Event-Related Potential Activity in the Basal Ganglia Differentiates Rewards From Nonrewards: Temporospatial Principal Components Analysis and Source Localization of the Feedback Negativity: Commentary

Michael X Cohen,[1,2]* James F. Cavanagh,[3] and Heleen A. Slagter[1]

[1]*Department of Psychology, Universiteit van Amsterdam, Amsterdam, the Netherlands*
[2]*Department of Physiology, University of Arizona, Amsterdam, the Netherlands*
[3]*Department of Cognitive, Linguistic and Psychological Sciences, Brown University, Providence, RI*

Abstract: Foti et al. propose that a reward-related brain potential component recorded from scalp EEG is generated by deep brain basal ganglia structures. Previous work, cited in their original article, provides only speculative and theoretical support for this interpretation. Based on empirical and anatomical evidence, we argue that this scalp-recorded ERP component is highly unlikely to be generated by the basal ganglia. *Hum Brain Mapp 00:000–000, 2011.*

Key words: EEG; source localization; dipole; basal ganglia; putamen

INTRODUCTION

Advances in scalp electrode technology and data analytic approaches have improved the spatial resolution of EEG considerably. However, imaging subcortical structures remains difficult, in large part due to fundamental issues that cannot be overcome with current EEG technology or analyses. In a recent report by Foti et al. (2011), a dipole source localized to the putamen was interpreted as evidence of a basal ganglia generator of scalp-recorded reward-related EEG activity. For several anatomical and analytical reasons, we disagree with this interpretation.

*Correspondence to: Michael X Cohen, Department of Psychology, Universiteit van Amsterdam, Netherland.
E-mail: mikexcohen@gmail.com

Received for publication 25 March 2011; Revised 22 April 2011; Accepted 25 April 2011
DOI: 10.1002/hbm.21358
Published online in Wiley Online Library (wileyonlinelibrary.com).

Anatomical Considerations

1. The striatum comprises mainly medial spiny neurons and inhibitory interneurons. These neurons do not have a geometrically parallel organization like cortical pyramidal cells; it is therefore unlikely that dendritic potentials from the striatum could propagate to the scalp. Indeed, empirical measures of synchrony between the human ventral striatum and surface EEG is at best ~0.2 (on a scale from 0 to 1) (Cohen et al., 2009). More importantly, maximal correlation is temporally lagged such that ventral striatal and scalp-recorded EEG signals do not occur simultaneously.
2. Large-potential surface topographical maps (Foti et al. Fig. 2b) likely include cortical generators because dipole source contribution attenuates as a function of distance to the scalp (Scherg, 1990). For example, brainstem-evoked potentials require thousands of trials for averaging (e.g., 8000 in Stone et al., 2009) and result in small amplitude potentials. Foti et al. used 20 trials, which may have provided insufficient signal-to-noise for deep sources.

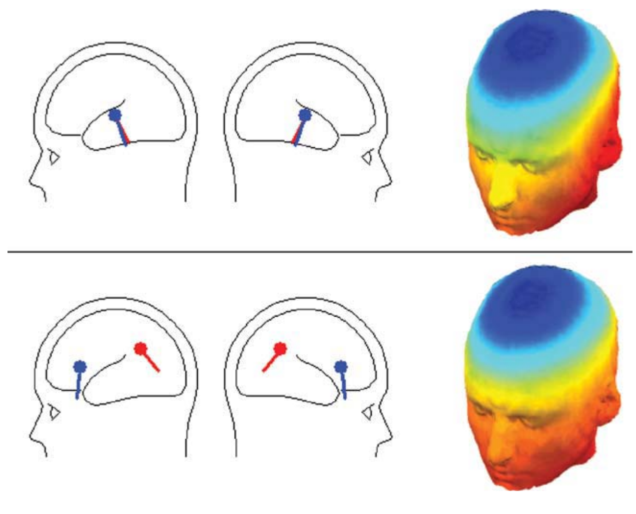

Figure 1.
Forward models (created with the BESA dipole simulator; megis.com/udbesa.htm) of a symmetrical dipole pair in the basal ganglia (top) and of dipoles in the rostral anterior and posterior cingulate (bottom) produce nearly identical scalp topographies, despite the very different brain sources. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

3. Previous studies using dipoles and combined EEG-fMRI estimate the origin of the medial frontal feedback-related negativity to the anterior and posterior cingulate (among others: Luu, et al., 2003; Nieuwenhuis et al., 2005). Although fMRI studies show reward-related activity in the striatum, a hemodynamic response does not necessitate an electrical response that can be measured with scalp EEG.

Dipole Methodological Limitations

4. Given the inverse problem (no unique source of topographical activity), it is important to test whether adding dipoles decreases residual variance or changes the location of the original dipoles, and whether dipole models with different starting locations converge on the same location/orientation (Scherg, 1990). Because alternative models were not shown, it is difficult to assess whether the putamen source was superior to alternative models.
5. Relatedly, very different dipole models produce nearly identical topographical maps. The broad scalp topography in Foti et al. could result from cortical generators such as the anterior and posterior cingulate (Fig. 1). Spatiotemporal transforms such as PCA do not eradicate this issue if brain sources are highly correlated.

The authors acknowledge the difficulties of detecting a subcortical generator of scalp-recorded EEG, and explicitly discuss the possibility of an alternative neural generator in the anterior cingulate. Yet they nonetheless draw the firm conclusion in the title, abstract, and discussion, that the medial frontal positivity was generated by the putamen.

The investigation of the cortical electrophysiological dynamics of reward is important for a better understanding of motivation and learning in healthy and diseased brains. Many aspects of Foti et al. contribute to this literature (e.g., using principle components analysis to disentangle overlapping ERP components). However, a medial frontal scalp negativity resulting from a dipole in the putamen is highly unlikely.

REFERENCES

Cohen MX, Axmacher N, Lenartz D, Elger CE, Sturm V, Schlaepfer TE (2009): Neuroelectric signatures of reward learning and decision-making in the human nucleus accumbens. Neuropsychopharmacology 34:1649–1658.

Foti D, Weinberg A, Dien J, Hajcak G (2011): Event-related potential activity in the basal ganglia differentiates rewards from nonrewards: Temporospatial principal components analysis and source localization of the feedback negativity. Hum Brain Mapp. Epub ahead of print.

Luu P, Tucker DM, Derryberry D, Reed M, Poulsen C (2003): Electrophysiological responses to errors and feedback in the process of action regulation. Psychol Sci 14:47–53.

Nieuwenhuis S, Slagter HA, von Geusau NJ, Heslenfeld DJ, Holroyd CB (2005): Knowing good from bad: Differential activation of human cortical areas by positive and negative outcomes. Eur J Neurosci 21:3161–68.

Scherg M. 1990. Fundamentals of dipole source analysis. In: Grandori F, Hoke M, Romani GL, editors. Auditory evoked magnetic fields and electric potentials. Advances in Audiology. Basel: Karger. pp 40–69.

Stone JL, Calderon-Arnulphi M, Watson KS, Patel K, Mander NS, Suss N, Fino J, Hughes JR (2009): Brainstem auditory evoked potentials--A review and modified studies in healthy subjects. J Clin Neurophysiol 26:167–175.