attention to social ingroup cues (see Dickter & Bartholow, 2007; Ito & Urland, 2003, 2005). Another relatively early negative component, the N170 (typically prominent at right-hemisphere occipital electrodes), is of particular interest to researchers interested in social perception because it appears to be specific to face processing (e.g., Bentin, Allison, Puce, Perez, & McCarthy, 1996). The distinction in psychological function between these early components is often unclear, beyond the notion that they reflect attentional engagement, and their neural sources are not well-understood.

The No-Go N2 is a special case of a stimulus-locked component that is elicited at about 300 ms following a “No-Go” stimulus in a Go/No-Go task. Unlike most other stimulus-locked waves, the No-Go N2 is associated with self-regulatory executive control processes such as inhibition (e.g., Kopp, Rist, & Mattler, 1996) and conflict detection (e.g., Nieuwenhuis, Yeung, van den Wildenberg, & Ridderinkhof, 2003), and has been shown to emerge from activity in the anterior cingulate cortex (ACC). However, there is reason to believe that the No-Go is associated with the behavioral process of inhibition (i.e., muscle contractions that stop a response), which would explain why it has the characteristics of many response-locked components (see below).

Late components. The widely-studied P3 (also sometimes referred to as the P300 or, more generically, as the late positive potential or LPP; see Cacioppo, Crites, Gardner, & Berntson, 1994) is a relatively large positive deflection that typically peaks between 300 and 800 ms post-stimulus. The P3 has been associated with the processing of novelty (Friedman, Cycowicz, & Gaeta, 2001), in that its amplitude increases as the subjective probability of an event decreases (e.g., Donchin & Coles, 1988; Duncan-Johnson & Donchin, 1977). The P3 also has been described as an index of working memory updating, based on numerous studies indicating better subsequent memory for stimuli that elicit larger P3 amplitude (e.g., Donchin, 1981; Donchin & Coles, 1988; Friedman & Johnson, 2000). The latency at which the P3 peaks has been described as an indicator of stimulus evaluation or categorization time, with longer latencies indicating more effortful categorization (see Kutas, McCarthy, & Donchin, 1977). Although the neural source of the P3 has been elusive, recent research suggests it may arise from multiple activations in the brain coordinated by norepinephrine signaling from the locus coeruleus in responses to an arousing event (Nieuwenhuis, Ashton-Jones, & Cohen, 2005). Nieuwenhuis et al.’s (2005) analysis provides a parsimonious explanation for the sometimes disparate functions ascribed to the P3.

A final stimulus-locked component that develops after the P3 has resolved is the negative slow wave (NSW). This component typically is most prominent over central or fronto-central electrode locations, and has been associated with the implementation of self-regulatory cognitive control processes such as those required for inhibiting responses (Bartholow, Dickter, & Sestir, 2006) or overcoming cognitive conflict such as that occurring on incongruent trials in a Stroop task (e.g., West & Alain, 1999; see also Curtin & Fairchild, 2003). Like the No-Go N2, the NSW shares characteristics of response-locked waves in that it is associated with self-regulation and may reflect a behavioral response rather than the processing of a stimulus.

Response-locked components

Whereas stimulus-locked components are typically associated with perception and attentional engagement, response-locked components are useful for examining mechanisms associated with the formation and regulation of a behavioral response. Response-locked waves tend to be named according to their polarity and the type of response that elicits them, such as the “error-related negativity” (ERN) and “error-positivity” (P_e), and they tend to be pronounced at frontal or fronto-central scalp sites.

ERN. The widely-studied ERN component develops concurrently with the onset of a behavioral response, peaking around 50-80 ms post-response, and is almost always larger for incorrect than for correct responses (Figure 3). Much research has localized the ERN’s source to the dorsal ACC (Dehaene, Posner, & Tucker, 1994; van Veen & Carter, 2002). The fact that the

ERN occurs specifically with response errors initially led researchers to interpret the ERN as a neural indicator of error detection (see Falkenstein, Hohnsbein, Hoormann, & Blanke, 1991; Gehring, Goss, Coles, Meyer, & Donchin, 1993). However, more recent reports of ERN-like negativities occurring on correct response trials under some conditions (i.e., the correct-response negativity or CRN) have led to the hypothesis that the ERN/CRN reflects a more general process associated with conflict monitoring (e.g., Botvinick, Braver, Barch, Carter, & Cohen, 2001; Yeung, Botvinik, & Cohen, 2004), consistent with fMRI studies of the ACC (Carter et al., 1998). The ERN has also been interpreted as a neural “distress signal” sent by the ACC to other neural structures as an indication that enhanced cognitive control is required (see Bartholow et al., 2005; Bush, Luu, & Posner, 2000).

P_e. The P_e component follows the ERN in the response-locked waveform, typically peaking between 250-400 ms after a response. Whereas the ERN has been shown to arise from activity in the dorsal ACC, the P_e has been localized the rostral ACC and adjoining region of medial prefrontal cortex (van Veen & Carter, 2002). Although considerably less research has been conducted on the P_e and its functional significance, research by Nieuwenhuis et al. (2001) suggests that the P_e is associated with the conscious awareness that one has made a response error, whereas the ERN occurs regardless of error awareness (but see Scheffers & Coles, 2000). More recent research (described in the next section) suggests that the P_e reflects the monitoring of conflict between one’s behavior and external (e.g., normative) cues for response regulation (Amodio, Kubota, Harmon-Jones, & Devine, 2006).

Anticipatory ERP components

A third class of ERP components are anticipatory waves, such as the *stimulus-preceding negativity* and *contingent negative variation* components. These components emerge as a participant prepares for an upcoming stimulus or response and are believed to reflect attentional engagement or preparatory control. These anticipatory ERP components are useful for examining participants' motivations for engaging in certain trials within a task. For example, a researcher may seek an unobtrusive measure of a participants' motivation to respond to certain stimuli as a function of an experimental manipulation, such as the application of peer pressure, or of individual differences, such as motivations to respond without prejudice (e.g., Chiu, Ambady, & Deldin, 2004). As described above, the NSW also shares some characteristics of anticipatory waveforms, and thus one's interpretation of these waves relies on one's theoretical position and the design of the experimental task.

A related component is the LRP. Kornhuber and Deecke (1965) first noted that a negativity develops in the ERP during the warning interval preceding an imperative stimulus and is most pronounced over the motor cortex contralateral to the responding hand. Observing that this ERP appears to reflect preparation for a motor response, they labeled it a "readiness potential" (or Bereitschaftspotential). Approximately 20 years later, researchers began to use the lateralization of readiness potentials in choice reaction tasks to infer whether and when participants had preferentially prepared a particular motor response (e.g., Coles & Gratton, 1986; Gratton, Coles, Sirevaag, Eriksen, & Donchin, 1988; De Jong, Wierda, Mulder, & Mulder, 1988). Substantial evidence now indicates that, indeed, the lateralized readiness potential (LRP) reflects activation in motor cortex associated with preparation to initiate a particular motor response (e.g., with the right or left hand; see Coles, 1989). In this regard, the LRP may be considered a special case of an anticipatory waveform, as the LRP often develops as participants are anticipating a response to a target (e.g., following a warning cue or in a sequential priming task).

Interpretational issues

An important caveat to the interpretation of ERP components is that a given component elicited in different modalities (e.g., visual vs. auditory), or in the context of different experimental tasks, likely reflects the activity of different neural structures and/or represents engagement of different psychological processes. For example, as noted by Luck (2005), the auditory P1 and N1 components appear to bear no relationship to the visual P1 and N1 components. Therefore, readers are cautioned against assuming that, for example, the N2 that has been associated with an ingroup attention bias in social categorization tasks (e.g., Ito & Urland, 2003, 2005) shares a similar neural source or reflects similar information-processing operations as the prominent N2 often seen in tasks involving response conflict or inhibition.

Examples of ERP Research in Social Neuroscience

How can ERPs be used to elucidate social processes? As theories of social cognition have advanced, they have become increasingly sophisticated in their treatment of cognitive processes underlying social judgments and behavior. However, it is often difficult to test hypotheses about underlying mechanisms using only behavioral and self-report methods. First, these traditional research tools are unsuitable for assessing rapid changes in cognitive processes believed to drive phenomena such as social perception, categorization, and stereotyping. Furthermore, implicit processes are by definition not amenable to explicit self-report, and the extent to which they can be clearly inferred from expressions of behavior is a matter of debate. Finally, it is difficult to measure subtle online changes in cognitive processes unobtrusively using these traditional tools, as these measures often interfere with the process of interest. However, we are happy to report that ERPs can provide a solution to these problems. In this section, we describe research that has used ERPs addresses some enduring questions about social processes.

Attitudes and Evaluative Processes

Using ERPs to assess attitudes. In a seminal early report, Cacioppo, Crites, Berntson, and Coles (1993) applied theory and methods of the P3 component of the ERP to examine attitudes. The authors noted that P3 amplitude often is increased when a given stimulus represents a category different from that of preceding stimuli (e.g., Donchin & Coles, 1988; Squires, Wickens, Squires, & Donchin, 1976). Their paradigm represented a modification of a classic "oddball" task often used to study the P3, in which relatively infrequent target stimuli (i.e., oddballs) are presented among more frequent context stimuli. This approach ensures an enhanced P3 to the targets, which represent an evaluatively different category than the neutral context images. They reasoned that because attitudes represent a type of evaluative categorization (e.g., good vs. bad), an evaluatively-inconsistent attitude word (e.g., a negative word preceded by positive words) should elicit a larger P3 than evaluatively consistent attitude words (e.g., a negative word preceded by other negative words). Cacioppo et al.'s (1993) results confirmed this hypothesis, and opened the door to a method for studying attitudes that did not rely on participants' self-reports (see also Cacioppo et al., 1994; Crites & Cacioppo, 1996; Ito, Larsen, Smith & Cacioppo, 1998). Subsequent work suggested the promise of using ERPs as an implicit measure of attitudes (for a review, see Ito & Cacioppo, 2007). For example, Crites, Cacioppo, Gardner, & Berntson (1995) compared P3 amplitudes for conditions in which participants truthfully reported versus misreported their attitudes toward target objects. Across reporting conditions, the P3 was sensitive to the underlying evaluative nature of the stimuli and not to subjects' explicitly reported evaluations (see also Ito & Cacioppo, 2000). Similar work has shown that self-relevant stimuli elicit larger P3s than other stimuli, even when participants' explicit task is to categorize stimuli along other dimensions (see Gray, Ambady, Lowenthal, & Deldin, 2004).

ERPs to measure implicit attitudes. Perhaps the most significant contribution of the research just reviewed is demonstration of the utility of ERPs to assess implicit evaluations without relying on self-report, or indeed on any behavioral response whatsoever. In fact, P3 might be considered an ideal measure of implicit responding in the sense that P3 is independent of behavioral processes (e.g., Donchin & Coles, 1988; Magliero, Bashore, Coles, & Donchin, 1984; McCarthy & Donchin, 1981). This fact has implications for a broad range of paradigms in social and personality psychology (not to mention cognitive psychology), in which response latency continues to be the gold standard for measuring the strength of association between constructs (see Bargh, Chaiken, Govender, & Pratto, 1992; Fazio, Sanbonmatsu, Powell, & Kardes, 1986; Greenwald, McGhee, & Schwartz, 1998). However, the use of behavioral measures to infer implicit processes is potentially problematic because response latency scores confound relevant stimulus processing with (often) irrelevant motor activation and execution processes (see Bartholow & Dickter, 2007).

Mechanisms of affective priming. This issue (and similar issues) recently has been discussed within the context of affective or evaluative priming tasks. Fazio et al. (1986) first demonstrated that the valence of affective target words is categorized more quickly when they are preceded by prime words of the same valence (i.e. congruent trials) than by prime words of the opposite valence (i.e., incongruent trials). Similar results have been reported by numerous other researchers (e.g., see Klauer & Musch, 2003). However, researchers continue to debate the underlying mechanism for this "affective congruency effect." Recently, some researchers have begun using ERPs to investigate the neural underpinnings of this effect. Zhang, Lawson, Guo, and Jiang (2006) were the first to use ERPs to study neural responses in an affective priming task. These authors reported more negativity to incongruent targets in 2 different ERP components, one corresponding to an N2 component (180-280 ms post-stimulus) and one referred to by the authors as an N400 component (480-680 ms). Based on these data, Zhang et al. concluded that the N400 component is sensitive not only to semantic mismatches (see Kutas & Hillyard, 1980), but also to affective mismatches, suggesting that affective priming shares a similar mechanism with semantic priming.

More recently, Bartholow, Schepers, Saults and Lust (under review) used ERPs to test competing theoretical models of affective congruency effects. One prominent model holds that the affective congruency effect stems from facilitation and inhibition within the evaluative categorization process (see Klauer, Musch, & Eder, 2005), while another model posits that the effect stems from conflict occurring during the response output stage of processing (e.g., Klinger, Burton, & Pitts, 2000). Bartholow et al. used ERPs to investigate the locus of the affective congruency effect within the information-processing system. Under conditions in which congruent trials were highly likely (80%) or were as likely as incongruent trials (50%), the amplitude of the LRP elicited by prime words showed that participants initially activated the incorrect response on incongruent trials (at prime onset) before ultimately activating the correct response (following target onset). These conflicting response activations influenced the amplitude of the N2 component, which was larger on incongruent than on congruent trials (again, when the probability of congruent trials was either 80% or 50%). Evidence in favor of the evaluative categorization hypothesis would be seen if the amplitude and/or latency of the P3 component mirrored the behavioral affective congruency effect (e.g., slower P3 latency on incongruent vs. congruent trials). However, this did not occur. Hence, overall these findings were consistent with the idea that affective congruency effects were a result of conflict during the response output stage rather than from simple evaluative match vs. mismatch.

Person Perception

Numerous ERP components have been used to understand rapidly unfolding processes in person perception. Some early work in this area was carried out by Cacioppo et al. (1994), who extended the basic evaluative inconsistency paradigm (Cacioppo et al., 1993) to person perception by measuring variability in P3 amplitude as a function of positive and negative personality trait words. Inspired by this work, Bartholow, Fabiani, Gratton, and Bettencourt (2001) used ERPs to study the effects of expectancy violations associated with person perception. Bartholow et al. (2001) asked participants to form impressions of several fictitious characters by reading short paragraphs designed to induce a positive or negative trait inference. These paragraphs were followed by sentences depicting specific behaviors that either confirmed or violated the trait information presented previously. Consistent with their hypotheses, Bartholow et al. (2001; see also Bartholow, Pearson, Gratton, & Fabiani, 2003) found that expectancy-violating behaviors elicited larger P3 amplitude than did expectancy-consistent behaviors. Expectancy-violating behaviors also were recalled better on a subsequent recall test than expectancy-consistent behaviors, consistent with the hypothesized working memory updating function reflected in the P3 (see Donchin & Coles, 1988).

ERPs also have been used to track the timecourse and level of engagement of processes associated with social categorization (see Ito, Willadsen-Jensen, & Correll, 2007). Ito and Urland (2003) had White participants categorize faces of Black and White men and women according to either race or gender. Differential ERP responses to race were observed as early as 120 ms, in the N100 component, and effects for gender were observed at about 170 ms, in the P200 component.

Similar to earlier work (see Mouchetant-Rostaing, Girard, Bentin, & Aguera, 2000), these effects occurred regardless of whether participants were explicitly categorizing race or gender (see also Ito & Urland, 2005). More recent research (Willadsen-Jensen & Ito, 2006) that has included an additional racial outgroup (Asians) observed a larger P200 to outgroup Asian faces than to White faces, but a larger N200 to White faces than to outgroup Asian faces.

Ito and colleagues also have used ERPs to better understand the relationship between spontaneous categorization processes and White participants' explicit, self-reported evaluations of Blacks as a group. Ito, Thompson and Cacioppo (2004) presented participants with equally infrequent pictures of White faces and Black faces among more frequent negatively-valenced context images (Experiment 1) or positive context images (Experiment 2) while ERPs were recorded. Across both experiments, the amplitude of the P3 indicated more negative evaluative categorization of Black faces compared to White faces. Moreover, the extent of this race bias in the P3 was positively correlated with more negative explicit evaluations of Blacks.

The fact that all participants in these previous studies were White leaves some ambiguity with respect to whether the findings reflect biased processing of particular racial group cues or rather differential processing of ingroup and outgroup cues. For example, it could be that Black and Asian faces attract more attention early in processing (N100 and P200) because they are relatively rare for White participants, or because the faces activate specific knowledge structures (e.g., stereotypes) that motivate attention. This issue was addressed in a study by Dickter and Bartholow (2007), which included both White and Black male and female participants and White and Black male and female target faces. Among White participants, Black targets elicited larger P200 and smaller N200 compared to White targets, replicating previous work (see Ito & Urland, 2003, 2005; Willadsen-Jensen & Ito, 2006). However, among Black participants these patterns were reversed (i.e., larger P200 to White targets and larger N200 to Black targets), suggesting that these early ERP components are sensitive to general ingroup-outgroup distinctions rather than to specific features of any one racial group (for a similar demonstration with Asian participants, see also Willadsen-Jensen & Ito, in press).

Stereotyping

In addition to revealing the neural correlates of social categorization, ERPs also have been used to investigate the consequences of category activation, namely, stereotyping. In an early example of this research, Osterhout, Bersick and McLaughlin (1997) recorded ERPs while participants read sentences that violated definitional (e.g., "the mailman took a shower after *she* got home") or stereotypical (e.g., "Our aerobics instructor gave *himself* a break") noun-pronoun agreement (or violated neither). Their findings indicated that P3 amplitude was enhanced to both definitionally and stereotypically incongruent sentences (compared to control sentences), and that these effects were independent of participants' overt judgments of the grammatical and syntactical correctness of the sentences.

More recently, Bartholow et al. (2006; Experiment 1) used the P3 as a neurocognitive measure of stereotype violation effects within a stereotype priming paradigm. Participants responded to trait words that either were stereotype-consistent or stereotype-inconsistent (or were irrelevant) with the race of Black and White faces (primes) that preceded them (see Dovidio, Evans & Tyler, 1986). Bartholow et al. (2006) replicated previous work showing faster responses to stereotype-consistent words (indicating that the face primes activated stereotypes), but also showed that stereotype-inconsistent words (e.g., "athletic" following a White face) elicited larger and slower P3s compared to stereotype-consistent words. These findings provide evidence that stereotype violations are more difficult for perceivers to categorize and produce enhanced updating of working memory compared to stereotype confirmations (see also Macrae, Bodenhausen, Schloersheidt, & Milne, 1999).

Whereas these previous studies investigated the neural correlates of stereotype confirmation and violation, other research has used ERPs to study how stereotypes influence perceptual and behavioral processes related to race. For example, Bartholow and Dickter (in press) had participants identify as quickly as possible the race of briefly presented Black faces and White faces (targets). On each trial, the target faces were surrounded on 4 sides by “distracter” words that either were congruent with the stereotype for the target’s race (e.g., the word “violent” presented with a Black face) or were stereotype-incongruent with the target (e.g., the word “smart” presented with a Black face). The proportion of stereotype-congruent and stereotype-incongruent stimulus arrays was manipulated across trial blocks such that half of the blocks contained 80% congruent arrays and half contained only 20% congruent arrays. Bartholow and Dickter reasoned that a high proportion of stereotype-congruent distracter trials would lead participants to use the distracter words as information to help categorize the race of the targets, and that doing so would create response conflict (i.e., the tendency to activate multiple responses on the same trial) when incongruent distracter trials were encountered (see Gratton, Coles, & Donchin, 1992). Their results confirmed this prediction, showing that incongruent trials encountered in the 80% congruent blocks were associated with initial activation of the incorrect categorization response, as seen in the amplitude of the LRP, and also elicited enhanced amplitude of the N2 conflict monitoring component.

Another recent study by Correll, Urland, and Ito (2006) suggests that contextual cues associated with racial stereotypes can influence perceptions of threat in a situation analogous to one faced by many police officers. Correll et al. had participants play a game in which they made speeded shoot/don’t shoot decisions to armed and unarmed Black and White target persons while ERPs were recorded. Of primary interest were results showing that target race differences in the amplitude of the P2 and N2 components, which the authors interpreted as threat detection and inhibitory processes, respectively, mediated the relationship between self-reported strength of cultural stereotypes linking Blacks with violence and the tendency to “shoot” unarmed Black targets during the game.

Self-regulation

Self-regulation refers broadly to the process of coordinating goal-consistent responses. Most research on self-regulation focuses on the process of overriding a prepotent tendency with a competing intentional response. An initial ERP study examining mechanisms of self-regulation in social psychology addressed a longstanding question about the control of stereotyping: Do people sometimes fail to override automatic stereotypes because (a) they are unable to detect the unwanted influence of the stereotype? Or (b) because they are unable to implement control, even though the unwanted influence of the stereotype was detected? Building on research in cognitive neuroscience (e.g., Botvinick et al., 2001), Amodio et al. (2004) suggested that the self-regulation of responses to stereotyped targets involves the coordination of two separate mechanisms: an initial, conflict monitoring mechanism subserved by activity in the dorsal ACC (see Botvinick et al., 2001) and often associated with the N2 and ERN components of the ERP, and a subsequent regulative mechanism, associated with activity in lateral PFC (see Kerns et al., 2004) and sometimes associated with the NSW component of the ERP (West & Alain, 1999), that strengthens the influence of intentional responses to override an unwanted tendency.

Amodio et al. (2004) sought to address the question of whether failures to override the influence of racial stereotypes were due to problems with conflict monitoring or regulative function. Subjects in this study completed the weapons identification task (Payne, 2001), in which they quickly classified objects as either handguns or hand tools after briefly viewing the face of a Black or White person. Consistent with stereotypes of Black people as violent and dangerous (Devine & Elliot, 1995), Black faces facilitated the correct classification of guns and, as a consequence, interfered with the classification of tools, relative to White faces (Payne, 2001). As a result, subjects responded more accurately on Black-gun trials, on which the Black faces prime the correct “gun” response, but made more errors on Black-tool trials, on which the Black faces prime conflicts with the correct “tool” response. This pattern suggests that responding accurately on Black-tool trials requires greater control relative to Black-gun trials, due to the biasing effect of African American stereotypes.

To examine the role of conflict-related ACC activity, Amodio et al. (2004) compared ERN amplitudes on trials that required the inhibition of stereotypes (Black-tool) or did not (Black-gun). As expected, ERNs on Black-tool trials were significantly larger than those on Black-gun trials, indicating that stronger conflict was being registered on trials requiring the control of race bias. This finding indicated that stereotype-biased response errors were being made despite the detection of conflict, suggesting that failures to control were associated with a problem in engaging regulative processes. Analyses of the CRN component (sometimes referred to as the $N2_{correct}$) corroborated this finding, such that it was largest on the high-conflict Black-tool trials and smallest on the low-conflict Black-gun trials (cf. Bartholow et al., 2005).

A more recent, similar study by Bartholow et al. (2006, Experiment 2) used ERPs to more directly investigate the role of the regulative mechanism in the control of race bias. Bartholow et al. hypothesized that alcohol intoxication interferes with the regulative function of control, rather than conflict monitoring. Participants in this study completed a version of the

Stop-Signal task that was adapted to involve stereotype-consistent vs. inconsistent responses. The primary ERP results from this study are shown in Figure 4. As predicted, the NSW was larger for sober vs. intoxicated subjects, and this difference was largest for the more difficult stereotype-consistent stop trials, indicating that inhibiting responses on those trials required implementation of greater cognitive control than inhibiting responses on stereotype-inconsistent trials. Similarly, the amplitude of the No-Go N2 component, associated with conflict monitoring, was larger on stereotype-consistent than stereotype-incongruent stop trials, but did not differ across beverage groups. The different patterns of results observed for the NSW and the No-Go N2 components indicated that alcohol causes a selective impairment on the regulative function of control while sparing conflict monitoring. These findings further supported the idea that the control of intergroup responses involves multiple dissociable mechanisms.

Amodio et al. (2006) recently applied their ERN approach to examine different mechanisms involved in regulating responses in accordance with internal vs. external cues. In this study, larger ERN amplitudes were associated with greater internally-driven response control on the weapons identification task. However, when participants completed the task in public, the P_e component was more strongly associated with response control, but only among subjects who reported being highly sensitive to external pressures to respond without prejudice. These findings suggested that the P_e, and its associated rostral ACC/medial PFC neural generator, was specifically involved in externally-driven forms of response control, consistent with the theory that the rostral ACC/medial PFC region functions to regulate responses in accordance with social cues (Amodio & Frith, 2006).

A third set of studies in this program of research addressed the question of why egalitarians who hold positive attitudes toward Black people nonetheless show substantial variability in their ability to respond without bias on reaction-time measures of stereotyping (Amodio et al., 2008). The authors hypothesized that egalitarians vary in the extent to which the activation of stereotypes creates conflict with simultaneously-activated motives to respond without bias. Consistent with this hypothesis, they found that among subjects with equally pro-Black attitudes, failure to control stereotype-driven responses was associated with smaller ERNs when stereotype inhibition was needed. These findings suggest that some egalitarians are prone to unwanted race-biased expressions because activated stereotypes do register cognitive conflict.

Other social neuroscience research has examined ERP responses on basic conflict tasks, such as the Stroop or Go/No-Go tasks, as a means to test hypotheses about self-regulation as being rooted in basic neurocognitive mechanisms (e.g., Amodio, Jost, Master, & Yee, 2007; Amodio, Master, Yee, & Taylor, 2008; Forbes, Schmader, & Allen, under review; Inzlicht & Gutsell, 2007). For example, Amodio et al. (2007) demonstrated that the individual differences in cognitive styles associated with more liberal vs. more conservative political view is related to the sensitivity of the conflict-monitoring system, as measured by the ERN. Other research has used ERPs to indicate the effects of a manipulation on self-regulatory capacity (Inzlicht & Gutsell, 2007), such that a regulatory load associated with stereotype threat led to diminished ERN amplitudes during incongruent Stroop trials.

It is notable that in the recent ERP research on the self-regulation of bias, ERPs have been used not simply as indicators of generic neural events, but as indices of specific underlying neural activations. For example, the ERN and P_e have been used to assess activation of the dorsal and rostral ACC, respectively (e.g., Amodio et al., 2004, 2006), and the NSW is believed to reflect activity of the prefrontal cortex (e.g., Bartholow et al., 2006). By linking ERPs to specific neural substrates, researchers can draw from the vast literatures of behavioral and cognitive neuroscience and neuropsychology to inform their theories and to interpret their findings.

Another important feature of ERP research on self-regulation is the use of behavioral measures to validate interpretations of ERP effects. For example, Amodio et al. (2004) proposed that the ERN should be associated with controlled, but not automatic, patterns of behavior on the weapons identification task. Using a process-dissociation method of computational modeling to create independent estimates of automatic and controlled responding (Jacoby, 1991; Payne, 2001), the authors demonstrated that ERN amplitudes were strongly associated with control but were uncorrelated with automaticity. Thus, by combining ERPs with computational modeling of behavior, researchers can achieve a high level of theoretical and methodological precision (see also Gonsalkorale, Sherman, Allen, Amodio, & Bartholow, under review).

Methodological Issues for ERP Research in Social Neuroscience

ERPs offer a powerful tool for probing mental processes associated with social cognition and social behavior, provided they are used in the context of an appropriate theoretical question and experimental design. Because valid ERP measures require the averaging of responses to many (i.e., ~30-50) trials, ERPs are appropriate only for assessing psychological phenomenon that can be measured repeatedly within a task. Psychological phenomena that are difficult to produce in the laboratory (e.g., an epiphany during problem solving), or can only be meaningfully experienced once or twice in a single sitting (i.e., before practice or habituation effects set in), or involve sustained psychological processes, are not good candidates for ERP experiments. ERPs are responses to independent, discrete events, and thus a good experimental task must contain several such events, each of which is psychologically meaningful. By contrast, manipulations that involve, say, freely reading a paragraph of text are inappropriate because it is difficult to determine exactly when a significant psychological event (e.g., a sudden insight) might occur. Finally, ERP measurement relies on high-quality EEG recordings, and thus a participant must be able to complete a task while keeping his or her head and upper body still. Tasks should be designed to keep participants' attention, as mind wandering may diminish the effectiveness of the experimental manipulations on ERPs, and shifting eye-gaze (e.g., looking around the room) will create electroocular artifacts that will interfere with ERP scoring. It is often a good idea to coach participants to keep their gaze fixed on the stimulus. Note that these same constraints also generally apply to other methods of neuroimaging, such as fMRI.

As described above, ERPs provide an excellent way to assess temporal changes in neural activity, but they provide poor spatial information concerning the source of neural activity. For this reason, ERP methods are not usually appropriate for addressing questions about the location of a neural process for reasons outlined above (except in a few cases where the neural generator of a given component has been well-characterized). However, recent advances in dipole modeling procedures have enhanced researchers' ability to estimate the neural generator of an ERP by modeling data obtained from a "dense-array" of electrodes. That is, EEG signals recorded from an array of 64, 128, or 256 channels provide dipole modeling algorithms with relatively high spatial resolution that can be used to estimate the source of an ERP dipole. Such models are typically constrained by anatomical parameters (e.g., specifying that a signal may only emerge from cortex with columnar organizations of neurons) and also may be constrained by the number of possible generators. Although source localization models are becoming increasingly accurate, the best approach to understanding the source of an ERP effect is to compare the ERP results with findings from fMRI studies that have used the same task.

In the previous section, we described four broad classes of ERP components, each of which is associated with different types of theoretical questions. In what follows, we provide some methodological recommendations for research taking each approach.

Stimulus-locked ERP approaches. Stimulus-locked ERP research in social cognition is primarily useful for probing the timing of differential attentional responses to social stimuli. To use ERPs in this way, one must design an experimental task that permits perceptual processing of a stimulus without the interruption of other psychological processes, such as the preparation and implementation of a behavioral response. That is, an ideal task would involve presentation of single stimuli for a period of time that allows the full range of ERP components to unfold. For example, the P300/LPP wave often emerges 500-1000 ms following a stimulus, depending on various task parameters, and therefore it is important to allow participants to view the stimulus for that entire period of time without interruption or distraction. If some event, such as stimulus offset or a response, occurs before the later waveforms are able to emerge, these events will create their own ERP responses that will interfere with the scoring of the component of interest.

Alternatively, tasks can be designed so that ERP activity associated with extra-stimulus events (e.g., responses) can be subtracted from the stimulus-locked ERP waveform, thus permitting the use of tasks in which, for example, speeded responses must be made. Many ERP studies of social cognition have used sequential priming tasks, in which a prime stimulus precedes the target. The use of sequential priming tasks in ERP research is somewhat novel and requires special care. The most common practice in such cases is to include a number (up to one-third of all trials; see Woldorff, 1993) of “prime-only” trials in which a prime is presented without a subsequent target. This approach permits later subtraction of averaged prime-related ERP activity from the average target-locked waveforms, effectively removing the influence of prime processing from target processing ERP effects. This procedure also permits examination of prime processing that is not confounded by overlapping target-related ERP activity.

Response-locked ERP approaches. Response-locked ERPs are often used to address questions about the engagement of behavior and self-regulation. Research using response-locked ERP components depends on a good behavioral task. When preparing to conduct an ERP study, one should begin with a behavioral task that is effective in modeling the psychological variables of interest. It is often a good idea to conduct a behavioral experiment prior to the ERP study to ensure that the task is effective (i.e., that the task produces variability across conditions in behavioral outcomes of interest). The timing of components in the task is very important. In most cases, trials should begin with a fixation point to ensure the participant will be prepared to see the experimental stimulus. Participants should know ahead of time how to respond to each stimulus (e.g., through an initial set of practice trials) so that their responses are not interrupted by attempts to remember how to complete the task. Following a response, time is needed for all response-locked components to unfold. This may take a second or more. Finally, it is often advisable to jitter the timing of the intertrial intervals so that ERPs associated with the response and with the subsequent trial are not confounded. The use of event-related designs in which different trial types are presented in random order, rather than in a single block, further aids in reducing ERP confounds associated with expectancy effects.

In some cases, a researcher may be interested in examining ERPs associated with error responses (e.g., ERN). In these cases, one must design a task that elicits a sufficient number of error responses to permit a valid average of error-related EEG epochs. This is often accomplished by imposing a time deadline on the participants’ responses (e.g., 500 ms) that has proven effective for that particular task. When averaging epochs of EEG to create ERPs, epochs associated with correct and incorrect responses should be averaged separately within each trial condition. Response windows are also useful because they keep participants focused on the task and discourage mind wandering and inattentiveness.

Anticipatory ERP approaches. Anticipatory ERPs are useful for examining participants' motivations for engaging in certain trials within a task. In order to examine anticipatory ERP waves, one must use a task that allows participants to anticipate the onset of an upcoming stimulus or signal to respond (e.g., a pre-trial fixation point or warning cue). Because it takes nearly a second for these waves to emerge clearly, an appropriate task will present the anticipatory signal at least a second before the target stimulus. Note that many experimental tasks may inadvertently create response anticipation. That is, if a new trial always begins at a regular interval following the response to the previous trial, anticipatory ERPs may be observed, and the amplitudes of these ERPs may be related to features of the previous response. In order to separate activity associated with two consecutive trials, it is advisable to jitter the intertrial intervals so that any systematic relationship between the anticipatory ERP and the participant's response to the previous trial with be removed in the averaging process.

LRP approaches. As noted previously, LRPs are something of a special case, sharing features of both stimulus-locked waveforms and anticipatory waveforms. LRPs can be measured in numerous contexts, but often are used to characterize how an initial stimulus (e.g., warning cue) influences preparation to response to a subsequent target stimulus (see Gehring, Gratton, Coles, & Donchin, 1992). However, stimulus-locked LRPs also can be derived in tasks involving only a single stimulus on every trial, as a way to shed light on how particular stimulus parameters or task features affect response activation (see Gratton et al., 1992). In either case, measurement and scoring of the LRP requires, at a minimum, measurement of ERPs from electrodes positioned bilaterally over the motor cortex (i.e., just left and right of midline at central scalp locations), and that the researcher know which hand (i.e., left or right) each participant used to make correct overt responses in each experimental condition. This can be achieved most easily with two-alternative forced choice tasks, in which participants use one hand to respond to targets in one condition and the other hand to respond to targets in the other condition, and in which response hand and stimulus type are counter-balanced across participants. (For a more detailed explanation of the LRP and its applications for understanding information processing, see Coles, 1989; Coles, Smid, Scheffers, & Otten, 1995.)

Practical Considerations for conducting ERP Research

Like all methods used to study social behavior and its underlying mechanisms, use of ERPs has both advantages and disadvantages. A major advantage of ERPs as a dependent measure is their unrivaled capacity for tracking the precise timing of neural processes. That is, ERPs provide a direct measure of neural firing with extremely high temporal resolution. In contrast, the temporal resolution of fMRI is limited by the much slower changes in blood flow that are believed to follow the firing of neurons. Another major advantage of ERPs over traditional behavioral measures, as mentioned previously, is the ability to measure psychological processes independently from, or in the absence of, any behavioral response. This property allows researchers to separate, for example, the latency of overt responses from the timing of underlying cognitive processes on which those responses are thought to depend (see McCarthy & Donchin, 1981), as well as processes associated with cognitive processing vs. response implementation (see Coles et al., 1995).

Perhaps the most significant disadvantage of the ERP method for most social psychologists is the time and resources required to implement it. Social psychologists interested in incorporating ERPs into their research programs must typically augment their traditional training with additional training in a psychophysiology lab, often as a post-doctoral fellow. Although this is still a common route, some graduate training programs now offer joint training in social psychology and psychophysiology and/or cognitive neuroscience. Even in such programs, trainees must master additional theoretical background (e.g., foundations of cognitive or affective neuroscience; basics of electrical circuits and physiology) and acquire specific skill sets (e.g., knowledge of complex EEG recording hardware and software; trouble-shooting electrophysiological measurement) beyond the basics of social psychological theory and experimental methodology that are required in all graduate training programs. For the psychophysiologist or cognitive neuroscientist who wishes to apply his or her skills toward study of social processes, the challenge is reversed; one must seek training and experience in social psychology or related fields.

An additional consideration is the cost required to set up and maintain an ERP laboratory. Although system costs can vary a great deal, it is not unusual for a modest ERP set-up to cost $75,000 to $100,000, including amplifiers, data acquisition and analysis software, electrode caps, and other necessary equipment (e.g., computers), in addition to any necessary building renovations. Most major universities will provide sufficient start-up funds for new faculty to outfit a lab, but some smaller universities and colleges will not. In such cases researchers must obtain funds for setting up a lab from other sources (e.g., grants). Once a laboratory is equipped, costs for using the lab are continuous. For example, measuring ERPs requires a number of disposable laboratory supplies, including electrode gel, skin preparation materials (e.g., alcohol pads, skin cleansers), electrode collars (to hold facial electrodes in place), and so on, all of which represent ongoing laboratory costs (though the cost of maintaining an EEG lab is far less than an MRI center).

ERP research is more time-consuming than behavioral research at virtually every step of the process. First, unlike many studies based on self-report or behavioral measures, participants in ERP experiments must be run individually. Moreover, each experimental session in an ERP study lasts considerably longer than a comparable session in a behavioral experiment. For example, a typical session in an ERP study would require additional time at each step, from the consent document (which generally requires extended explanation of the risks and discomforts associated with electrophysiological recording) to the instructions (which are often more elaborate) and especially the paradigm itself, which would need to include at least 4 times as many trials as in a behavioral study to ensure sufficiently stable ERP waveforms. Moreover, additional time is required to apply the electrode cap (with even a simple electrode montage, this step itself takes 30-45 min) and to remove it and clean it after the session – not to mention allowing time for participants to clean up (e.g., rinsing conductive electrode gel from their hair). All-in-all, a typical experimental session of this kind would last approximately 3-4 times longer than a comparable behavioral experiment, and would garner only 1 participants' worth of data.

The good news is that ERP experiments typically require fewer participants overall compared to similar behavioral experiments, due in part to the larger number of trials used in ERP protocols, which results in less error variance. However, this advantage is greatly attenuated in between-subjects designs, which can limit the kinds of paradigms that reasonably can be used in an ERP lab. Other design considerations also must be carefully taken into account when considering the use of ERPs, as mentioned previously (see Luck, 2005, for extended discussion).

Conclusions

We have provided an overview on how ERPs may be used to address a range of critical questions concerning social cognition and social behavior. Given the unique assessments afforded by ERPs, such as exquisite temporal measurement of neurocognitive processes and their versatile use with a range of experimental tasks, ERP methodology is a valuable tool in the social neuroscientist’s toolbox. As the field of social neuroscience continues to grow, research will increasingly depend on scientists’ ability to integrate a broad set of physiological and behavioral approaches and their associated theoretical models. Those who understand and incorporate cognitive and affective science with basic behavioral approaches will be well positioned to make significant contributions to the understanding of social behavior and, ultimately, to society.

References

Allison, T., Wood, C. C., & McCarthy, G. M. (1986). The central nervous system. In M. G. H. Coles, E. Donchin, & S. W. Porges (Eds.), *Psychophysiology: Systems, processes, and applications* (pp. 5-25). New York: Guilford Press.

American Encephalographic Society (1994). Guideline thirteen: Guidelines for standard electrode position nomenclature. *Journal of Clinical Neurophysiology*, 11, 111–113.

Amodio, D. M., Devine, P. G., & Harmon-Jones, E. (2008). Individual differences in the regulation of intergroup bias: The role of conflict monitoring and neural signals for control. *Journal of Personality and Social Psychology, 94*, 60-74.

Amodio, D. M., Master, S. L., Yee, C. M., & Taylor, S. E. (2008). Neurocognitive components of the behavioral inhibition and activation systems: Implications for theories of self-regulation. *Psychophysiology*, *45*, 11-19.

Amodio, D. M., Jost, J. T., Master, S. L., & Yee, C. M. (2007). Neurocognitive correlates of liberalism and conservatism. *Nature Neuroscience, 10*, 1246-1247.

Amodio, D. M., Kubota, J. T., Harmon-Jones, E., & Devine, P. G. (2006). Alternative mechanisms for regulating racial responses according to internal vs. external cues. *Social Cognitive and Affective Neuroscience, 1*, 26-36.

Amodio, D. M., & Frith, C. D. (2006). Meeting of minds: the medial frontal cortex and social cognition. *Nature Reviews Neuroscience, 7*, 268-277.

Amodio, D. M., Harmon-Jones, E., Devine, P. G., Curtin, J. J., Hartley, S. L., & Covert, A. E. (2004). Neural signals for the detection of unintentional race bias. *Psychological Science, 15,* 88-93.

Bargh, J. A., Chaiken, S., Govender, R., & Pratto, F. (1992). The generality of the automatic attitude activation effect. *Journal of Personality and Social Psychology, 62*, 893-912.

Bartholow, B. D., & Dickter, C. L. (in press). A response conflict account of the effects of stereotypes on racial categorization. *Social Cognition*.

Bartholow, B. D., & Dickter, C. L. (2007). Social cognitive neuroscience of person perception: A selective review focused on the event-related brain potential. In E. Harmon-Jones & P. Winkielman (Eds.), *Social neuroscience: Integrating biological and psychological explanations of social behavior* (pp. 376-400). New York: Guilford Press.

Bartholow, B. D., Dickter, C. L., & Sestir, M. A. (2006). Stereotype activation and control of race bias: Cognitive control of inhibition and its impairment by alcohol. *Journal of Personality and Social Psychology, 90*, 272-287.

Bartholow, B. D., Fabiani, M., Gratton, G., & Bettencourt, B. A. (2001). A psychophysiological analysis of cognitive processing of and affective responses to social expectancy violations. *Psychological Science*, *12,* 197-204.

Bartholow, B. D., Pearson, M. A., Dickter, C. L., Sher, K. J., Fabiani, M., Gratton, G. (2005). Strategic control and medial frontal negativity: Beyond errors and response conflict. *Psychophysiology, 42*, 33-42.

Bartholow, B. D., Pearson, M. A., Gratton, G. & Fabiani, M. (2003). Effects of alcohol on person perception: A social cognitive neuroscience approach. *Journal of Personality and Social Psychology, 85*, 627-638.

Bartholow B. D., Schepers, M. A., Saults, J. S., & Lust, S. A. (under review). *Investigating the Neural Locus of Affective Congruency Effects: Electrophysiological Evidence of Response Conflict and Strategic Control of Responses.* Manuscript submitted for publication.

Bartholow, R. (1882). Medical electricity: *A practical treatise on the applications of electricity to medicine and surgery* (2nd ed.). Philadelphia, PA: Henry C. Lea's Son & Co.

Bentin, S., Allison T., Puce, A., Perez, E., & McCarthy, G. (1996). Electrophysiological studies of face perception in humans. *Journal of Cognitive Neuroscience, 8,* 551-565.

Berger, H. (1929). Über das Elektrenkephalogramm das Menchen. *Archiv für Psychiatrie, 87,* 527-570.

Botvinick, M. M., Braver, T. S., Barch, D. M., Carter, C. S., & Cohen, J. D. (2001). Conflict monitoring and cognitive control. *Psychological Review, 108*, 624-652.

Bush, G., Luu, P., & Posner, M. L. (2000). Cognitive and emotional influences in anterior cingulate cortex. *Trends in Cognitive Sciences, 4*, 215-222.

Cacioppo, J. T., Crites, S. L., Jr., Berntson, G. G., & Coles, M. G. H. (1993). If attitudes affect how stimuli are processed, should they not affect the event-related brain potential? *Psychological Science, 4,* 108-112.

Cacioppo, J. T., Crites, S. L., & Gardner, W. L. (1996). Attitudes to the right: Evaluative processing is associated with lateralized late positive event-related brain potentials. *Personality and Social Psychology Bulletin, 22,* 1205-1219.

Cacioppo, J. T., Crites, S. L., Gardner, W. L., Berntson, G. G. (1994). Bioelectrical echoes from evaluative categorizations: I. A late positive brain potential that varies as a function of trait negativity and extremity. *Journal of Personality and Social Psychology, 67,* 115-125.

Cacioppo, J. T., Visser, P. S., & Pickett, C. L. (2005). *Social neuroscience: People thinking about thinking people.* Cambridge, MIT Press.

Carter, C. S., Braver, T. S., Barch, D. M., Botvinick, M. M., Noll, D., & Cohen, J. D. (1998). Anterior cingulate cortex, error detection, and the online monitoring of performance. *Science*, *280*, 747-749.

Chiu, P., Ambady, N., & Deldin, P. (2004). Contingent negative variation to emotional in- and out-group stimuli differentiates high- and low-prejudiced individuals. *Journal of Cognitive Neuroscience*, *16*, 1830-1839.

Coles, M. G. H. (1989). Modern mind-brain reading: Psychophysiology, physiology, and cognition. *Psychophysiology*, *26*, 251-269.

Coles, M. G. H., & Gratton, G. (1986). Cognitive psychophysiology and the study of states and processes. In G. R. J. Hockey, A. W. K. Gaillard, & M. G. H. Coles (Eds.), *Energetics and human information processing* (pp. 409-424). Dordrecht, NL: Marinus Nijhof.

Coles, M. G. H., & Rugg, M. D. (1995). Event-related brain potentials: An introduction. In M. D. Rugg & M. G. H. Coles (Eds.), *Electrophysiology of mind: Event-related brain potentials and cognition* (pp. 1-26). New York: Oxford University Press.

Coles, M. G. H., Smid, H. G. O. M., Scheffers, M. K., & Otten, L. J. (1995). Mental chronometry and the study of human information processing. In M. D. Rugg & M. G. H. Coles (Eds.), *Electrophysiology of mind: Event-related brain potentials and cognition* (pp. 86-131). New York: Oxford University Press.

Correll, J., Urland, G. R., & Ito, T. A. (2006). Event-related potentials and the decision to shoot: The role of threat perception and cognitive control. *Journal of Experimental Social Psychology*, *42*, 120-128.

Crites, S. L., & Cacioppo, J. T. (1996). Electrocortical differentiation of evaluative and nonevaluative categorizations. *Psychological Science*, *7*, 318-321.

Crites, S. L., Cacioppo, J. T., Gardner, W. L., & Berntson, G. G. (1995). Bioelectrical echoes from evaluative categorization: II. A late positive brain potential that varies as a function of attitude registration rather than attitude report. *Journal of Personality and Social Psychology*, *68*, 997-1013.

Curtin, J. J., & Fairchild, B. A. (2003). Alcohol and cognitive control: Implications for regulation of behavior during response conflict. *Journal of Abnormal Psychology*, *112*, 424-436.

Davidson, R. J., Jackson, D. C., & Larson, C. L. (2000). Human electroencephalography. In J.T.Cacioppo, G. G. Bernston, & L. G. Tassinary (Eds.), *Handbook of Psychophysiology* (2nd ed., pp. 27-52). New York: Cambridge University Press.

Dehaene, S., Posner, M.I., & Tucker, D.M. (1994). Localization of a neural system for error detection and compensation. *Psychological Science*, *5*, 303–305.

De Jong, R., Wierda, M., Mulder, G, & Mulder, L. J. M. (1988). Use of partial information in responding. *Journal of Experimental Psychology: Human Perception and Performance, 14,* 682-692.

Devine. P. G., & Elliot, A. J. (1995). Are racial stereotypes really fading? The Princeton Trilogy revisited. *Personality and Social Psychology Bulletin, 21,* 1139-1150.

Dickter, C. L., & Bartholow, B. D. (2007). Event-related brain potential evidence of ingroup and outgroup attention biases. *Social, Cognitive, and Affective Neuroscience, 2,* 189-198.

Donchin, E. (1981). Surprise!…Surprise? *Psychophysiology, 18,* 493-513.

Donchin, E., & Coles, M. G. (1988). Is the P300 component a manifestation of context updating? *Behavioral and Brain Sciences*, *11*, 357-427.

Dovidio, J. F., Evans, N., & Tyler, R. B. (1986). Racial stereotypes: The contents of their cognitive representations. *Journal of Experimental Social Psychology, 22,* 22-37.

Duncan-Johnson, C. C., & Donchin, E. (1977). On quantifying surprise: The variation of event-related potentials with subjective probability. *Psychophysiology, 14,* 456-467.

Fabiani, M., Gratton, G., & Federmeier, K. (2007). Event related brain potentials. In J. T. Cacioppo, L. G. Tassinary, & G. G. Berntson (Eds.), *Handbook of psychophysiology* (3rd ed., pp. 85-119*)*. New York: Cambridge University Press.

Fabiani, M., Gratton, G., Karis, D., & Donchin, E. (1987). The definition, identification, and reliability of measurement of the P300 component of the event-related brain potential. In P. K. Ackles, J. R. Jennings, & M.G.H. Coles (Eds.), *Advances in psychophysiology* (Vol. 1, pp. 1-78). Greenwich, CT: JAI.

Falkenstein, M., Hohnsbein, J., Hoormann, J., & Blanke, L. (1991). Effects of crossmodal divided attention on late ERP components: II. Error processing in choice reaction tasks. *Electroencephalography and Clinical Neurophysiology,* 78, 447-455.

Fazio, R. H., Sanbonmatsu, D. M., Powell, M. C., & Kardes, F. R. (1986). On the automatic activation of attitudes. *Journal of Personality and Social Psychology, 50*, 229-238.

Forbes, C. E., Schamder, T., & Allen, J. J. B. (under review). *The role of devaluing and discounting in performance monitoring: A neurophysiological study of minorities under threat*.

Friedman, D., & Johnson, R. Jr. (2000). Event-related potential (ERP) studies of memory encoding and retrieval: A selective review. *Microscopy Research and Technique, 51*, 6-28.

Friedman, D., Cycowicz, Y. M., & Gaeta, H. (2001). The novelty P3: An event-related brain potential (ERP) sign of the brain's evaluation of novelty. *Neurosceince and Biobehavioral Reviews, 25,* 355-373.

Gerhing, W. J., Goss, B., Coles, M. G. H., Meyer, D. E., & Donchin, E. (1993). A neural system for error detection and compensation. *Psychological Science, 4,* 385-390.

Gehring, W. J., Gratton, G., Coles, M. G. H., & Donchin, E. (1992). Probability effects on stimulus evaluation and response processes. *Journal of Experimental Psychology: Human Perception and Performance, 18,* 198–216.

Gonsalkorale, K., Sherman, J. W., Allen, T. J., Amodio, D. M., Bartholow, B. D. (under review). *On the underlying bases of implicit attitude variability and malleability*.

Gratton, G. (2000). Biosignal processing. In J. T. Cacioppo, L. G. Tassinary, & G. G. Berntson (Eds.), *Handbook of psychophysiology* (2nd ed., pp. 900-923). New York: Cambridge University Press.

Gratton, G., Coles, M. G. H., & Donchin, E. (1992). Optimizing the use of information: Strategic control of activation of responses. *Journal of Experimental Psychology: General, 121*, 480-506.

Gratton, G., Coles, M. G., Sirevaag, E. J., Eriksen, C. W., & Donchin, E. (1988). Pre- and poststimulus activation of response channels: A psychophysiological analysis. *Journal of Experimental Psychology: Human Perception and Performance, 14,* 331-334.

Gray, H. M., Ambady, N., Lowenthal, W. T., & Deldin, P. (2004). P300 as an index of attention to self-relevant stimuli. *Journal of Experimental Social Psychology, 40,* 216-224.

Greenwald, A. G., McGhee, D. E., & Schwartz, J. L. K. (1998). Measuring individual differences in implicit cognition: The implicit association test. *Journal of Personality and Social Psychology, 74,* 1464-1480.

Harmon-Jones, E., & Winkielman, P. (2007). *Social neuroscience: Integrating biological and psychological explanations of social behavior*. New York: Guilford Press.

Hillyard, S. A., Vogel, E. K., & Luck, S. J. (1998). Sensory gain control (amplification) as a mechanism of selective attention: Electrophysiological and neuroimaging evidence. *Philosophical Transactions of the Royal Society: Biological Sciences, 353,* 1257-1270.

Hopfinger, J. B. & Mangun, G. R. (2001). Electrophysiological studies of reflexive attention. In C. Folk & B. Gibson (Eds.), *Attraction, distraction, and action: Multiple perspectives on attentional capture* (pp. 3-26). Amsterdam: Elsevier Science.

Inzlicht, M., & Gutsell, J. N. (2007). Running on empty: Neural signals for self-control failure. *Psychological Science, 8,* 233-238.

Ito, T. A., & Cacioppo, J. T. (2000). Electrophysiological evidence of implicit and explicit categorization processes. *Journal of Experimental Social Psychology, 35,* 660-676.

Ito, T. A., & Cacioppo, J. T. (2007). Attitudes as mental and neural states of readiness: Using physiological measures to study implicit attitudes. In B. Wittenbrink & N. Schwarz (Eds.), *Implicit measures of attitudes* (pp. 125-158). New York: Guilford Press.

Ito, T. A., Larsen, J. T., Smith, N. K., & Cacioppo (1998). Negative information weighs more heavily on the brain: The negativity bias in evaluative categorizations. *Journal of Personality and Social Psychology, 75,* 887-900.

Ito, T. A., Thompson, E., & Cacioppo, J. T. (2004). Tracking the timecourse of social perception: The effects of racial cues on event-related brain potentials. *Personality and Social Psychology Bulletin, 30,* 1267-1280.

Ito, T. A. & Urland, G. R. (2003). Race and gender on the brain: Electrocortical measures of attention to the race and gender of multiply categorizable individuals. *Journal of Personality and Social Psychology, 85(4),* 616-626.

Ito, T. A. & Urland, G. R. (2005). The influence of processing objectives on the perception of faces: An ERP study of race and gender perception. *Cognitive, Affective, and Behavioral Neuroscience, 5,* 21-36.

Ito, T.A., Willadsen-Jensen, E.C., & Correll, J. (2007). Social neuroscience and social perception: New perspectives on categorization, prejudice, and stereotyping. In E. Harmon-Jones & P. Winkielman (Eds.), *Social neuroscience: Integrating biological and psychological explanations of social behavior* (pp. 401-421). New York: Guilford.

Jacoby, L. L. (1991). A process dissociation framework: Separating automatic from intentional uses of memory. *Journal of Memory and Language, 30*, 513-541.

Kerns, J. G., Cohen, J. D., MacDonald, A. W. III, Cho, R. Y., Stenger, V. A., & Carter, C. S. (2004). Anterior cingulate conflict monitoring predicts adjustments in control. *Science, 303,* 1023-1026.

Klauer, K. C., & Musch, J. (2003). Affective priming: Findings and theories. In J. Musch & K.C. Klauer (Eds.), *The psychology of evaluation: Affective processes in cognition and emotion* (pp. 7-49). Mahwah, NJ: Lawrence Erlbaum.

Klauer, K. C., Musch, J., & Eder, A. B. (2005). Priming of semantic classifications: Late and response related, or earlier and more central? *Psychonomic Bulletin &Review, 12,* 897-903.

Klinger, M. R., Burton, P. C., & Pitts, G. S. (2000). Mechanisms of unconscious priming I: Response competition not spreading activation. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 26,* 441-455.

Kopp, B., Rist, F., & Mattler, U. (1996). N200 in the flanker task as a neurobehavioral tool for investigating executive control. *Psychophysiology, 33*, 282-294.

Kornhuber, H. H., & Deecke, L. (1965). Hirnpotentialanderungen bei willkarbewegungen und passiven bewegungen des Mensehen: Bereitschaftspotential und reafferente Potentiale. *Pflfigers Arehiv, 284*, 1-17.

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

Kutas, M., McCarthy, G. & Donchin, E. (1977). Augmenting mental chronometry: The P300 as a measure of stimulus evaluation time. *Science, 197,* 792-795.

Luck, S. J. (2005). *An introduction to the event-related potential technique*. Cambridge, MA: MIT Press.

Macrae, C. N., Bodenhausen, G. V., Schloersheidt, A. M., & Milne, A. B. (1999). Tales of the unexpected: Executive function and person perception. *Journal of Personality and Social Psychology, 76,* 200-213.

Magliero, A., Bashore, T. R., Coles, M. G. H., & Donchin, E. (1984). On the dependence of P300 latency on stimulus evaluation processes. *Psychophysiology, 21,* 171-186.

Mangun, G. R., Hillyard, S. A., & Luck, S. J. (1993). Electrocortical substrates of visual selective attention. In D. Meyer & S. Kornblum (Eds.), *Attention and Performance XIV* (pp. 219-243). Cambridge, MA: MIT Press.

McCarthy, G., & Donchin, E. (1981). A metric of thought: A comparison of P300 latency and reaction time. *Science, 21*, 171–186.

Marshall-Goodell, B. S., Tassinary, L. G., & Cacioppo, J. T. (1990). Principles of bioelectrical measurement. In J.T. Cacioppo and L.G. Tassinary (Eds.), *Principles of psychophysiology: Physical, social, and inferential elements* (pp. 113-148). New York: Cambridge University Press.

Mouchetant-Rostaing, Y., Girard, M. H., Bentin, S., & Aguera, P.E. (2000). Neurophysiological correlates of face gender processing in humans. *European Journal of Neuroscience, 12,* 303-310.

Nieuwenhuis, S., Aston-Jones, G., & Cohen, J.D. (2005). Decision making, the P3, and the locus coeruleus-norepinephrine system. *Psychological Bulletin, 131,* 510-532.

Nieuwenhuis, S., Yeung, N., van den Wildenberg, W., & Ridderinkhof, K. R. (2003). Electrophysiological correlates of anterior cingulate function in a go/nogo task: Effects of response conflict and trial type frequency. *Cognitive, Affective, & Behavioral Neuroscience, 3,* 17-26.

Osterhout, L., Bersick, M., & McLaughlin, J. (1997). Brain potentials reflect violations of gender stereotypes. *Memory & Cognition, 25*, 273-285.

Ostrom, T. M. (1984). The sovereignty of social cognition. In R. S. Wyer, Jr., & T. K. Srull (Eds.), *Handbook of social cognition* (Vol. 1, pp. 1-38). Hillsdale, NJ: Lawrence Erlbaum.

Payne, B. K. (2001). Prejudice and perception: The role of automatic and controlled processes in misperceiving a weapon. *Journal of Personality and Social Psychology, 81*, 181-192.

Picton, T. W. (1980). The use of human event-related potentials in psychology. In I. Martin & P. H. Venables (Eds.), Techniques in psychophysiology (pp. 357–395). Chicester, UK: Wiley.

Scheffers, M. K., & Coles, M. G. H. (2000). Performance monitoring in a confusing world: Event-related brain activity, judgements of response accuracy, and types of errors. *Journal of Experimental Psychology: Human Perception and Performance, 26*, 141–151.

Squires, K. C., Wickens, C., Squires, N. K., & Donchin, E. (1976). The effect of stimulus sequence on the waveform of the cortical event-related potential. *Science, 193*, 1142-1146.

van Veen, V., & Carter, C. S. (2002). The timing of action-monitoring processes in the anterior cingulate cortex. *Journal of Cognitive Neuroscience, 14*, 593–602.

West, R., & Alain, C. (1999). Event-related neural activity associated with the Stroop task. *Cognitive Brain Research, 8*, 157-164.

Willadesn-Jensen, E., & Ito, T. A. (2006). Ambiguity and the timecourse of racial perception. *Social Cognition, 24*, 580-606.

Willadesn-Jensen, E., & Ito, T. A. (in press). A foot in both worlds: Asian Americans' perceptions of Asian, White and racially ambiguous faces. *Group Processes and Intergroup Relations*.

Woldorff, M. G. (1993). Distortion of ERP averages due to overlap from temporally adjacent ERPs: Analysis and correction. *Psychophysiology, 30*, 98-119.

Yeung, N., Botvinick, M. M., & Cohen, J. D. (2004). The neural basis of error detection: Conflict monitoring and the error-related negativity. *Psychological Review, 111*, 931-959.

Zhang, Q., Lawson, A., Guo, C., & Jiang, Y. (2006). Electrophysiological correlates of visual affective priming. *Brain Research Bulletin, 71*, 316-323.

Figure Captions

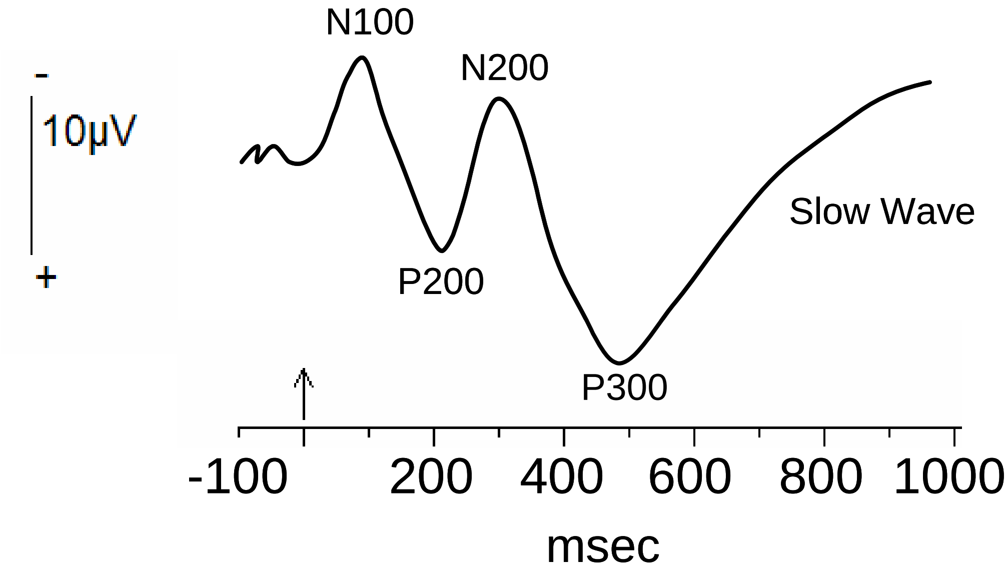
Figure 1. A schematic representation of an ERP waveform elicited by a novel visual stimulus. The vertical arrow on the timeline (horizontal axis) represents stimulus onset time. The positive and negative deflections in the waveform represent typical ERP components, named here according to their polarity ("P" for positive deflections and "N" for negative deflections) and the approximate time (in msec) following stimulus onset at which they peak. Note, however, that this temporal naming convention is based on broad generalities and often does not conform to observed peak latencies. Another method for component naming involves assigning numbers to the positive and negative deflections as a function of their serial order following stimulus onset (e.g., N1, P1, N2, etc.). Note, also, that negative voltage is plotted up here in accordance with convention, but that ERP waveforms sometimes are oriented with positive voltage up.

Figure 2. Effects of successive ERP averaging to an auditory stimulus. The far-left column shows single trial waveforms from each of 4 participants, recorded at the Cz (midline central) electrode location. The next column shows single-participant averages derived from each of the original 4 single trials. The third column shows the grand average of all participants and all single trials. The fourth column shows a grand average waveform derived from 64 trials of the same type. Comparison of this grand average with the grand average in the third column shows that inclusion of more trials results in less variance in the waveform (i.e., a cleaner, smoother signal). (Adapted from Picton, 1980.)

Figure 3. Response-locked ERP waveforms recorded from the FCz (midline fronto-central) channel during the weapons identification task. ERPs are displayed for correct and incorrect tool (**A**) and gun (**B**) trials as a function of accuracy and the race (Black vs. White) race of the face prime. The ERN, CRN, and P_e components are labeled in panel A. On the x-axis, zero indicates

the point at which responses were given. This figure shows that both the CRN and ERN waves are larger on Black-tool trials, which require enhanced control over automatic stereotypes, compared with all other trial types

Figure 4. ERP waveforms recorded from the FCz (midline fronto-central) electrode on stop trials in Bartholow et al. (2006) for participants who consumed either a placebo alcohol beverage (Placebo) or a .80 g/kg alcohol beverage (High dose) prior to completing the stereotype-related stop-signal task (see text for details). Time 0 represents the onset of the stop signal. NSW = negative slow wave; Ster-Con = stereotype-consistent trial; Ster-Inc = stereotype-inconsistent trial. This figure illustrates that withholding a stereotype-consistent response (solid line) elicited stronger engagement of cognitive control in prefrontal cortex (larger NSW amplitude) than did withholding a stereotype-incongruent response (dashed line). However, this did not occur in the high dose group, indicating that alcohol impaired engagement of cognitive control. The No-Go N2 also was larger on stereotype-consistent trials, indicating heightened conflict monitoring on those trials, but this effect was not significantly influenced by alcohol. (Adapted from Bartholow et al., 2006.)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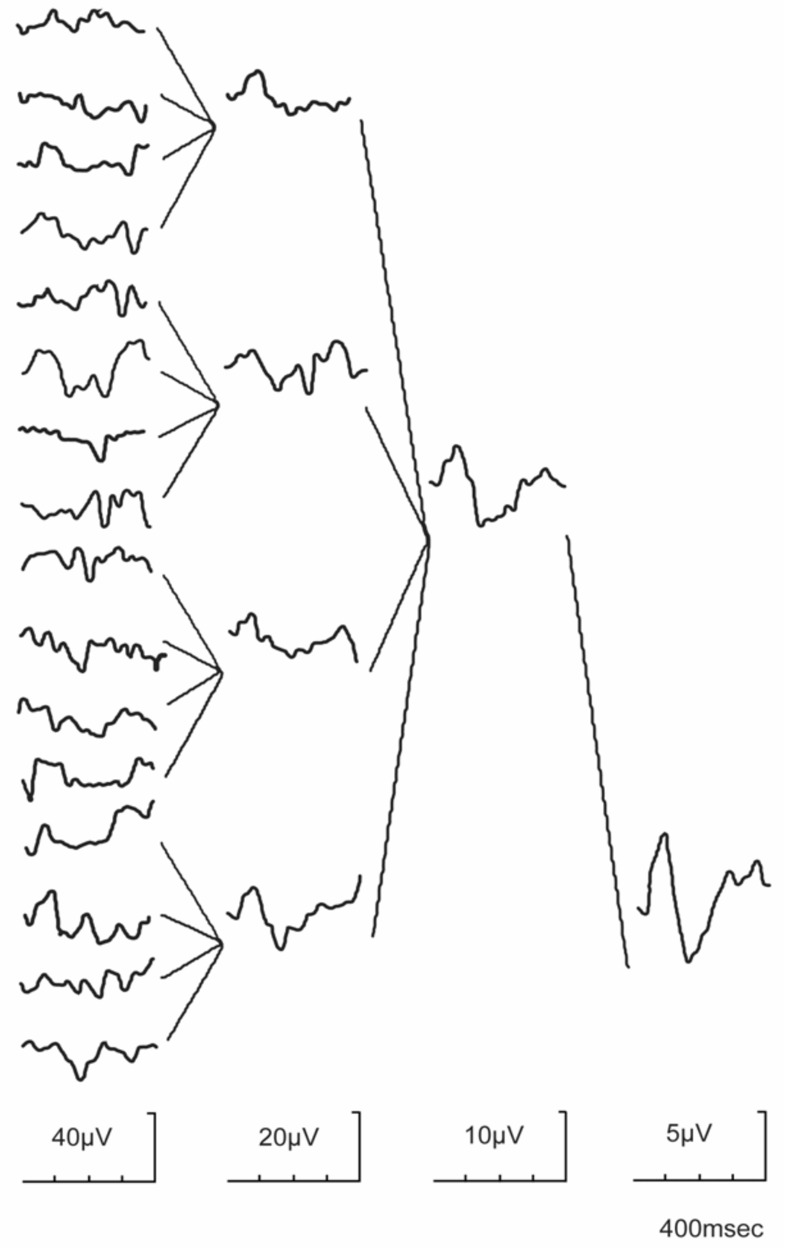
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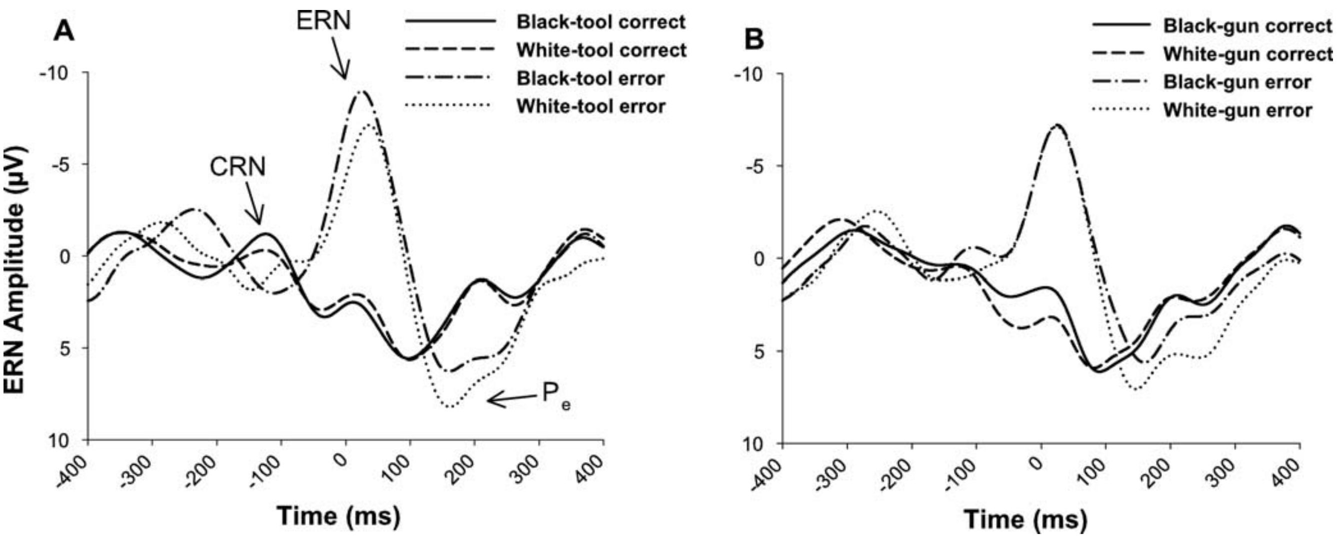
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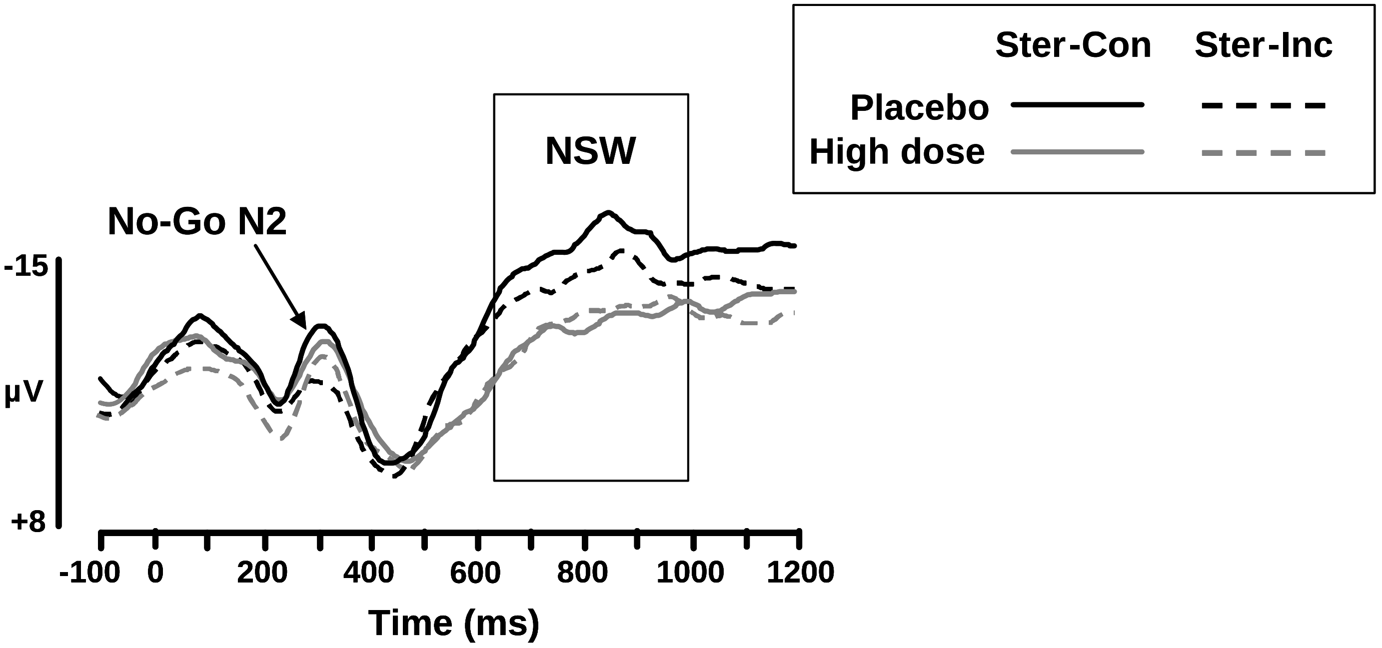
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