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EDITORIAL

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Frontal EEG alpha asymmetry and emotion: From neural underpinnings and methodological considerations to psychopathology and social cognition

John J. B. Allen[1] | **Philipp M. Keune**[2,3] | **Michael Schönenberg**[4] | **Robin Nusslock**[5]

[1] Department of Psychology, University of Arizona, Tucson, Arizona, USA

[2] Klinikum Bayreuth GmbH, Department of Neurology, Bayreuth, Germany

[3] Department of Physiological Psychology, University of Bamberg, Bamberg, Germany

[4] Department of Clinical Psychology and Psychotherapy, University of Tübingen, Tübingen, Germany

[5] Department of Psychology, Northwestern University, Evanston, Illinois, USA

Correspondence
John J. B. Allen, Department of Psychology, Room 312, University of Arizona, P.O. Box 210068, Tucson, AZ 85721-0068, USA.
Email: John.JB.Allen@Arizona.edu

1 | INTRODUCTION

Forty years ago, in September of 1978, at the annual meeting of the Society for Psychophysiological Research in Madison,[1] Wisconsin, the early-career scientist Richie Davidson presented a paper suggesting that the experience of positive affect and of negative affect were associated with differently lateralized patterns of frontal brain electrical activity. Following the publication of the abstract of this presentation on frontal EEG asymmetry the next year (Davidson, Schwartz, Saron, Bennett, & Goleman, 1979), there were almost no publications in the following decade, with only 15 empirical articles examining frontal EEG asymmetry and emotion by 1990. It might have been hard to predict at that time how popular this measure of frontal brain asymmetry would become, with now hundreds of articles published using frontal EEG asymmetry to examine emotion-related and motivation-related trait individual differences and state-related changes. Among other topics, frontal EEG asymmetry has been used to investigate risk for depression, anxiety, and internalizing psychopathology, as well as externalizing disorders such as mania, addiction, and attention-deficit hyperactivity disorder (ADHD). It has also been used extensively to examine individual differences in temperament and motivational style, and responses to emotional stimuli and social provocation.

An advantage of frontal EEG asymmetry is its association with a highly successful conceptual model of emotion and motivation. The approach-withdrawal model of frontal asymmetry posits that increased relative left-frontal activity indicates a propensity to approach or engage a stimulus, whereas decreased relative left-frontal activity indicates a propensity toward reduced approach motivation or increased withdrawal motivation (e.g., Coan & Allen, 2004; Davidson, 1998; Harmon-Jones, 2003). Thus, frontal EEG asymmetry involves a unidimensional metric capturing large variations in motivation, emotion, and behavior. This metric is not only useful in understanding normative variation in motivation and emotion, but also abnormal variation, including mania and depression. Additionally, frontal asymmetry can be assessed as both a trait-like individual differences variable and as a measure of state-related variation to particular stimuli or experimental paradigms (Coan & Allen, 2004; Coan, Allen, & McKnight, 2006).

1.1 | Methodological and conceptual issues

Although frontal asymmetry has been linked to myriad psychological constructs and is now embedded within a widely

[1] Of historical note is that this meeting was rather quickly rearranged to be held in Madison, WI, rather than the original location in Florida. Florida was one of a handful of states that had not ratified the Equal Rights Amendment. In 1978, with 35 of the necessary 38 states having ratified the amendment, many organizations, including SPR, opted not to financially support the nonratifying states in order to pressure them to ratify this amendment designed to guarantee equal rights for all citizens regardless of sex. Despite widespread popular support, and a joint resolution of Congress that extended the ratification deadline, the amendment was never ratified by enough states before the extended deadline.

researched conceptual model, it is important to note that there remains considerable variability in signal processing and analysis approaches (Allen, Coan, & Nazarian, 2004; Smith, Reznik, Stewart, & Allen, 2017) that can lead to variability in the replicability of findings and pose challenges for interpreting findings. Arguably, the most important variation across studies concerns the scalp montage/reference. Among studies in the last decade and a half, the predominant reference montages have been averaged mastoids, the average reference (of all scalp sites), and, to a lesser extent, Cz (**Reznik & Allen, 2018**). Unfortunately, all of these montages suffer from the undesirable feature that alpha activity recorded at frontal sites will to a large extent reflect alpha power that is volume conducted from distal sources, especially occipital alpha (Smith et al., 2017). Transforming data using the surface Laplacian (i.e., current source density, CSD) can mitigate contamination of alpha at frontal sites from nonfrontal alpha sources that may be unrelated to motivational/emotional states and traits of interest (Allen & Reznik, 2015; Hagemann, Naumann, Thayer, & Bartussek, 2001; Smith et al., 2017; Stewart, Bismark, Towers, Coan, & Allen, 2010). By ensuring that metrics of frontal alpha in fact reflect predominantly frontal alpha, theoretical links to frontal brain systems can be better substantiated, and efforts for identifying the neural correlates of frontal EEG asymmetry may be facilitated (e.g., **Smith, Cavanagh, & Allen, 2018**).

Additional methodological considerations have been detailed by several authors (Allen, Coan et al., 2004; Coan et al., 2006; Davidson, Jackson, & Larson, 2000; Hagemann et al., 2001; Smith et al., 2017). These considerations comprise a large list of analysis-related and recording-related decisions that can influence the final metrics of frontal asymmetry, and influence the interpretation of relationships between frontal asymmetry and individual differences or experimental manipulations. Among these considerations are several particularly influential issues (Smith et al., 2017): (a) the choice of reference (or CSD transformation), (b) the selection of methods for handling artifacts, (c) using designs with resting state versus experimental challenges, and (d) specifying models explicitly for testing mediating and moderating relationships of frontal asymmetry with individual differences or experimental manipulations. In this issue, several articles include exemplary treatment of these issues including the use of the CSD transformation (**Rodrigues, Müller, Mühlberger, & Hewig, 2018; Smith, Cavanagh, & Allen, 2018**) and experimental state manipulations (**Meyer et al., 2018; Nelson, Kessel, Klein, & Shankman, 2018; Rodrigues et al., 2018; Schmid, Hackel, Jasperse, & Amodio, 2018; Wacker, 2018**).

Beyond methodological considerations, it is not clear what specific neural systems give rise to frontal EEG asymmetry. Frontal EEG asymmetry is assumed to reflect activity in underlying neural systems involved in the experience, expression, and regulation of emotion, yet evidence linking surface-recorded asymmetry to underlying neural systems remains elusive (Allen & Kline, 2004). For frontal EEG asymmetry as a measure to be most useful, it should integrate constructs at both the psychological/behavioral level as well as the neurophysiological level. One framework that may be helpful in guiding this research is the Positive Valence Systems domain of the Research Domain Criteria (RDoC) initiative developed by NIMH (Insel et al., 2010). The RDoC initiative proposes measures at multiple units of analysis (e.g., self-report, behavior, physiology, circuits) sensitive to variation in approach motivation, the construct most directly related to frontal asymmetry. Relatively unexplored, but potentially worth examining, is frontal EEG asymmetry's relationship to another RDoC construct within the Cognitive Systems domain: cognitive control, described by RDoC as a system that modulates the operation of other cognitive and emotional systems in the service of goal-directed behavior. Generating a "nomological network" of associations between frontal asymmetry and other indices of approach motivation (e.g., **Wacker, 2018**) or cognitive control (e.g., **Harmon-Jones & Gable, 2018; Schmid et al., 2018**) at multiple levels of analysis will enhance our understanding of both normative and nonnormative (e.g., anhedonia, mania) affective states.

An additional consideration related to linking frontal EEG asymmetry to neural systems concerns the temporal scale. Frontal EEG asymmetry on the one hand is viewed as a relatively stable trait measure (Allen, Urry, Hitt, & Coan, 2004; Hagemann, Naumann, Thayer, & Bartussek, 2002) while also being responsive to state manipulations (Coan & Allen, 2004; **Reznik & Allen, 2018**) and showing dynamic changes over the course of fractions of a second (Allen & Cohen, 2010). Thus, when searching for neural correlates of frontal asymmetry as a trait measure, methods such as fMRI functional connectivity (Allen et al., 2013) or positron emission thermography (PET) resting images might be most suitable. On the other hand, state-related frontal EEG asymmetry changes might be more suitably related to event-related or block fMRI designs (Gorka, Phan, & Shankman, 2015). Additionally, whereas examining frontal EEG asymmetry as a trait individual difference might allow for between-subjects correlations with other measures of neural imaging (thus not requiring simultaneous data acquisition), state-related and event-related changes in asymmetry would ideally be related within subjects to other neuroimaging measures, thus requiring simultaneous data acquisition (cf. Zotev et al., 2016).

Recent work has begun to identify neural correlates of frontal EEG asymmetry. For example, Gorka, Phan, and Shankman (2015) found that, during reward anticipation, increased left frontal activity was associated across subjects with increased activation in several regions including left anterior cingulate cortex, medial prefrontal cortex, and left

orbitofrontal cortex. This study is exemplary in many respects, and advances our understanding of neural structures involved in the mediation of approach- and withdrawal-related behaviors; however, such findings would be even more informative if a relationship could be demonstrated within subjects by examining simultaneously acquired fMRI and EEG data. A recent study (Zotev et al., 2016) did exactly this, using a neurofeedback paradigm: within subjects, changes in frontal EEG asymmetry were related to changes in several regions that may be important for emotional experience and emotion regulation including the amygdala, anterior cingulate cortex, insular cortex, and dorsolateral prefrontal cortex, among others. Frontal EEG asymmetry, by virtue of its rather coarse spatial resolution (especially with commonly-used reference montages), captures activity from a spatially distributed set of neural structures. As a result, the specific regions that are identified as related to frontal asymmetry may vary across studies depending on particular experimental manipulations or depending on which individual differences are examined. Future studies have much to explore in this regard, and can provide the important data to serve as the foundation for developing a comprehensive account of the neural systems that may give rise to frontal EEG asymmetry.

2 | IN THIS ISSUE

2.1 | Reviews

In this special issue, readers will find articles examining frontal EEG asymmetry from diverse perspectives. The issue begins with reviews by **Reznik and Allen (2018)** and by **Harmon-Jones and Gable (2018)** that discuss conceptual arguments and research on the role of frontal EEG asymmetry in emotional and motivational processes. In their review of EEG asymmetry research, Reznik and Allen focus on enhancing the conceptual understanding of frontal asymmetry in emotion and psychopathology, by outlining conceptual models that assess frontal EEG asymmetry as moderators, mediators, predictors, and outcomes. In their review, they categorize studies since the last major review (Coan & Allen, 2004) in terms of whether studies used asymmetry as predictor, outcome, moderator, or mediator, and they conclude with an enumeration of suggestions that researchers should consider for future studies using frontal EEG asymmetry.

Harmon-Jones and Gable (2018) focus on research that measured trait (baseline) frontal asymmetry and related it to other individual difference measures related to motivation, as well as research on state frontal asymmetry in response to situational manipulations of motivation and emotion. Harmon-Jones and Gable also summarize work illustrating that anger —an approach-oriented emotion despite its negative valence —is associated with elevated relative left-frontal activity, and that certain forms of positive affect are associated with low approach motivation. The authors argue that this work highlights the need to consider motivational direction as separate from affective valence in conceptual models of emotional space.

2.2 | Psychopathology

Several articles in this issue focus on psychopathology. These articles stand in contrast to a recent meta-analysis of 16 studies (van der Vinne, Vollebregt, van Putten, & Arns, 2017) that issued a cautionary note about the utility of frontal alpha asymmetry for differentiating those with depression from those without depression. Importantly, in the meta-analysis, the authors did not comprehensively examine moderating factors and ignored the clear advantage of the CSD reference for identifying those with a history of major depression (cf. Stewart et al., 2010). The articles in this issue attend to issues relating to moderating factors and diagnostic heterogeneity, and in so doing find clear relationships between frontal EEG asymmetry and psychopathology.

The first article in this section, by **Nelson and colleagues (2018)**, provides support for an association between frontal alpha asymmetry and depression. In consideration of the fact that depression is heterogeneous, Nelson et al. assessed various symptom dimensions of depression and obtained alpha asymmetry during a computerized slot machine task. The symptom dimensions of dysphoria and lassitude were associated with decreased relative left-frontal activity during the anticipation of reward. This highlights the importance of considering that depression is heterogeneous and that examining alpha asymmetry during state challenges can increase the strength of association with relevant criterion variables (Coan et al., 2006). Nelson et al. found that depressive symptoms characterized by motivational disengagement appear to be particularly associated with decreased left-frontal activity.

Related, **Nusslock et al. (2018)** report that only individuals with a history of childhood onset depression and no comorbid anxiety disorder show reduced left-frontal activity compared to psychiatrically healthy controls. In contrast, women with a history of depression and pathological levels of anxious apprehension—as indexed by a current generalized anxiety disorder, obsessive-compulsive disorder, or separation anxiety disorder—were statistically indistinguishable from controls. These findings by Nusslock and colleagues suggest that anxious-apprehension may mask the relationship between frontal EEG asymmetry and depression. Thus, studies that, either by design or chance, have a high percentage of depressed individuals with co-occurring anxious apprehension are likely to observe a weaker (or no) relationship between relative left frontal activity and depression. This potential moderating role of anxious apprehension may help explain some of the inconsistencies in the literature on the

relationship between frontal EEG asymmetry and depression, and suggests that comorbid anxious apprehension should be taken into consideration in future research.

Meyer and colleagues (2018) investigated whether frontal EEG asymmetry can be linked to posttraumatic stress disorder (PTSD) symptoms in trauma victims. The authors showed that frontal asymmetry in response to emotional provocation (negative and trauma-related pictures), but not at rest, may serve as a marker of PTSD symptoms and found that frontal asymmetry in response to provocation is specifically associated with the intensity of reexperiencing symptoms. Thus, the study by Meyer et al. aligns with the emerging consensus in the literature suggesting that state-dependent frontal asymmetry is particularly informative about individual differences in psychopathology (see also the article by Nelson et al. in this issue).

Recent work has also examined the relation between alpha asymmetry and approach-related traits in individuals characterized by potentially excessive approach motivation. In this issue, **Keune, Mayer, Jusyte, and Schönenberg (2018)** report the results of a small study that examined the relationship between alpha asymmetry, callous-unemotional traits, and aggression in imprisoned violent offenders. Trait callousness was related to a withdrawal-related asymmetry pattern while a link between frontal alpha asymmetry and aggression was not replicated, implicating callous unemotional traits as an important moderator of the relationship between frontal alpha asymmetry and aggression. Even though callousness has been shown to be associated with aggressive behavior, the trait itself might be related to a withdrawal-related pattern due to the interpersonal detachment it implies. The results also suggest that it is required to implement specific clinical diagnostic procedures when examining prisoners, as heterogeneous psychopathology could affect the relation between alpha asymmetry and behavioral traits of interest.

2.3 | Neural systems and methodological aspects

Smith et al. (2018) related surface asymmetry to intracranial asymmetry modeled using a distributed inverse solution. In a large data set of individuals with current depression, previous (but not current depression), and no history of depression, they examined (a) asymmetry in intracranial regions of interest (ROIs) that were related to surface frontal EEG alpha asymmetry, (b) intracranial ROIs that were related to any history of depression, and (c) regions where these ROIs overlapped. A generator in lateral midfrontal regions was related to both surface asymmetry and depression risk, whereby participants with any lifetime history of depressive episodes had less left than right activity in the precentral midfrontal gyri.

Schmid and colleagues (2018) report findings from a study aimed at elucidating the role of frontal EEG asymmetry in reinforcement learning. Participants completed a probabilistic selection task in which they learned to select some targets and avoid others through correct/incorrect feedback while both EEG and ERPs were collected. Results revealed that greater right-lateralized frontal cortical activity during learning was associated with better avoidance learning, and that relatively greater left-frontal activity may relate to reinforcement feedback processing, as measured by the feedback-related negativity ERP component. Their results offer preliminary evidence regarding the role of frontal cortical activity in reinforcement learning and reflect a novel integration of frontal EEG asymmetry and reward-related ERP research.

In a novel paradigm, **Rodrigues et al. (2018)** examined the differential involvement of frontal EEG asymmetry and bilateral frontal activation in motivational tendencies versus actual behavior using a virtual reality maze. The authors found greater relative left-frontal brain activation during approach behavior and more relative right brain activation for withdrawal behavior of any kind. Moreover, more bilateral frontal brain activation was observed when participants were engaged in behavior compared to taking no action. The results by Rodrigues and colleagues highlight the importance of dissociating motivational tendencies that are associated with frontal asymmetry from actual motivated behavior.

An article by **Wacker (2018)** examined the role of positive emotions, extraversion, and dopamine on cognitive stability-flexibility and frontal EEG asymmetry. An experimental paradigm (AX continuous performance task) was used to assess cognitive stability-flexibility, and an emotion induction (personal imagery and emotional film clips) was used to elicit two forms of positive emotions—wanting/expectancy and warmth/liking. Only the former elicited approach motivation. Frontal EEG asymmetry was assessed as an indicator of approach motivation, with relatively higher left frontal alpha activity assumed here as an indicator of wanting/expectancy. Crucially, dopamine activity, which has also been related to approach motivation and cognitive stability-flexibility, was also manipulated using a D2 receptor blocker. The findings implicate dopaminergic activity as a factor that influences frontal alpha asymmetry, underlies trait extraversion, and affects the modulating role of positive emotion on cognitive stability-flexibility.

2.4 | Perspectives and future directions

The article by **Gable, Neal, and Threadgill (2018)** reviews evidence relating the hypothetical construct of a supervisory control system (revised behavioral inhibition system) to asymmetric activity in the frontal cortex. This attempt extends beyond associating frontal asymmetry to approach and avoidance motivations to better understand how frontal asymmetry

may relate to cognitive (or inhibitory) control. A broad base of evidence is reviewed, and the weight of that evidence lends support to the idea that the right frontal cortex is crucially involved in a regulatory control system that supervises the motivational systems of approach and avoidance.

A compelling new perspective is provided by **Hewig (2018)**, whereby the idea is developed that intentionality may represent a useful notion for research on frontal alpha asymmetry. According to this perspective, much of the prior research may be viewed as examining the volitional phase of action, and thus may reflect the strength of an intention. This concept in turn may be useful to understand phenomena related to frontal alpha asymmetry, such as depression or other psychopathology that suffer from relatively weak or absent volitions. In addition to providing a novel unifying perspective on the asymmetry literature, this article highlights the importance of carefully delineating the phases of action (ranging from intention formation to action execution and postexecution evaluation) in studies linking behavior and motivational tendencies to frontal EEG asymmetry.

3 | CONCLUDING THOUGHTS

Frontal EEG alpha asymmetry has enjoyed considerable popularity as a measure of individual differences as well as normative responses, one that links motivation, emotion, and psychopathology. Frontal EEG asymmetry can serve as both a mediator and a moderator of emotional responses and risk for psychopathology, and has contributed to the development of a theoretical framework of motivational processes that has been applied to a wide variety of research domains. The articles in this special issue highlight the value and the promise of frontal EEG asymmetry for future research.

Looking ahead, future studies should explicitly specify models of mediation and moderation (**Reznik & Allen, 2018**) to clarify the specific role that frontal asymmetry plays in relation to emotion and psychopathology. Future work should also build on a small number of recent studies that link frontal EEG asymmetry to activity in underlying neural systems (**Smith et al., 2018**). Finally, the relationship of frontal asymmetry to psychopathology will be facilitated by moving beyond viewing diagnostic entities as homogeneous constructs. Future studies should examine frontal alpha asymmetry's relationship to specific symptoms (**Nelson et al., 2018**), to clusters of features (**Keune et al., 2018; Nusslock et al., 2018**), or to transdiagnostic dimensions reflecting fundamental processes (**Nelson et al., 2018**) that may underlie a variety of psychopathology (Insel et al., 2010; Patrick & Hajcak, 2016).

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