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Commentary

Feelings and emotions: roles for electrophysiological markers

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Abstract

Asymmetrical electroencephalogram (EEG) alpha activity over anterior regions of the scalp predicts a variety of outcome measures of interest to emotion researchers. This vast and diverse literature is examined from three different viewpoints. First, the organization of this vast literature is contrasted from theoretical and statistical perspectives, and the advantages and disadvantages of each perspective are considered. Second, the correlates of EEG asymmetry are sometimes treated as criterion (dependent) measures and at other times treated as predictor (independent) measures. Differences in the interpretation of each are surveyed, and the need for attention to whether EEG asymmetry is a simple correlate, mediator, or moderator of the associated affective measures is noted. Finally, the studies of EEG asymmetry and emotion that adopt a psychological perspective are contrasted with those that adopt a neurophysiological perspective, and the import of each for theory, experimental design, and analytic strategy is discussed.

Keywords: Electroencephalogram (EEG); Criterion; Predictor

1. Introduction

For centuries scholars regarded feelings (e.g. sadness, fear, anger, disgust, dysphoria) as the most (if not only) appropriate data for the study of emotion. The reasoning for this position, on the surface, is straightforward. When one finds oneself teetering dangerously on the edge of a cliff, positioned in the path of a charging beast, or trapped on the top floors of a burning skyscraper, the consequences are not subtle: the unmistakable feeling of fear commands center stage, the expression of terror is etched involuntarily across one's face, attention is narrowed to a focal set of stimuli, actions are driven by attempts to avoid

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the imminent peril, and metabolic resources are mobilized to support these actions. When the same set of responses is elicited by normal circumstances, such as when an individual approaches a podium to deliver a speech, encounters a nonpoisonous snake, or prepares to board an airplane, normal life is disrupted and individuals complain about the horrific feelings that hijack their will and their way.

Feelings represent a special class of outcomes that are important to explain in theories of emotion, to be sure, but it does not follow from their position in center stage that the most appropriate data for constructing or testing theories of emotion are *limited* to feelings or self-reports (cf. Cacioppo et al., 1997, 1999). An important contribution of both the cognitive revolution in psychology and animal research on emotion is an appreciation that feelings provide an incomplete glimpse of their underlying information processing structures and operations. LeDoux (2000), in his recent survey of the field in the *Annual Review of Neuroscience*, echoed this point:

> It is widely recognized that most cognitive processes occur unconsciously, with only the end products reaching awareness, and then only sometimes. Emotion researchers, though, did not make this conceptual leap. They remained focused on subjective emotional experience. . . . The main lesson to be learned. . . is that emotion researchers need to figure out how to escape from the shackles of subjectivity if emotion research is to thrive (LeDoux, 2000, p. 156).

How are we to plumb noninvasively the structures and processes of emotion in humans if not through self-reports? The work summarized in this special issue suggests that measures of frontal electroencephalogram (EEG) asymmetry have much to offer in this regard. My aim in this commentary is to highlight a few themes in this literature that I hope will foster this effort.

1.1. Theoretical and statistical perspectives

Research on EEG frontal asymmetry and emotion is one of the most promising and fertile in the field. The assortment of variables associated with EEG frontal asymmetry, for instance, ranges from child temperament (see Fox et al., 2001), the maternal depression of infants (Jones et al., 2004) and adolescents (Tomarken et al., 2004), self-report measures of affect and personality (e.g. Tomarken and Davidson, 1994), shyness and social anxiety (Schmidt, 1999), socioeconomic status (Tomarken et al., 2004), basal cortisol levels (Kalin et al., 1998), and immune function (e.g. Kang et al., 1991) to cognitive dissonance arousal (Harmon-Jones, 2004), the emotional content of dreams upon awakening (Donzella et al., 1994), the memory recognition of sad narrative material (Nitschke et al., 2004), and reassurance seeking (Minnix et al., 2004).

The number of associations between EEG frontal asymmetry and various aspects of emotion is sufficiently large, and the measures that are associated with EEG frontal asymmetry are sufficiently diverse, that it can be difficult to see beyond these data to underlying organizations, structures, and processes. One way of dealing with such a complex array of associations is to rely on a theoretical formulation to guide one's analysis and interpretation. The most influential is Davidson's (e.g. 1993, 2004) model, which specifies that high levels of relative left frontal activity are associated with the expression and experience of positive, approach-related emotions, and high levels of relative right frontal activity are associated with the experience and expression of negative, withdrawal-related emotions. Harmon-Jones (2004) has argued that this model includes both motivational and valence components, which can be distinguished conceptually and empirically. In doing so, he has identified a valence model of EEG asymmetry in which high levels of relative left frontal activity are associated with the expression and experience of positive emotions and high levels of relative right frontal activity are associated with the experience and expression of negative emotions; and a motivational direction model in which high levels of relative left frontal activity are associated with the expression of approach-related emotions and high levels of relative right frontal activity are associated with the expression of withdrawal-related emotions. Although positive emotions are typically associated with motivations to approach and negative emotions are typically associated with motivations to withdraw, there are notable exceptions (e.g. anger-out). Through the development and tests of competing hypotheses, Harmon-Jones (2004) and colleagues have pursued the goal of specifying more precisely what the emotional and motivational functions of asymmetrical frontal brain activity might be.

In the pursuit of the simplest single theoretical construct that might account for these assorted findings, it may be worthwhile to ask whether the various correlates of EEG asymmetry are themselves sufficiently correlated that they likely result from a unitary underlying faculty or mechanism. Indeed, philosophers of science have long noted the beneficial effect of theory testing on scientific progress (see Brazier, 1959), but in the past century there has been an increasing recognition of the ways in which a theoretical focus can also hinder scientific progress (e.g. by biasing the selection of measurement instruments, Eddington, 1939, or the construction or interpretation of crucial tests, Greenwald et al., 1986). A multivariate statistical approach to investigate the structure of the correlates of EEG asymmetry may also be informative by pointing to possible oversimplifications in existing theoretical formulations and, relatedly, by suggesting new theoretical hypotheses that can be tested empirically.

Consider a thought experiment in which all of the known correlates of EEG asymmetry (e.g. see Tables 1–4 in Coan and Allen, this issue) were measured in a single study with a large sample size. Would one expect EEG asymmetry to predict each of these outcome measures? The answer is yes, of course, assuming measurement error was negligible and the findings reliable. So far, this thought experiment simply constitutes a replication of prior research. However, because all of the outcome measures in this thought experiment are obtained from the same individuals, it is possible to use multivariate statistical techniques to explore the interrelationships among and the statistical coherences among these measures. It would be possible, for instance, to submit the data from half of the participants to an exploratory factor analysis using an oblique rotation to examine the statistical structure of the multivariate dataset. The data from the other half of the participants could then be subjected to a confirmatory factor analysis to validate this structure.

If the results confirmed these measures were sufficiently coherent and they represented a single dimension, then not only would this provide additional evidence for their being a unitary faculty or single mechanism underlying their production, but also the factor loadings of the measures should bear on the core features of this unidimensional construct. If, on the other hand, the results of this thought experiment indicated a single dimension was insufficient to represent the correlates of EEG asymmetry, the nature of the multidimensional representation and the factor loadings on these dimensions could have considerable theoretical import, as they would lead to new and testable hypotheses about what precisely EEG asymmetry is predicting in specific contexts.

The point of this thought experiment is not to prejudge what the outcome might be, but rather to underscore the complementary role of theoretical and statistical perspectives on a literature as complex and diverse as that on the associations of anterior EEG asymmetry. The concept of arousal—once a popular construct in the field of emotion, was undermined not so much by its lack of empirical support as by its oversimplification of the accumulated empirical data. Arousal came to stand for such a diverse set of outcomes, many of which were only so poorly correlated, that the formulation lost its predictive power and, thus, its scientific import. The same fate need not befall an area of work as fertile as EEG asymmetry and emotion if both statistical and theoretical approaches are used to complement each other.

1.2. Associations between EEG frontal asymmetry and emotion

Coan and Allen (2004) classified studies of EEG asymmetry and emotion as falling under one of four categories: (a) research on trait frontal EEG asymmetry and other trait-like measures, (b) studies of trait frontal asymmetry as a predictor of state dependent changes, (c) studies of trait frontal EEG asymmetry and measures of psychopathology, and (d) research on frontal EEG activation asymmetry as a state measure. This categorization leads to several quick observations. First, EEG asymmetry is not itself a mechanism but rather it is a marker of some underlying neural processes. Although the first three categories of research concern trait frontal EEG asymmetry as it relates to traits, state changes, and psychopathology, there appears to be a paucity of research on the neural structures and processes that are responsible for these associations (cf. Davidson, 2003). I return to this issue in Section 1.3.

Second, it is judicious to ask for each new association whether EEG asymmetry, or more specifically the neural mechanism responsible for frontal EEG asymmetry, plays a causal role in the outcome measure. Although the studies tend to be treated similarly, some studies of frontal EEG asymmetry are designed to examine behavioral correlates, other studies treat frontal EEG asymmetry as an independent (blocking) variable and behavioral variables as the dependent measure, and still others treat one or more behavioral measures as the independent (blocking) variable and frontal EEG asymmetry as the dependent measure. These distinctions are significant. Studies of frontal EEG asymmetry designed to examine behavioral correlates speak only the probability of the co-occurrence of these measures (i.e. *P*(EEG asymmetry, behavioral measure)), studies that treat frontal EEG asymmetry as an independent (blocking) variable and behavioral variables as the dependent measure speak the probability of the behavioral variable given frontal EEG asymmetry (i.e. *P*(behavioral measure/EEG asymmetry)), and studies that treat one or more behavioral measures as the independent (blocking) variable and frontal EEG asymmetry as the dependent measure speak the probability of frontal EEG asymmetry given the behavioral variable differs (i.e. *P*(EEG asymmetry/behavioral measure)). We have dealt elsewhere with the different implications for the interpretation of empirical findings for each of these classes of studies (e.g. Cacioppo and Tassinary, 1990; Sarter et al., 1996). Suffice it to say that statements about the causal role of frontal EEG asymmetry in producing a particular emotional state or predisposition are inappropriate in studies that treat frontal EEG asymmetry as the dependent measure and a behavioral measure (e.g. depression) as the independent (blocking) variable.

Studies that treat frontal EEG asymmetry as a blocking variable and behavioral variables as the dependent measure are better suited to such interpretations, but alternative interpretations still need to be considered. Allen et al. (2001), for instance, recognized that most of the extant evidence about the possible role of frontal EEG asymmetry and emotional responses is based on correlational evidence. To examine the potential causal role of frontal EEG asymmetry in the production of emotional responses, they used biofeedback training to increase either relative right or relative left frontal EEG activity. Manipulation checks confirmed that 5 consecutive days of biofeedback training produced the expected differences in EEG asymmetry, and self-reported responses to emotionally evocative film clips indicated that individuals trained to increase left frontal activity reported more positive affect to a happy film clip than individuals trained to increase right frontal activity. This is a laudable effort on a number of fronts, including the attempt to test the causal role played by the neural processes marked by frontal EEG asymmetry, the extensive biofeedback training provided to participants over 5 consecutive days in an effort to manipulate frontal activity, and the treatment of EEG asymmetry as a blocking variable and emotional responses as the dependent variable. It is possible that the biofeedback training operated directly to increase right or left frontal activity which then in turn led to more positive or negative affective responses to happy film (see Harmon-Jones, 2004), but the opposite is also possible. For instance, it is conceivable that participants tried different mental strategies to achieve reinforcement in the biofeedback training task. If participants discovered during biofeedback training that thinking happier thoughts led to reinforcement for producing relative right frontal activity and that thinking less happy thoughts led to the opposite, then the frontal EEG asymmetry may not have been the cause of the affective responses they observed. Techniques such as transcranial magnetic stimulation, which would avoid this alternative interpretation, may prove a valuable additional tool for investigating questions of this form (e.g. see Nahas et al., 2003).

As Coan and Allen (2004) suggest, experimental designs and statistical tests to determine whether EEG asymmetry may be serving as a moderator or a mediator of emotional processes can be especially helpful at this point in time to advance theory and research in the area. The frontal EEG asymmetry marks some underlying neural process or processes. Continued efforts are needed to identify the neural processes that underlie the correlation between resting EEG alpha asymmetry and emotional style and the neural processes that underlie differential EEG alpha activation in emotionally evocative situations. Nevertheless, EEG asymmetry as a marker of these underlying events can be examined using the procedures outlined by Coan and Allen (2004) to determine whether the processes it marks are likely to be serving as a mediator, moderator, or simple correlate in a given study. The frontal EEG asymmetry is conceptualized as a mediator when the neural processes underlying the differential frontal activation is thought to be instrumental in the production of tonic affective states or state changes (e.g. more or less pleasant or unpleasant feelings about a stimulus) or approach- or withdrawal-motivational tendencies, whereas frontal EEG asymmetry is conceptualized as a moderator when the neural processes underlying it are thought to dampen or augment the processes instrumental in the production of tonic affective states or state changes. Allen and Coan's (2004) description of the methodological and statistical conditions needed to differentiate these possible roles is a valuable contribution to the field as it may explain some apparent inconsistencies in results (e.g. see Reid et al., 1998).

1.3. Psychological and physiological perspectives

Whether frontal EEG asymmetry is treated as an individual difference variable or a state-dependent concomitant, its association to emotion and emotion-related constructs has generally reflected a search for functional relationships to other behavioral constructs rather than a search for underlying neural mechanisms. The studies comprising this special issue are a case in point, and they nicely illustrate the theoretical value of this psychological approach to the study of frontal EEG asymmetry and emotion. Indeed, Coles et al. (1987) noted in their discussion of event-related brain potentials (ERPs) that knowledge of the neural substrates of ERPs is logically neither necessary nor sufficient to ascribe psychological meaning to ERP components, and this is true for frontal EEG asymmetry, as well. The ascription of psychological meaning to the ERP components, frontal EEG asymmetry measures, or any other such marker ultimately resides in the quality of the experimental design and the psychometric properties of the measurements. Although numerous aspects of the physiological bases of ERPs remain uncertain, for instance, functional relationships within specific paradigms have been established between elementary cognitive operations and components of these potentials by systematically varying one or more of the former and monitoring changes in the latter (e.g. Coles et al., 1986). This literature has also revealed that the psychological interpretation of an ERP measure may differ across paradigms—a finding that should serve as a cautionary note to those who wish to interpret EEG asymmetry measures as necessarily reflecting the same substrates, predispositions, or information processing operations across different paradigms or methods of measuring frontal asymmetries (cf. Hagemann et al., 1998; Reid et al., 1998).

Continued efforts are also needed, however, to further specify the neural processes or processes that are responsible for the pattern of resting EEG alpha asymmetry associated with specific facets of emotional style and those that are responsible for differential EEG alpha activation in emotionally evocative situations (cf. Davidson, 2003, 2004). Among the major evolutionary advances in humans is the striking development of the human cerebral cortex, especially the frontal region. The cerebral cortex is a mantle of between 2.6 and 16 billion neurons with each neuron receiving 10,000–100,000 synapses in their dendritic trees (e.g., Pakkenberg, 1966). The frontal lobes constitute approximately 32% of this cerebral mantle. The vast expansion of the frontal regions in the human brain is largely responsible for the human capacity for reasoning, planning, and performing mental simulations, and an intact frontal region contributes to the human ability to reason, remember and work together. The neocortex in particular is a recent development in evolutionary time, and the means for guiding behavior through the environment, albeit in a more rigid and stereotyped fashion, emerged prior to neocortical expansion. These evolutionarily older systems likely also play a role in human information processing, emotion, and behavior, and ample anatomical connections between frontal and limbic regions are documented (Davidson and Irwin, 1999).

The specification of the neural substrates and processes underlying specific measures of EEG asymmetry in a given paradigm can constrain and inspire theoretical hypotheses, foster experimental tests of otherwise indistinguishable theoretical explanations, and increase the comprehensiveness and relevance of theories of emotion. In addition, the measurement characteristics and psychometric properties of frontal EEG asymmetry have received careful attention (e.g. see Allen et al., 2004; Hagemann, 2004), but knowledge of the specific neural structures and processes underlying tonic and phasic EEG asymmetry measures may contribute further to the accuracy of its measurement in particular paradigms and in specific populations.

The point is not that either a neurophysiological or the psychological perspective is preeminent, but rather that both are fundamental to and complementary in studies of EEG asymmetry and emotion (see also, Hagemann, 2004). Inattention to the logic underlying psychophysiological inferences simply because one is dealing with observable electrocortical responses is likely to lead to simple and restricted descriptions of empirical relationships and/or to erroneous interpretations of relationships involving these responses. An entirely aphysiological attitude, in contrast, ignores relevant information and therefore increases the chances of misinterpretations of the empirical relationships that are found between EEG asymmetry measures and emotional processes or states. It is the joint consideration of physiological and psychological perspectives that enriches theory and research on human emotion by reducing errors of operationalization, measurement, and inference. The field of research on frontal EEG asymmetry appears well positioned for such a multi-level integrative approach to the study of emotion.

2. Summary

The frontal regions of the neocortex have led to dramatic expansions in emotional, behavioral, and social capacities. Perhaps it should not be surprising that research on frontal EEG asymmetry and emotion has uncovered such a diverse set of associations, therefore. Rather than reducing this literature to its simplest theme, I have discussed ways investigators might investigate whether frontal EEG asymmetry bears on separable but ultimately related facets of affective information processing, expression, and response. Metabolic and electrophysiological images of brain activity hold the promise of examining when and where affective information processing is unfolding in the brain, from which investigators will be in a better position to infer the nature of the information processing operation being performed moment by moment in the brain.

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