Amodio, D. M., & Bartholow, B. D. (2011). Event-related potential methods in social cognition. In A. Voss, C. Stahl, & C. Klauer (Eds.), *Cognitive methods in social psychology* (pp. 303-339). New York: Guilford.

Contact information:

David M. Amodio
Department of Psychology
New York University
6 Washington Place, rm. 760
New York, NY 10003
david.amodio@nyu.edu

Event-Related Potential Methods in Social Cognition

Methodological approaches from cognitive psychology are valuable to the social psychologist because they can reveal the inner workings of the social mind. Questions about the cognitive processes that underlie social behavior – that is, about *social cognition* – have been a foremost concern of social psychology for many years (Ostrom, 1984; Ross & Nisbett, 1991; for a review, see Fiske & Taylor, 2008). For example, what are the mechanisms through which social targets are perceived and categorized? Do attitudes operate implicitly? How quickly do social stereotypes come to mind? How does one manage conflicts between personal desires and social norms? Such questions assume that cognitive operations underlie social thought and behavior, yet these processes cannot be measured directly. Thus, psychologists traditionally have relied on behavioral assessments and subjective reports to make inferences concerning the operations of such processes. Recently, however, event-related potential (ERP) methods have emerged as a critical tool for assessing neural signals associated with cognitive processes as they unfold in real time, and thus they have become a valuable tool for testing theories of social cognition.

The goal of this chapter is to describe how the ERP may be used to explore and test hypotheses about the cognitive mechanisms that underlie social 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 a discussion of the practical advantages and disadvantages of using ERP methods in the social psychology laboratory.

What is the ERP?

The ERP is an electrical potential that is generated by the firing of cortical neurons in response to a specific event, such as the presentation of a stimulus or the delivery of a response. 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, known as the electroencephalogram (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) measures 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 & Peterson, 2009). When measured in the context of an experimental task involving specific events (e.g., stimuli or responses), it becomes possible to examine specific portions of the EEG that reflect neural responses uniquely associated with those events. This event-related EEG response comprises 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 it is typically not measured. In some cases, opposite ends of a source dipole can be detected in scalp electrodes placed on opposite sides of the head (e.g., at the very back and very front) as ERP deflections that are similar in timing but opposite in polarity. However, not all neural signals are picked up by scalp-recorded 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 such 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 columnar orientation, activity in a particular neural structure in one area of the brain may produce an ERP that is most pronounced at relatively distant scalp locations. Finally, neural structures that are not organized in columns (e.g., subcortical structures like the amygdala) do not produce large summated dipoles, and thus activity of these structures is not measureable using scalp electrodes.

Psychologically, ERPs represent neural manifestations of specific information processing operation associated with a stimulus or response event. The ERP waveform is typically composed of a series of positive and negative voltage deflections often referred to as components (see Figure 1). Although specific ERP components are often described as reflecting a particular information-processing operation (see Fabiani et al., 2007), it is likely that any given ERP 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).

ERP Measurement

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). Although single electrodes can be adhered to the scalp, electrodes are more often embedded in a stretch-nylon cap that can be worn by the participant, which aid in standardizing electrode placement across participants and laboratories. The 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 neurons within the brain 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 most common. In principle, the sampling rate should be at least twice as high as the frequency of the waveforms of interest (i.e., the Nyquist frequency) to avoid aliasing, a type of sampling artifact in which an analog waveform is inaccurately rendered because the sampling rate is too low to capture its contours (Gratton, 2000). 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).

Recording considerations in ERP experiments

An initial consideration in conducting an ERP experiment is to take steps to ensure a clean physiological recording. Some important sources of measurement error can be reduced 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. However, modern amplifiers typically are robust to low-level electrical noise, and provided the researcher is careful in monitoring and limiting sources of such noise electrical shielding is usually unnecessary.

A second consideration is preparation of participants for electrophysiological recording (for details on preparation of participants for EEG recording, see Harmon-Jones & Peterson, 2009). First, the location of the electrode site must be determined carefully, according to anatomical or fiduciary landmarks (e.g., the 10-20 system). If an electrode is misplaced, such that it covers a different region of scalp than is intended, is misaligned with the vertical or horizontal axes of eye moments (in the electrooculogram), or is not placed directly over the intended muscle (in EMG), then the signal of the recording will be diminished relative to "noise," regardless of other recording factors. Furthermore, when using low-impedance gel-based recording systems, care is needed in the preparation of the electrode site, such that the skin is clean and exfoliated to remove oil and dead skin cells that interfere with electrical signals. When using high-impedance saline-based recording systems, in which a saline-soaked sponge is attached to the electrode to make contact with the scalp, one must be careful to avoid "bridging" that occurs when excessive saline runs down the scalp and forms an electrical connection with another electrode (this problem also can occur with gel-based systems if too much gel is applied). However, as the saline sponges dry over the course of the experiment, EEG signals may be disrupted. Care should also be taken when choosing a reference electrode site for the EEG recording, as the reference scheme has implications for the amplitude and polarity of particular ERP components (Picton et al., 2000).

In addition to electrical sources of noise, movements of the participant also can create artifact. 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). Eye movements, especially blinks, also create large artifacts in the EEG signal. The eyeball is polarized, with a dipole running along the corneal-retinal axis, with the cornea holding a positive polarity relative to the retina. When the eyes move, activity from this dipole is picked up by scalp EEG electrodes, particular those nearest to the eyes. Therefore, participants must be instructed to hold a steady gaze and avoid excessive blinking during recordings. Provided that eye blink movements follow a consistent pattern and produce relatively uniform deflections in the EEG recording, blink-related artifacts can be removed from the EEG channels during post processing using one of several mathematical algorithms. It is also important to control for any distractions that can cause eye movements, such as sounds from outside the experimental chamber. Irregular eye movements that often result from distractions are more difficult to remove with standard algorithms, and instead the EEG epochs containing such artifacts often must be excluded from analysis. It is for this reason, especially, that the participant should be isolated from the activities of the experimenter during the experimental recordings.

Extracting the ERP signal

Assuming that the EEG data are recorded cleanly, the next concern is to extract the relatively low-amplitude ERP signal (a few microvolts) from the higher-amplitude background

EEG (upwards of 50 microvolts). EEG recordings reflect ongoing activity from sources throughout the brain, most of which have little to do with the experimental task or psychological processes of interest. The most common methods for extracting ERP “signal” from background EEG “noise” are filtering and averaging. Filtering involves passing the analog signal through a combination of capacitors and resistors designed to allow only signal within a particular frequency 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 first 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 that captures ERPs of interest using digital filters.

Once filtered, background noise is further removed from the ERP signal through the process of averaging. The averaging process capitalizes on the principle that EEG signals unrelated to the processing of a particular event will vary randomly across trials and, after the EEG signal from each trial epoch is normalized around zero (typically, by subtracting a pre-event baseline period), these randomly-varying aspects of the background EEG noise that fluctuate around zero within epochs will average to zero across epochs. Meanwhile, aspects of the EEG that correspond to processing of the event of interest will be preserved in the averaging process and 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 EEG noise (fourth column).

Finally, it should be noted that there are several alternatives to the averaging approach to deriving ERP signals, such as principle components or independent components analysis and the use of Fast Fourier Transformations to identify the spectral power of EEG responses that occur as a particular ERP frequency. Principal component approaches have become increasingly popular in recent years as ERP theorists have argued that the components (i.e., the positive and negative deflections) apparent in the observed waveform do not necessarily represent the number and nature of true sources of variability in neural responses to given stimulus events (e.g., see Dien & Frischkoff, 2004). However, in most situations averaging and PCA produce highly similar results. Thus, although alternatives such as PCA have been available for many years (e.g., Horst & Donchin, 1980), they remain far less common in the literature than averaging.

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, which may be defined as the minimum or maximum voltage within a predefined timeframe in which that component emerges. Although there are general conventions for the timing of particular ERP waves (e.g., the P2 component usually peaks around 200 ms post-stimulus onset), the timing of ERP components varies considerably as a function of the experimental task, with more complex tasks yielding slower ERP latencies. When determining the timeframe for scoring an ERP wave, it is advisable to inspect the waveform visually to determine the timing of the component's onset and offset, setting the scoring parameters accordingly. The goal is to include the peaks of the wave of interest without including other signals. As an alternative to peak scoring, researchers will sometimes compute the average voltage within the entire timeframe surrounding the component of interest. 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 (i.e., in milliseconds) at which the component reaches its peak value after an event occurs (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 and scoring and analysis can be accomplished using user-created batch files.

Interpreting ERP Data

To a psychologist, ERPs are interesting to the extent that they can be used to index a psychological process. Therefore, a critical aspect of ERP research in social cognition concerns the way in which psychological functions are inferred from ERP responses. The functional significance of different ERP components is inferred by a combination of factors, such as the nature of the task used to elicit them, the timing and the 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 is 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 behavioral response is made (i.e., a response-locked waveform), using either response time or the onset of muscle movement (e.g., if the electromyogram was recorded) as the event marker. 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 varies between fields (e.g., cognition vs. visual and auditory psychophysics) and continues to expand.

Stimulus-locked components

Stimulus-locked ERP components arise in response to a specific stimulus, such as a visual image or auditory tone. Most stimulus-locked ERP components reflect some aspect of perceptual or attentional processing of a stimulus, with larger ERP amplitudes typically interpreted as reflecting stronger engagement of those processes. 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. These early components are characterized by their punctate, high-frequency waveforms. In particular, the P1 and the N1 components have been linked to very early attentional processes (Fabiani et al., 2007), in that increased amplitude of these components is thought to reflect increased direction of selective attention and orienting to stimulus processing (Hillyard, Vogel, & Luck, 1998; Hopfinger & Mangun, 2001; Mangun, Hillyard, & Luck, 1993).

Another relatively early negative component is the N170, which is typically most prominent at temporo-occipital scalp sites and often stronger on the right side. The N170 component responds selectively to faces and is believed to reflect low-level structural encoding of a face in visual perception (e.g., Bentin, Allison, Puce, Perez, & McCarthy, 1996; Eimer, 2000). However, some recent evidence also suggests that the N170 is sensitive to higher-level social/motivational factors, such as ingroup-outgroup distinctions (Herrmann et al., 2007; Stahl et al., 2008; Walker, Silvert, Hewstone, & Nobre, 2008). Research on the putative neural generator of the N170 suggests that the N170 is produced by multiple structures located in the occipito-temporal region of the brain, one of which is believed to be the fusiform gyrus (Deffke, et al., 2007). The N170 component is of special interest for the study of social cognition because it presumably reflects the earliest stage of social perception. However, to date, very little research has explored the utility of the N170 for testing theories of social cognitive mechanisms (but see Walker et al., 2008).

The P2 ERP component is typically observed at midline scalp sites in the range of 150-250 ms following a stimulus, depending on the particular task. The P2 has received much attention in the social cognition literature, in part because it tends to be prominent in response to social targets, such as faces of individuals from a social outgroup (Amodio, in press-a; Dickter & Bartholow, 2007; Ito & Urland, 2003). Although some researchers have suggested that the P2 reflects a threat response (Correll, Urland, & Ito, 2006), the broader literature indicates that the P2 is responsive to a range of stimuli that carry emotional or motivational significance, including both happy and angry faces (relative to neutral faces; Schutter, de Haan, & van Honk, 2004) and to racial cues that engage self-regulatory responses (Amodio, in press-a; Mendoza & Amodio, in prep). 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 N2 is a prominent ERP component that typically peaks between 200 and 350 ms after stimulus onset, and it has been related to both attentional processing and response preparation, depending on its timing and scalp location (Folstein & van Petten, 2008). Early forms of the N2 are typically associated with the detection of stimulus novelty or mismatch (i.e., expectancy violations) and are largest over anterior midline sites (e.g., Luck & Hillyard, 1994; Suwazono, Machado, & Knight, 2000). A slightly later form of the N2 is more prominent over posterior midline sites and has been associated with the degree of attention allocated to processing stimuli in the visual cortex (Suwazono et al., 2000). A third form of the N2 is also prominent at anterior sites and is believed to be associated with attentional processes linked to response preparation and cognitive control (Bartholow et al., 2005; Folstein & van Petten, 2008). This form of the stimulus-locked N2 component has been associated with differential responses to racial ingroup vs. outgroup in several studies (Amodio et al., 2004; Dickter & Bartholow, 2007; Henry, Bartholow, & Arndt, in press; Ito & Urland, 2003, 2005).

The No-Go N2 is a special case of a stimulus-locked component that is elicited at about 300 ms following the onset of a “No-Go” stimulus in a Go/No-Go task and is largest when a response to the No-Go stimulus was correctly withheld. Because the inhibition of a response to a No-Go stimulus is not registered behaviorally and thus cannot be indexed, the No-Go N2 component must be locked to the stimulus. Thus, it is technically a stimulus-locked component, but it likely reflects the inhibition response (but see Bruin, Wijers, & van Staveren, 2001, for an alternative interpretation). Consistent with this interpretation, the No-Go N2 is associated with self-regulatory executive control processes such as behavioral inhibition and/or and conflict monitoring (e.g., Amodio, Master, Yee, & Taylor, 2008; Kopp, Rist, & Mattler, 1996; Nieuwenhuis, Yeung, van den Wildenberg, & Ridderinkhof, 2003), and has been shown to emerge from activity in the anterior cingulate cortex (ACC; Amodio, Master, et al., 2008; Nieuwenhuis et al., 2003). There is reason to believe that the No-Go N2 is associated with motor processes involved in response inhibition (i.e., muscle contractions that stop a response; see Folstein & van Petten, 2008, for a review) – another characteristic that it shares with response-locked components (see below). Finally, it is notable that the broader class of negative-polarity, stimulus-locked midline components are often referred to a “medial negativities,” and these usually represent some form of the frontal N2 component.

Late components. In comparison with early stimulus-locked components, the later components are characterized by waveforms that have lower frequencies and are often amorphous. 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, Aston-Jones, & Cohen, 2005). Nieuwenhuis et al.'s (2005) broadly suggest that the P3 component reflects attentional processes associated with arousal and heightened cognitive processing, providing a parsimonious explanation for the sometimes disparate functions ascribed to the P3.

Another relatively late, stimulus-locked component is the negative-going N400, which generally peaks between 360 and 450 ms post-stimulus. The N400 (or N4) tends to be most prominent in paradigms that use verbal stimuli, and is believed to reflect aspects of language comprehension (see Kutas & Federmeier, 2000). In particular, the N4 appears sensitive to semantic incongruity during language processing. Kutas & Hillyard (1980) first famously reported that the N4 is larger to the terminal word of a sentence such as "The pizza was too hot to *cry*," relative to a sentence like "The pizza was too hot to *eat*." This feature has led some researchers to posit that the N4 might be sensitive to violations of semantic social knowledge, such as social stereotypes (see Bartholow, Fabiani, Gratton, & Bettencourt, 2001). Recently, for example, White, Crites, Taylor and Corral (2009) observed larger N400 responses when subjects read sentences that violated rather than confirmed gender stereotypes.

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. Bartholow, Dickter, and Sestir (2006) scored the NSW as the peak negative amplitude between 600 and 1200 ms following the onset of a "go" or "stop" cue on the Go/Stop task (similar to the Go/No-Go). Like No-Go responses, the NSW cannot be locked to a specific behavior, and therefore it must be locked to the stimulus. It is notable that NSW typically peaks after the task response was made. The NSW has been associated with the implementation of self-regulatory cognitive control processes such as those required for inhibiting responses (Bartholow et al., 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). Thus, it is thought to reflect the engagement of top-down control and expectancy processes that occurs just after a difficult trial and that prepares an individual to respond more carefully to the upcoming trial. Thus, the NSW shares characteristics of anticipatory ERP components that are typically locked to an upcoming stimulus or response.

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; see Vidal, Hasbroucq, Grapperon, & Bonnet, 2000) have led to the hypothesis that the ERN/CRN reflects a more general process associated with the conflict monitoring process, which functions in part to recruit other mechanisms of top-down control (e.g., Botvinick, Braver, Barch, Carter, & Cohen, 2001; Yeung, Botvinick, & Cohen, 2004), consistent with fMRI studies of the ACC (Carter et al., 1998). The ERN has also been interpreted as reflecting a negative emotional response to an unexpected or unwanted event, such as a response error (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). Research in social psychology (described in the next section) suggests that the P_e reflects processes involved in monitoring one's social context as it relates to one's own actions (Amodio, Kubota, Harmon-Jones, & Devine, 2006), in line with more general theories of medial PFC and rostral ACC function (Amodio & Frith, 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 they are believed to reflect attentional engagement or preparatory control. Anticipatory ERP components are useful for examining participants' attentional focus and motivation 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 lateralized readiness potential or LRP. Kornhuber and Deecke (1965) first noted that a negativity develops in the ERP during the warning period that precedes an imperative stimulus for which a behavioral response will be required and is most pronounced over the motor cortex contralateral to the responding hand. The authors 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 LRP reflects activation in motor cortex associated with preparation to initiate a contralateral 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, in the sense that it is triggered by a warning cue but represents the preparation for an upcoming response.

Interpretational issues

Like most physiological responses, and like neural signals in particular, a researcher must be very careful in making psychological interpretations of ERP components. As a general principal, particular ERP components are likely involved in multiple psychological functions, and one can never assume a 1-to-1 mapping of a psychological construct onto a physiological indicator (Amodio, in press-b; Cacioppo et al., 2003; Cacioppo & Tassinary, 1990). 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 associated with an ingroup attention bias in social categorization tasks (e.g., Ito & Urland, 2003, 2005) reflects the same neural source or represents similar information-processing operations as the prominent N2 often seen in tasks involving response conflict or inhibition (Amodio et al., 2004; Dickter & Bartholow, in press), as reviewed by Folstein and van Petten (2008).

Examples of ERP Research in Social Psychology

How can ERPs be used to elucidate mechanisms of social cognition? Although theories of the cognitive processes that underlie social judgments and behavior have become increasingly sophisticated, it is often difficult to test hypotheses about underlying mechanisms using only behavioral and self-report methods. That is, these traditional research tools are unsuitable for assessing rapidly changing processes believed to drive phenomena such as social perception, categorization, and stereotyping. Furthermore, implicit processes are defined by their occurring outside and individual's awareness, and thus by definition are not amenable to explicit self-report. Moreover, the extent to which implicit processes can be clearly inferred from expressions of behavior is a matter of debate (Amodio & Mendoza, in press; Bartholow, Riordan, Saults, & Lust, 2009; Payne, 2001). Finally, it is difficult to measure subtle online changes in mental processes unobtrusively using these traditional tools, as the measurement of these processes often interferes with their natural psychological function (i.e., when interrupting a response to have a participant complete an emotion questionnaire). We are happy to report that ERPs can provide a solution to these problems. In this section, we describe research that has used ERPs to overcome some of the limitations of traditional methods to address 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. The oddball task reliably produces an enhanced P3 to the target stimuli, relative to the more frequent “context” stimuli, and the oddball P3 effect was taken to reflect a neural signal indicating that the target was perceived as different from the context. Cacioppo et al. (1993) applied the oddball paradigm to the categorization of evaluative (i.e., positive vs. negative) words. They predicted – and found – that a target word that was inconsistent with context words on the evaluative dimension, such as a negative word appearing within a series of positive words, should elicit the oddball P3 effect. This finding opened the door to a new ERP method for assessing 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 that this method could be used as a measure of implicit attitudes (for a review, see Ito & Cacioppo, 2007). For example, Crites, Cacioppo, Gardner, and 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).

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) tested a version of the oddball task in which faces of either White or Black people, or positive pictures, were presented in the context of negative pictures. Participants evaluated each picture as liked vs. disliked by button press. Using this task, the authors were able to examine whether oddball ERPs to Black and White faces differed in the context of negative words. On oddball trials, pictures of White faces elicited larger amplitudes of the P2 (also called the vertex positive potential) and the N2 than Black faces, suggesting the responses to White faces were more evaluatively discrepant from the negative context. A similar pattern was observed in the LPP component to the extent that participants reported highly prejudiced attitudes on the Modern Racism Scale (McConahay, Hardee, & Batts, 1981). This research illustrates a method for using ERPs to assess racial attitudes in the process of categorizing faces.

Mechanisms of affective priming. Fazio, Sanbonmatsu, Powell, & Kardes, 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 two 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 et al. (2009) used ERPs to test the extent to which affective congruency effects stem from differences in the evaluative categorization process, the response output process, or both (for discussion of this issue, see Klauer & Musch, 2003). In other words, 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 equally as likely as incongruent trials (50%), the amplitude of the LRP elicited by prime words showed that participants initially activated the response suggested by the prime but then corrected this response to match the target. 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.

Face perception. Much research has examined the face-specific N170 component as representing the earliest stage of face processing, and thus presumably the earliest stage of social processing (Bentin et al., 1996). However, relatively little research has been conducted on the role of the N170 in social cognition. The few social cognition studies using the N170 have examined responses to faces from different social groups. The goal of focus of these initial studies has been to explore the possibility that the race of a face influences very early perceptual processes, without testing a particular hypothesis about social cognition. However, the findings so far have been mixed, with some researchers observing larger N170 amplitudes to racial outgroups than ingroups (e.g., Stahl et al., 2008; Walker et al, 2008), others findings larger N170s to ingroup vs. outgroup faces (Ito & Urland, 2005), and other studies finding no differences (e.g., Caldara, Rossion, Bovet, & Hauert, 2004; Wiese, Stahl, & Schweinberger, 2009). Walker et al. (2008) further found that larger N170s to racial outgroup was associated with more lifetime experiences of contact with outgroup members. It is notable, however, that the tasks used to elicit the N170 component varies considerably across studies, and therefore inconsistencies within this small literature may be due to methodological variability. Another issue within the extant work on race and the N170 is that the face stimuli used in these studies have consisted of either color or grayscale images that do not control for low-level properties of visual stimuli, thereby introducing alternative non-social explanations for race effects (such as differences in contrast, color, or luminance). Nevertheless, much potential lies in the study of perceptual processes in social cognition using ERP methods.

Social categorization. ERPs have been used in several studies to track the timecourse and level of engagement of various processes associated with the social categorization of faces. Early research examined different ERP responses as a function of a person's gender (Mouchetant-Rostaing, Girard, Bentin, Aguera, & Pernier, 2000). Although gender did not moderate the face N170 component, gender effects emerged in negative-polarity ERP components as early as ~65 ms and then at ~165 ms in parietal regions. Studies of racial categorization have similarly observed similar patterns of early ERP effects. Ito and Urland (2003) used an oddball task in which targets were either consistent or inconsistent with context images as a function of both race (Black vs. White) and gender. Participants viewed the pictures and, in some blocks, responded to pictures that were different from the context according to gender, and in other blocks, when the picture differed according to race. Across blocks, the authors observed larger N1`and P2 ERP amplitudes to Black than to White faces. Effects for gender began to emerge in the P2 ERP, with larger amplitudes to makes than females. Effects for both race and gender were then reversed for the N2, with larger N2 amplitudes to White (vs. Black) and female (vs. male) faces. Finally, the authors observed an oddball LPP effect for race, such that LPP amplitudes to Black faces in a White context were larger than amplitudes to White faces in a Black context. Similar patterns of effects have been found using variations of this task in other studies (e.g., Kubota & Ito, 2007; Ito & Urland, 2005), as well sequential priming tasks (Amodio et al., 2004; Correll et al., 2006), the Implicit Associations Task (Hurtado, Haye, González, Manes, & Ibáñez, 2009), and a flanker-type task (Dickter & Bartholow, 2007).

Observations of early ERP effects for race indicate that certain aspects of the social categorization process occur very rapidly, and that these processes are relatively automatic and implicit (Ito, Willadsen-Jensen, & Correll, 2006). These observations corroborate the findings of previous behavioral research suggesting that these effects are to some extent automatic (e.g., Fazio, Jackson, Dunton, & Williams, 1995; Gaertner & McLaughlin, 1983). However, less is known about the psychological significance of the race effects seen in such studies – this is an important caveat in the extant ERP research on social categorization. It is likely that the ERP effects reflect aspects of attentional processing, motivation and/or response conflict, as reviewed in the previous section, but additional research will be needed to shed light on how these ERP effects might relate to specific psychological processes. At a broader level, the pattern of ERP effects found in a particular study is very likely to be related to the specific task used in the study. That is, the patterns of ERP effects seen in studies using the oddball task may reflect processes that are to some degree specific to that task (e.g., particular response strategies that participants use to complete the task). A consideration of task-specific effects is especially critical in studies without a strong theoretical foundation, in which one can only speculate about the meaning of ERP responses.

Stereotyping

By examining neural responses to semantic associations embedded within a sentence, researchers have used ERPs to assess individuals' processing of social stereotypes. 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 on the basis of gender (or violated neither). Their findings indicated that P3 amplitude was enhanced to both sentences containing definitional as well as stereotypical incongruities (compared with congruent control sentences), independent of participants' overt judgments of the grammatical and syntactical correctness of the sentences. As mentioned previously, White et al. (2009) reported observed enhanced N400 responses for sentences describing gender stereotype violations. Given previous research suggesting that the N400 reflects difficulty of accessing semantic information (Kutas & Federmeier, 2000), White et al. (2009) interpreted this finding as neural evidence for stereotype-based interference, consistent with previous behavioral research (e.g., Gaertner & McLaughlin, 1983).

Inspired by the ERP studies of semantic violations, 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 compared to stereotype confirmations, likely because they instigate an inconsistency resolution process (see also Macrae, Bodenhausen, Schloersheidt, & Milne, 1999).

In another line of research, Bartholow and Dickter (2008) measured conflict-related ERP components as a way to investigate the possibility that the presence of stereotype-incongruent information elicits response conflict. Participants viewed stimulus arrays in which White and Black target faces were surrounded by trait words that either confirmed or violated racial stereotypes. The authors found that stimulus arrays pairing faces with stereotype-incongruent words elicited larger LRP amplitudes, indicating the initial activation of an incorrect (i.e., stereotype-congruent) categorization response, as well as larger N2 amplitudes that presumably reflect detection of this increased response conflict. Moreover, the difference in LRP responses on stereotype-congruent versus –incongruent trials predicted the difference in RT between these conditions, suggesting that the locus of this effect lay, at least in part, within the response output process. By linking this behavioral effect to particular ERP responses, the authors were able to provide new information about the underlying cognitive processes that are involved in stereotyping priming effects.

Self-regulation

Self-regulation refers broadly to the process of coordinating goal-directed responses. Research on self-regulation and mechanisms of control have focused on both corrective i.e., bottom-up) and proactive (i.e., top-down) aspects of control, and ERP research has been instrumental in delineating and testing hypotheses about the specific mechanisms involved in different forms of control.

Corrective forms of self-regulation. Most research on self-regulation focuses on the corrective process of overriding an unwanted, yet prepotent tendency with a competing intentional response (e.g., Devine, 1989; Fazio, 1990; Sherman et al., 2008). In line with the broader literature, most ERP research on self-regulation has examined corrected models of control. In an initial ERP study examining mechanisms of self-regulation in social psychology, Amodio et al. (2004) 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 complementary processes: an initial, conflict monitoring mechanism subserved by activity in the dorsal ACC, and a regulative mechanism, associated with activity in lateral PFC (see Kerns et al., 2004), that strengthens the influence of intentional responses to override an unwanted tendency. As described above, the ERN and frontal N2 provide reliable indices of activity of the dorsal ACC with high temporal resolution, particularly in the context of cognitive control tasks such as the Stroop and Flankers tasks (Dehaene et al, 1994; Nieuwenhuis, Ridderinkhof, Blom, Band, &

Kok, 2001; van Veen & Carter, 2002), and that stronger activation of these components is associated with monitoring of response conflict (Yeung et al., 2004).

Participants in the Amodio et al. (2004) 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. As in previous work, and consistent with pervading stereotypes (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). This pattern suggested that responses on Black-tool trials required 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 for responses on these trial types. 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 provided evidence for the dissociation of detecting the influence of a stereotype and the implementation of control. Analyses of the N2 component, which indexed ACC activity leading to correct responses, showed the same pattern, indicating that although control sometimes fails, its success relies on the conflict monitoring process (Amodio et al., 2004). Finally, correlational analyses showed that individuals with larger conflict-related ERPs to unwanted stereotype activation demonstrated better control in behavior. This pattern has been replicated in studies of gender stereotypes, with stereotype mismatch trials (e.g., male faces followed by pictures of kitchen items) eliciting larger ERN amplitudes (Ma, Shu, Wang, Dai, & Che, 2008).

Subsequent research by Bartholow et al. (2006, Experiment 2) used ERPs to 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. Specifically, participants were asked to indicate as quickly as possible whether trait words (some were stereotypic and some were counter-stereotypic) could be used to describe Black and White faces (primes), but on 25% of the trials (i.e., “stop” trials) a red “X” appeared shortly after the onset of the trait word, signaling participants to halt the response they had initiated. 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 response inhibition on those trials required greater cognitive control compared with stereotype-inconsistent trials. Similarly, the amplitude of the No-Go N2 component, associated with conflict monitoring, was larger when inhibition was needed on stereotype-consistent than stereotype-incongruent, but did not differ across beverage groups, conceptually replicating Amodio et al. (2004). Other research that examined a similar ERP response, called the contingent negative variation, found that anticipatory ERPs prior to Black faces were larger for low prejudice (vs. high prejudice) participants, and that larger amplitude of this ERP predicted better response accuracy on the ensuring trial (Chui et al., 2004). Together, these findings further supported the idea that the control of intergroup responses involves dissociable mechanisms for detecting conflict and implementing control.

Amodio et al. (2006) recently applied their ERN approach to examine the effects of social influence on control. They asked whether different mechanisms were 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 also predictive of response control. Importantly, this P_e effect was primarily by participants who reported being highly sensitive to external pressures to respond without prejudice. This research suggested that the P_e, and its associated rostral ACC/medial PFC substrates, was specifically involved in externally-driven forms of response control, consistent with models positing that rostral ACC/medial PFC regions function to regulate responses in accordance with external (e.g., 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 nevertheless often show stereotyping bias on reaction-time measures (Amodio, Devine, et al., 2008). Based on their previous work (Amodio, Harmon-Jones, & Devine, 2003; Devine, Plant, Amodio, Harmon-Jones, & Vance, 2002), the authors hypothesized that among egalitarians, those who worry about normative pressures to respond without prejudice would be less sensitive to internal signals of response conflict on such task. Indeed, they found that among participants who reported strong internal motivation to respond without prejudice, those who also reported stronger external motivations showed worse control of stereotypes in their behavior, and this effect was associated with smaller ERNs in response to stereotype-related conflict. These findings suggest that some egalitarians are prone to unwanted race-biased expressions because automatic stereotyping tendencies to do not register as strongly in conflict monitoring processes.

Procative forms of self-regulation. With very few exceptions, social research on the mechanisms of self-regulation and control on social cognition has focused on corrective models of control; that is, the processes engaged when responses begin to deviate from one’s intentions. This is certainly true for ERP research on this topic (e.g., Amodio et al., 2004; Bartholow et al., 2005). In terms of self-regulation, corrective forms of control may be thought of as a “Plan B” – a contingency response for when plans go astray. But what about Plan A? Proactive control describes the set of processes involved in the coordination of intentional responses when correction is not necessarily needed (Amodio, in press-a). Proactive control is a top-down form of control that corresponds with selection models of working memory (Thompson-Schill, 2003). Although most research has examined corrective control, it is likely that in the vast majority of cases, self-regulation involves proactive control processes.

Amodio (in press-a) proposed that proactive control involves the coordination of motivational with perceptual processes to prepare for and to detect cues for action. On racial stereotyping tasks, as described above, the motivation to respond without prejudice would lead a participant to be vigilant for instances where prejudice is possible, such as when a racial minority face appears (Monteith, 1993), and then to respond to such cues with an intended, non-biased response. Amodio (in press) tested this hypothesis by examining patterns of left PFC activity in EEG linked to approach motivation while participants completed the weapons identification task. By examining PFC activity during intertrial intervals, this measure served as an index of proactive motivation prior to each trial. As an index of perceptual attention, P2 amplitudes to Black and White face primes during the task were assessed. Overall, P2 amplitudes were larger to Black than White faces, consistent with several previous studies (e.g., Ito & Urland, 2003). Importantly, stronger left PFC activity during intertrial intervals predicted a larger P2 effect to Black vs. White faces, consistent with the idea that greater proactive motivation would enhance the perceptual attention of relevant racial cues. Finally, among participants with low-prejudice attitudes, greater left PFC activity during the task and larger P2 amplitudes to Black faces predicted better response control in a pattern of statistical meditation. These results supported the proactive control model, such that motivation to respond without bias on the task enhanced perceptual attention to racial cues, which then enhanced response control.

Individual differences in self-regulatory processes

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, et al., 2008; Forbes, Schmader, & Allen, 2008; 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 (see Jost, Glaser, Sullaway, & Kruglanski, 2003) is related to the sensitivity of the conflict-monitoring system, as measured by the ERN. Other research by Inzlicht and Gutsell (2007) suggests that conflict-monitoring capabilities, as measured by the ERN during the Stroop task, are diminished following a manipulated of cognitive resources.

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, in multiple studies (e.g., Amodio et al., 2006; Nieuwenhuis et al., 2001), and the NSW is believed to reflect activity of the prefrontal cortex (e.g., Bartholow et al., 2006). Associations between ERP responses and neural substrates have been established through the combination of source localization studies and convergence with fMRI and patient data from studies using similar experimental tasks (Botvinick, Cohen, & Carter, 2004). By linking ERPs associated with psychological responses to specific neural substrates, researchers can draw from the vast literatures of behavioral and cognitive neuroscience to inform their theories about psychological processes 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 to model 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 the mathematical modeling of task behavior, researchers can achieve a high level of theoretical and methodological precision.

Practical Considerations for Using ERP Methods as a Research Tool

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. Relatedly, ERPs currently represent one of the only direct measures of brain activity as it occurs in real time (see also Gratton & Fabiani, 2001). In contrast, fMRI does not measure neural activity directly, but rather measures changes in blood flow believed to follow the firing of neurons. The relative sluggishness of the hemodynamic response can limit the inferences that can be drawn from fMRI data, particularly for testing hypotheses about rapidly-unfolding processes. 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, Smid, Scheffers& Otten, 1995).

Perhaps the most significant disadvantages of the ERP method for most social and/or personality psychologists are the time and resources required to implement it. Social/personality 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/personality 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 or personality processes, the challenge is reversed; one must seek additional training and experience in these 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

ERP methodology offers a powerful set of tools for probing the mechanisms of social cognition. Here, we have provided an overview of the ways that 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 neural activations and their versatile use with a range of experimental tasks, ERP methods are likely to become increasingly prominent in social cognition research, along with a host of other neural and physiological approaches that have emerged in the field of social neuroscience. We expect that researchers who understand and incorporate cognitive and affective neuroscience with basic behavioral approaches will be well positioned to make significant contributions to the understanding of social cognition, 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. (in press-a). Coordinated roles of motivation and perception in the regulation of intergroup responses: Frontal cortical asymmetry effects on the P2 event-related potential and behavior. *Journal of Cognitive Neuroscience*.

Amodio, D. M. (in press-b). Can neuroscience advance social psychological theory? Social neuroscience for the behavioral social psychologist. *Social Cognition*.

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. (2003). Individual differences in the activation and control of affective race bias as assessed by startle eyeblink responses and self-report. *Journal of Personality and Social Psychology*, *84*, 738-753.

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.

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., 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., & Mendoza, S. A. (in press). Implicit intergroup bias. To appear in B. Gawronski and B. K. Payne (Eds.) *Handbook of Implicit Social Cognition*. New York: Guilford.

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., Riordan, M. A., Saults, J. S., & Lust, S. A. (2009). Psychophysiological evidence of response conflict and strategic control of responses in affective priming. *Journal of Experimental Social Psychology, 45,* 655-666.

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.

Botvinick, M. M., Cohen, J. D., & Carter, C. S. (2004).Conflict monitoring and anterior cingulated cortex: An update. *Trends in Cognitive Sciences, 8*, 539-546.

Bruin, K. J., Wijers, A. A., & van Staveren, A. S. J. (2001). Response priming in a go/nogo task: Do we have to explain the go/nogo N2 effect in terms of response activation instead of inhibition? *Clinical Neurophysiology,112,* 1660–1671.

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., 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., & Tassinary, L. G. (1990). Psychophysiology and psychophysiological inference. In J. T. Cacioppo and L. G. Tassinary (Eds.), *Principles of psychophysiology: Physical, social, and inferential elements* (pp. 3-33). New York: Cambridge University Press.

Cacioppo, J. T., Berntson, G. G., Lorig, T. S., Norris, C. J., Rickett, E., Nusbaum, H. (2003). Just because you're imaging the brain doesn't mean you can stop using your head: A primer and set of first principles. *Journal of Personality and Social Psychology, 85*, 650-661.

Caldara, R., Rossion, B., Bovet, P., & Hauert, C. (2004). Event-related potentials and time course of the 'other-race' face classification advantage. *Neuroreport, 15*, 905.

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.

Deffke, I., Sander, T., Heidenreich, J., Sommer, W., Curio, G., Trahms, L., Lueschow, A. (2007). MEG/EEG sources of the 170-ms response to faces are co-localized in the fusiform gyrus. Neuroimage, 35, 1495-501.

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. (1989). Stereotypes and prejudice: Their automatic and controlled components. *Journal of Personality and Social Psychology, 56*, 5-18.

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

Devine, P. G., Plant, E. A., Amodio, D. M., Harmon-Jones, E., Vance, S. L. (2002). The regulation of explicit and implicit race bias: The role of motivations to respond without prejudice. *Journal of Personality and Social Psychology, 82*, 835-848.

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.

Dickter, C. L., & Bartholow, B. D. (in press). Ingroup categorization and response conflict: Interactive effects of target race, flanker compatibility and infrequency on N2 amplitude. *Psychophysiology.*

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.

Eimer, M. (2000). Event-related brain potentials distinguish processing stages involved in face perception and recognition. *Clinical Neurophysiology, 111*(4), 694-705.

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.

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. (1990). Multiple processes by which attitudes guide behavior: The MODE Model as an integrative framework. In M. P. Zanna (Ed.), *Advances in experimental social psychology* (Vol. 23, pp. 75-107). New York: Academic Press.

Fazio, R., Jackson, J., Dunton, B., & Williams, C. (1995). Variability in automatic activation as an unobtrusive measure of racial attitudes: A bona fide pipeline? *Journal of Personality and Social Psychology, 69*, 1013-1027.

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.

Fiske, S. T., & Taylor, S. E. (2008). *Social cognition: From brains to culture*. New York: McGraw-Hill.

Folstein, J. R., & Van Petten, C. (2008). Influence of cognitive control and mismatch on the N2 component of the ERP: A review. *Psychophysiology, 45*, 152-170.

Forbes, C. E., Schamder, T., & Allen, J. J. B. (2008). The role of devaluing and discounting in performance monitoring: A neurophysiological study of minorities under threat. *Social Cognitive and Affective Neuroscience, 3*, 253-261.

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.

Gaertner, S. L., & McLaughlin, J. P. (1983). Racial stereotypes: Associations and ascriptions of positive and negative characteristics. *Social Psychology Quarterly, 46*, 23-30.

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.

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.

Gratton, G. & Fabiani, M. (2001). Shedding light on brain function: The event-related optical signal. *Trends in Cognitive Sciences, 5*, 357-363.

Harmon-Jones, E. & Peterson, C. K. (2009). Electroencephalographic methods in social and personality psychology. In E. Harmon-Jones & J. S. Beer (Eds.), *Methods in Social Neuroscience* (pp. 170-197). New York, NY: Guilford.

Henry, E. A., Bartholow, B. D., & Arndt, J. (in press). Death on the brain: Effects of mortality salience on the neural correlates of ingroup and outgroup categorization. *Social, Cognitive, and Affective Neuroscience.*

Herrmann, M. J., Schreppel, T., Jäger, D., Koehler, S., Ehlis, A. C., & Fallgatter, A. J. (2007). The other-race effect for face perception: an event-related potential study. *Journal of Neural Transmission, 114*, 951-957.

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.

Horst, R., & Donchin, E. (1980). Beyond averaging II: Single-trial classification of exogenous event-related potentials using stepwise discriminant analysis. *Electroencephalography and Clinical Neurophysiology*, *48*, 113-126.

Hurtado, E., Haye, A., Gonzalez, R., Manes, F., & Ibanez, R. (2009). Contextual blending of ingroup/outgroup face stimuli and word valence: LPP modulation and convergence of measures. *BMC Neuroscience, 10:69.*

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.

Jost, J.T., Glaser, J., Kruglanski, A.W., & Sulloway, F. (2003a). Political conservatism as motivated social cognition. *Psychological Bulletin, 129*, 339-375.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.

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.

Kubota, J. T., & Ito, T. A. (2007). Multiple cues in social perception: The time course of processing race and facial expression. *Journal of Experimental Social Psychology, 43*, 738-752.

Kutas, M. and Federmeier, K. D. (2000). Electrophysiology reveals semantic memory use in language comprehension. *Trends in Cognitive Science, 4*, 463-470.

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.

Luck, S. J., & Hillyard, S. A. (1994). Electrophysiological correlates of feature analysis during visual search. *Psychophysiology, 31*, 291-308.

Ma Q, Shu L, Wang X, Dai S, & Che H. (2008). Error-related negativity varies with the activation of gender stereotypes. *Neuroscience Letters, 442*, 186-9.

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.

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.

McConahay, J. B., Hardee, B. B., & Batts, V. (1981). Has racism declined in America? It depends on who is asking and what is asked. *Journal of Conflict Resolution, 25*, 563-579.

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.

Mendoza, S. A., & Amodio, D. M. (in preparation). *Goal strategy effects on the expression of implicit racial bias: Mechanisms of attention and action control*.

Monteith, M. J. (1993). Self-regulation of prejudiced responses: Implications for progress in prejudice-reduction efforts. *Journal of Personality and Social Psychology, 65*, 469-485.

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., Ridderinkhof, K. R., Blom, J., Band, G. P. H., & Kok, A. (2001). Error-related brain potentials are differently related to awareness of response errors: Evidence from an antisaccade task. *Psychophysiology*, *38*, 752-760.

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.

Ross, L., & Nisbett, R. E. (1991). *The person and the situation: Perspectives of social psychology*. New York, NY: McGraw-Hill.

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.

Schutter, D. J. L. G., de Haan, E. H. F., & van Honk, J. (2004). Functionally dissociated aspects in anterior and posterior electrocortical processing of facial threat. *International Journal of Psychophysiology, 53*, 29-36.

Sherman, J. W., Gawronski, B., Gonsalkorale, K., Hugenburg, K., Allen, T. J., & Groom, C. J. (2008). The self-regulation of automatic associations and behavioral impulses. *Psychological Review, 115*, 314-335.

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.

Stahl, J., Wiese, H., & Schweinberger, S. R. (2008). Expertise and own-race bias in face processing: An event-related potential study. *NeuroReport, 19*, 583-58.

Suwazono, S., Machado, L., & Knight, R. T. (2000). Predictive value of novel stimuli modifies visual event-related potentials and behavior. *Clinical Neurophysiology, 111*, 29-39.

Thompson-Schill, S. L. (2003). Neuroimaging studies of semantic memory: Inferring “how” from “where.” *Neuropsychologia, 41*, 280-292.

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.

Vidal, F., Hasbroucq, T., Grapperon, J., & Bonnet, M. (2000). Is the ‘error negativity’ specific to errors? Biological Psychology, 51, 109–128.

Walker, P., Silvert, L., Hewstone, M., & Nobre, A. (2008). Social contact and other-race face processing in the human brain. *Social Cognitive and Affective Neuroscience, 3*, 16.

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

White, K. R., Crites, S. L. Jr., Taylor, J. H., & Corral, G. (2009). Wait, what? Assessing stereotype incongruities using the N400 ERP component. *Social Cognitive and Affective Neuroscience, 4*, 191-198.

Wiese, H., Stahl, J., & Schweinberger, S. (2009). Configural processing of other-race faces is delayed but not decreased. *Biological Psychology*, *81*, 103-109.

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

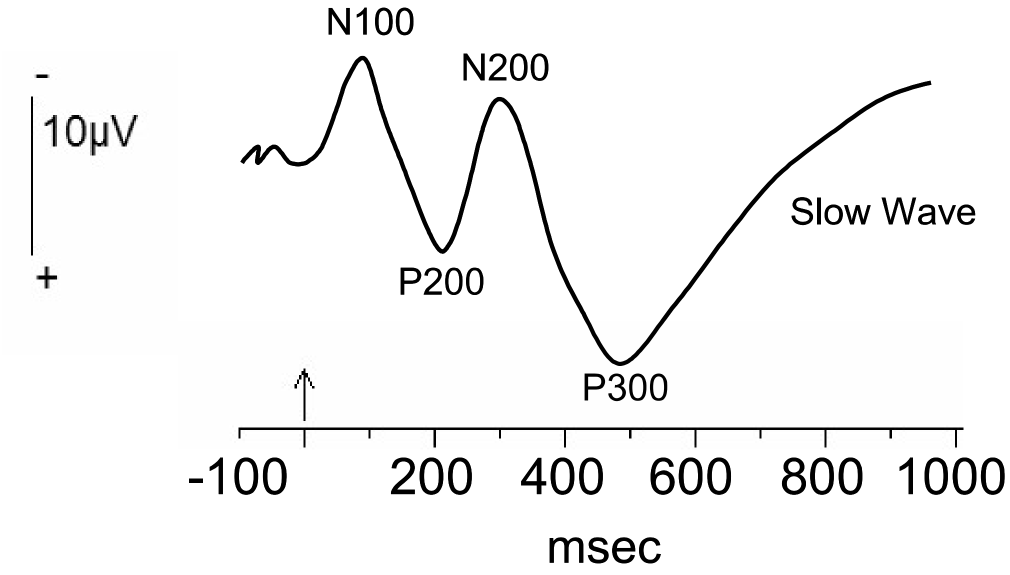
Figure 1. A schematic representation of an ERP waveform elicited by a novel visual stimulus. The vertical arrow on the timeline (horizontal axis) represents stimulus onset time. The positive and negative deflections in the waveform represent typical ERP components, named here according to their polarity ("P" for positive deflections and "N" for negative deflections) and the approximate post-stimulus time (in ms) of their peaks. 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 voltages are plotted above zero on the Y axis, following electrophysiological convention, but that ERP waveforms are sometimes plotted with negative voltages displayed below zero.

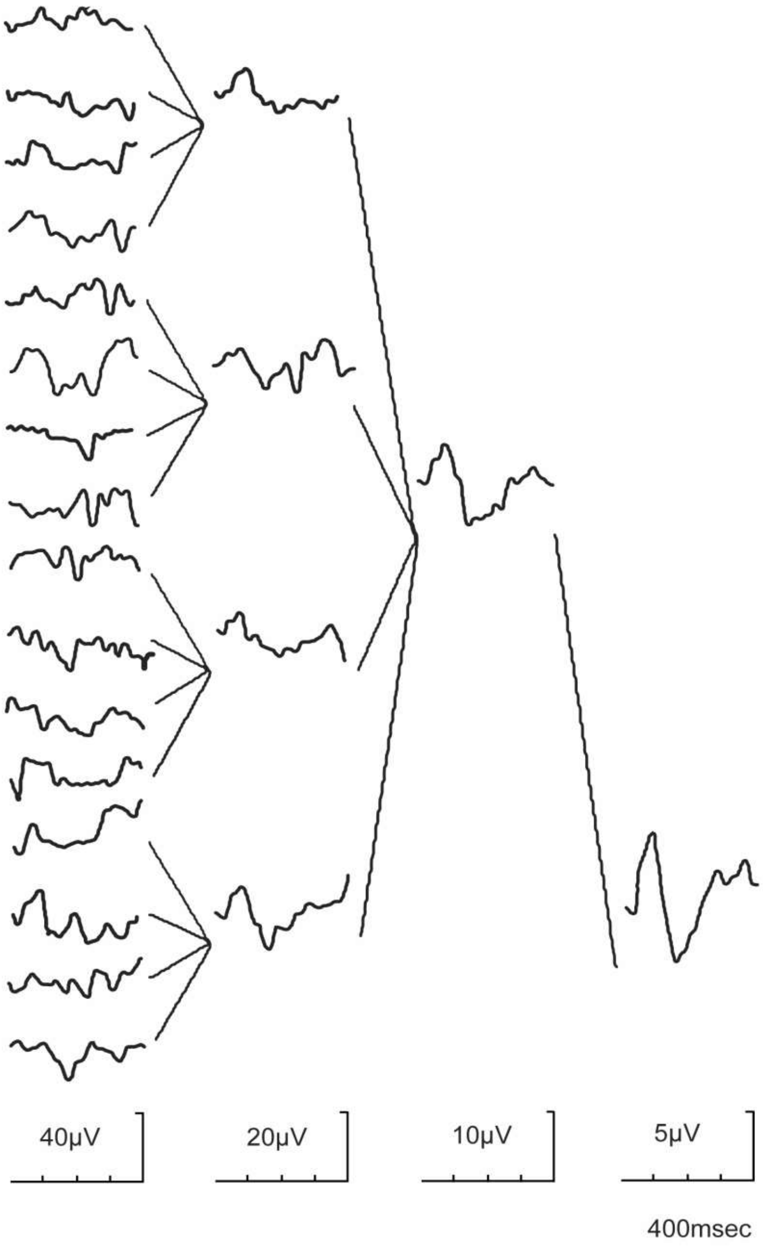
Figure 2. Effects of successive ERP averaging to an auditory stimulus. The far-left column shows single trial waveforms from each of 4 participants, recorded at the Cz (midline central) electrode location. The next column shows single-participant averages derived from each of the original 4 single trials. 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.)

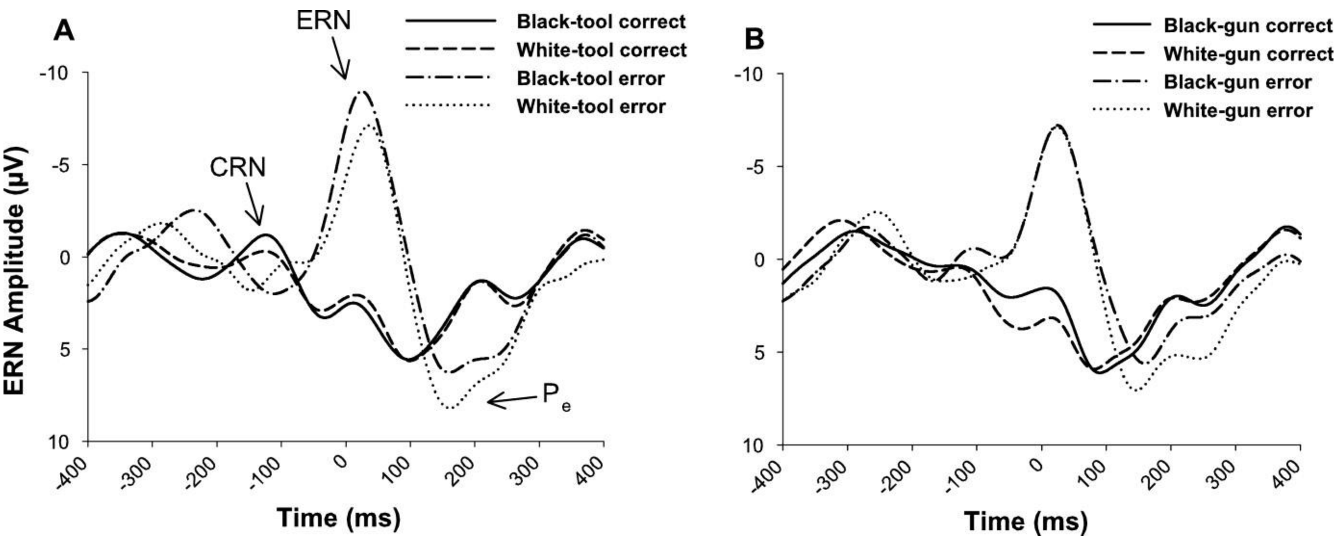
Figure 3. Response-locked ERP waveforms recorded from the FCz (midline fronto-central) channel during the weapons identification task. ERPs are displayed for correct and incorrect tool (**A**) and gun (**B**) trials as a function of accuracy and the race (Black vs. White) race of the face

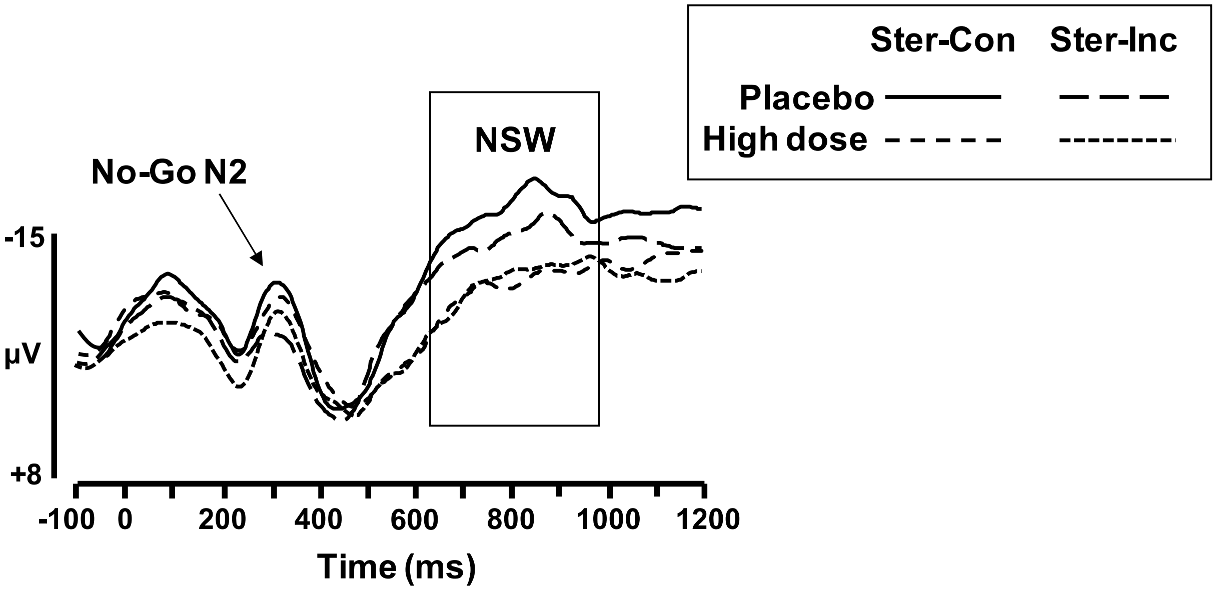
prime. The ERN, CRN, and P_e components are labeled in panel A. On the x-axis, zero indicates the point at which responses were given. This figure shows that both the response-locked N2 (or CRN) and ERN waves are larger on Black-tool trials, which require enhanced control over automatic stereotypes, compared with all other trial types (P_e amplitudes did not differ as a function of trial type). (Adapted from Amodio et al., 2004)

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 larger NSW amplitudes than did withholding a stereotype-incongruent response (dashed line). However, this did not occur in the high dose group, suggesting that alcohol impaired engagement of cognitive control. The No-Go N2 was also larger on stereotype-consistent trials, suggesting heightened conflict monitoring on those trials, but this effect was not significantly influenced by alcohol. (Adapted from Bartholow et al., 2006.)


N100
N200
-
10µV
+
P200
Slow Wave
P300
-100
200
400
600
800
1000
msec


40μV
20μV
10μV
5μV
400msec


A
ERN
CRN
Pe
Black-tool correct
White-tool correct
Black-tool error
White-tool error
ERN Amplitude (μV)
-10
-5
0
5
10
-400
-300
-200
-100
0
100
200
300
400
Time (ms)
B
Black-gun correct
White-gun correct
Black-gun error
White-gun error
-10
-5
0
5
10
-400
-300
-200
-100
0
100
200
300
400
Time (ms)


Ster-Con
Ster-Inc
Placebo
High dose
NSW
No-Go N2
-15
μV
+8
-100
0
200
400
600
800
1000
1200
Time (ms)