SCIENTIFIC
REPORT
Global Science Organisation, Ipsos

Scientific POV on EEG in Consumer Neuroscience

Vinod Venkatraman, Ph.D.
Associate Professor, Fox School of Business, Temple University
Ipsos Fellow, Global Science Organization, Ipsos

GAME CHANGERS

Electroencephalography (EEG) is a method for recording electrical activity in the brain by placing several electrodes along the scalp, often in the form of a cap [1]. It provides a reliable measure of neural activity along the surface of the brain, with high temporal resolution. It is also the most commonly used neuroscience method in advertising research and in the marketing industry due to its lower cost (relative to fMRI for measuring neural activations), lower complexity, and noninvasiveness [2].

EEG SIGNAL AND RELATIONSHIP TO BRAIN ACTIVITY

Neurons in the brain communicate via electrical impulses (called action potentials) which are transmitted through axons. Each neuron can produce multiple action potentials in sequence resulting in rhythmic oscillations, which in turn form the basis of information transfer in the brain. Critically, an ensemble of neurons can also produce oscillations when the firing patterns of several neurons get synchronized (action potentials produced by the individual neurons add up). This synchronized activity feeds into other cortical areas, resulting in larger-amplitude oscillations or local field potentials. Using a series of electrodes (typically ranging from 64 to 256 to obtain reliable whole-brain coverage; lesser if one is focused only a subset of measures) located on the scalp, EEG can then measure these oscillations or brain waves as they are commonly referred to. Therefore, EEG activity refers to summation of response from the synchronized activity of a group of neurons that all have similar spatial orientation – electric potentials from a single neuron are too small to be picked up on the scalp. In general, oscillations are characterized by their amplitude, frequency, phase, origin and location on the scalp and EEG can reveal oscillatory activity in several different frequency bands as discussed below. Since voltage fields fall off with the square of distance, EEG provides less reliable measures from subcortical and deep brain structures, relative to higher-level cortical areas. In other words, the EEG recordings are precise in their timing, but it’s difficult to extract their exact origin deeper within the brain.

SPECTRUM ANALYSES OF EEG DATA

The conventional and popular method of analysis of EEG data is a spectrum analysis, based on information contained in the frequency domain of the EEG waveform. These analyses are particularly popular in experimental designs that are more common to consumer research and marketing given the use of more dynamic and continuous stimuli (e.g., TV ads, video content, customer journey) [3]. The focus of the spectrum analyses is to decompose the EEG signal into its different component frequency bands using a Fourier Transform and statistical analyses and estimate the global field power (GFP) within each of the bands. The common frequency bands include delta (1-3.5 Hz), theta (4-7.5 Hz), alpha (8-12 Hz), beta (13-25 Hz), and gamma (26-40 Hz) bands. The various frequency brands are linked to different cognitive states like awareness and consciousness. For e.g., the various stages of sleep are often characterized by the spectral content, ranging from beta waves in alert wakefulness to delta in deep sleep.

The low-frequency (<1 Hz) delta rhythms are commonly generated in sleep directly in the cortex and reflects the cortical reorganization of waking circuits [4]. Besides cortical sources, generation of delta oscillations have also been related to spontaneous activity of the ventral tagmental area and nucleus accumbens, areas implicated in the brain reward system. These oscillations result in synchronized input to other cortical regions, which in turn shape behavior and action. Therefore, delta oscillations play a critical role in motivation, rewards and salience detection [5]. Similarly, there also exist multiple theta generators in the human brain, which facilitate the integration of the limbic system activity with activity of the brainstem, the hypothalamus, and the neocortex [6]. Theta oscillations have been found to correlate with a great variety of behavioral, cognitive and emotional variables but their main contribution seems to be related to memory and emotion regulation.

The earliest and best-known band is the alpha band (8-12 Hz) which is associated with relaxed wakefulness and can be detected in the occipital lobe [7]. The alpha spectrum is therefore commonly associated with cognitive processes like attention and memory, particularly within the occipital regions. Critically, these signals are inhibitory in nature and facilitate selective attention by actively suppressing distracting stimuli. On the other hand, frontal alpha is often associated with motivation and emotions. One particularly popular measure in decision making and market research is the Frontal Alpha Asymmetry (FAA), which refers to difference between frontal alpha activity in the left and right hemispheres. According to Davidson’s influential approach-withdrawal motivational model of emotion, the left- and right-anterior brain regions are part of two separate neural systems underlying approach and withdrawal motivation, respectively [8]. Extending this framework, approach related emotions (e.g., joy and anger) have been found to be associated with relatively greater left frontal activation, whereas withdrawal-related emotions (e.g., disgust and fear) are associated with relatively greater right frontal activation [9-12]. While these findings may be true for carefully controlled stimuli, the generalizability of FAA as a general and reliable measure of emotion with more dynamic stimuli remains to be validated. Additionally, it is also important to highlight that FAA is a measure of approach and avoidance, and not a direct measure of emotional valence (e.g., joy and anger are both approach emotions, but of different valence).

The gamma rhythm, consisting of a relatively high frequency variations, is modulated both by sensory input as well as higher-level processes such as working memory and attention. As a result, gamma has been observed in a number of cortical as well as subcortical structures. In higher cortex, gamma power is elevated during working memory [13] and learning [14]. Traditionally, researchers have related gamma-band activity to states of enhanced arousal and focused attention [15] and have also suggested activity in this region as a measure of engagement (see section below on EEG in Consumer Neuroscience). Similarly, previous research has linked medial frontal beta activity to reward processing including reward anticipation, rewards delivery, rewards evaluation and choice [16]. Specifically, high-frequency oscillation (beta and gamma bands) are thought of being well suited to synchronize the different components of the reward network and dynamic decision making, as they allow for the communication and integration of information across distant brain areas [17].

OTHER EEG ANALYTIC APPROACHES

Event related potential (ERP) represents averaged time-related changes in the voltage level in response to a stimulus. The temporal resolution of these measurements is on the order of tens of milliseconds, allowing ERPs to detect rapid processing changes that take place in the human brain. However, to extract reliable signals, ERPs often require time-locked averaging across multiple repetitions of the same stimulus, making it ideal for experimental research but not so effective for applied consumer neuroscience. ERPs provide information about a broad range of cognitive and affective processes [18,19] and are defined by topography, latency and amplitude. While time-averaging can be performed at any of the electrodes, certain ERP components are more popular in the literature. These include:

- A generic error processing component called error related negativity (ERN) or feedback-related negativity (FRN) which is a negative deflection in the averaged EEG time-series signal that occurs within 100ms of a response error or feedback [20].
- N1 (a negative deflection within the first 100ms of stimulus presentation), which reflects early attention selection and bottom-up sensory processing [21].
- P300 (a positive deflection in the scalp potential starting 300ms after stimulus presentation, see [22]) increases with greater top-down attention as well as with the motivational relevance of the task or the salience of the target stimulus [23, 24].
- N200 (a negative deflection in the scalp potential starting 200ms after stimulus presentation; see [25]), which has been associated with attentional shifts, inhibition of motor responses, conflict monitoring, maintenance of contextual information and detection of mismatch depending on the regions over which it is measured [26].

Another hybrid ERP-based methodology is “steady state topography” (SST), which was developed by Silberstein and colleagues [27]. This unique method involves the use of an additional dim ongoing oscillating visual stimulus that is presented in the peripheral visual field throughout the task, eliciting a small brain rhythmic sinusoidal response at the same frequency, termed the “steady-state visually evoked potential” (SSVEP). Changes in the phase of the extracted frequency represents variations in the latency between the SSVEP signal and the task itself. A latency reduction is considered as an increase in synaptic excitation, or simply “SST activity”, and vice versa. This technique, and its ability to measure differences in speed of processing in different regions of the brain, forms the basis of services offered by the neuromarketing firm Neuro-Insight, founded by Richard Silberstein.

EMERGING AREA IN EEG ANALYSIS – INTER-SUBJECT CORRELATION

EEG Inter-subject correlation (ISC, or synchronization, or coherence) is an EEG measurement that is particularly suitable for studies that involve continuous stimuli. Rather than averaging the responses across participants, ISC looks for the synchronization of responses across participants. If majority of the participants are responding similarly to a particular stimulus, it provides an index of engagement. (Note that this is not referring to the social influence of one participant on another, but the commonalities in the response towards an external stimulus at each of the different frequencies). In the original fMRI study where participants were freely viewing 30 min of a popular movie, the authors found high synchronization between subjects in primary, secondary and association areas in the visual and auditory systems. Specifically, they found that subjects’ activity patterns tended to synchronize more during emotionally engaging scenes [28,29]

Extending this idea to EEG, Dmochowski and colleagues measured activity evoked by multiple presentations of short film clips across participants to locate events with high correlation across subjects. They found strong correspondence between arousing moments within the film and the occurrence of peak correlations of neural activity. These correlations reduce when the scenes are scrambled or when the film is viewed a second time [30]. Lastly, Barnett and Cerf demonstrate that use cross-brain correlations to measure the degree of similarity in how people perceive different movie trailers, and demonstrate that this similarity predicts important marketing outcomes [31]. While we return to the commercial implications of these findings in the next section, these findings provide converging evidence that synchrony or inter-subject correlation can become a reliable index of engagement, defined as the ability of a stimulus to capture and maintain attention consistency across a group of individuals.

EEG IN CONSUMER NEUROSCIENCE

Most of the research in consumer neuroscience is based primarily on the frontal alpha asymmetry. For example, Ohme and colleagues showed that there are significant differences in frontal alpha asymmetry between two versions of a commercial with one altered scene [32]. Critically, while asymmetry is most commonly found in the alpha frequency band, it has been shown that asymmetry in the theta and gamma bands are related to retention between commercials, an element affecting preferences. Vecchiato and colleagues found that cortical activity elicited during the observation of TV commercials that were remembered was higher and localized in the left frontal brain areas when compared to the activity elicited during the presentation of the TV commercials that were later forgotten [33, 34]. In a later study, the group found an asymmetrical increase of theta and alpha activity in the left (right) hemisphere related to the observation of pleasant (unpleasant) video advertisements [35].

In the study by Dmochowski and colleagues discussed earlier [30], inter-subject correlation from a group of naive individuals in response to previously-broadcast television content predicted population level audience response, characterized by social media activity and audience ratings. Critically, the predictions were stronger for larger population-level audience than individuals from whom the neural data is obtained. Boksem and colleagues measured EEG oscillations as participants watched 18 movie trailers and predicted box office returns [16]. They found that medial frontal beta (16-18 Hz) correlated with preference ranking with participants and improved prediction beyond simply asking participants to state their willingness-to-purchase (WTP). However, though preference did not predict box office sales, activity in the medial frontal gamma did. In a more recent study, Barnett and Cerf used portable EEG to record brain activity of 58 moviegoers in a commercial theater and show that cross-brain correlation in alpha band across the whole brain predicts future free recall of the movie trailers and population-level sales of the corresponding movies [31].

Two other independent studies focused on predicting population-level behavior from neural data. In one study, participants were exposed to 8 Super Bowl commercials. While activity in the theta, beta and gamma bands all predicted ad liking, only activity in the theta band predicted ad recall and number of Youtube views for that ad [36]. Lastly, Christoforou and colleagues also sought to relate EEG activity from movie trailers to box office sales [17]. They estimated a cognitive-congruency metric (based on inter-subject coherence) for each of the frequency bands and used it to predict sales. They found that cognitive-congruency metric in the alpha band predicted about 70% of the variance in box office sales during the premiere weekend.

In summary, a series of studies show the ability of EEG metrics in predicting market performance, above and beyond traditional measures. Yet, the exact signals vary across studies (i.e. alpha in [31], gamma in [16] and [17], theta in [36]). This may be partly related to variability in analyses, the nature of stimuli and subject samples, and the actual metrics used to represent market performance. While additional research in still necessary, a meta-analysis by a group of researchers seems to suggest that activity in the gamma band may be the strongest candidate for predicting sales, while controlling for other variables [37].

EEG MEASUREMENTS AT IPSOS HOUSE

The experimental lab at Ipsos France is equipped with a state-of-the-art 32 channel Biosemi EEG system. Relative to 64 channels, the 32 channel system provides reasonable whole-brain coverage for questions in market research while optimizing set up time and complexity. This system was used to collect the multi-channel dataset with ground-truth stimuli and gambles. Preliminary analyses indicate that frontal alpha asymmetry (FAA) can reliably dissociate valence (gain vs. loss) in the gambling stimuli. While comprehensive analyses of this dataset is ongoing, the objectives include the evaluation of FAA as a reliable measure of emotional valence and arousal, the development of metrics for measuring attention and identification of EEG components that may be related to successful memory encoding and retrieval, and the evaluation of measures of synchrony in EEG responses as discussed above.

The Ipsos House in Mexico is equipped to collect EEG data as part of broader neuro physiological measurements including heart rate, facial affective response, GSR, and eye tracking. To implement this capability in a relatively scalable manner, Ipsos House uses the iMotions software as it provides an integrated platform to simultaneously record and synchronize different streams of data. The B-Alert x10 from ABM was selected as an EEG system for Ipsos House given its compatibility with the iMotions platform. It is a wireless EEG headset with 9 active electrodes. The Ipsos House is equipped with hardware and software to collect and analyze EEG (and others) responses while participants are exposed to stimuli such as images and videos.

The ABM headset and analytic model provides additional KPIs which include engagement (measure of attention and information processing) and workload (related to executive processes like working memory and problem solving). Additionally, the iMotions provides a measure of frontal alpha asymmetry as well as power spectral density (PSD) plots for each of the different frequency bands (alpha, beta, gamma, theta and delta). Based on the analyses with the ground-truth dataset, Ipsos can extend the EEG capabilities through the extension of analyses with these PSD outputs.

SUMMARY

EEG is a popular and valuable methodology in the Consumer Neuroscience toolkit for obtaining insights into decision-making process and strategies. As outlined above, when used appropriately, EEG can be used to measure various aspects of processing ranging from attention to memory and emotional valence. In the context of the broader Dynamic Decision Making Model (DDMM) at Ipsos [38], EEG is particularly critical for measuring aspects of adaptive processing (e.g., conflict detection, executive processing and cognitive load). Analysis and models built from the ground-truth dataset analysis [39] will provide independent validations for the KPIs currently used at Ipsos House, and opportunities to extend them for service lines through the development of additional KPIs.

REFERENCES

1. Haas, L. F. (2003). Hans Berger (1873–1941), Richard Caton (1842–1926), and Electroencephalography. *Journal of Neurology, Neurosurgery & Psychiatry*, *74*(1), 9-9.
2. Hakim, A., & Levy, D. J. (2019). A gateway to consumers' minds: Achievements, caveats, and prospects of electroencephalography-based prediction in neuromarketing. *Wiley Interdisciplinary Reviews: Cognitive Science*, *10*(2), e1485.
3. Luck, S. J. (2014). *An introduction to the event-related potential technique*. MIT press.
4. Steriade, M., Nunez, A., & Amzica, F. (1993). A novel slow (< 1 Hz) oscillation of neocortical neurons in vivo: depolarizing and hyperpolarizing components. *Journal of neuroscience*, *13*(8), 3252-3265.
5. Gray, J. A. (1999). Cognition, emotion, conscious experience and the brain.
6. Kirk, I. J., & Mackay, J. C. (2003). The role of theta-range oscillations in synchronising and integrating activity in distributed mnemonic networks. *Cortex*, *39*(4-5), 993-1008.
7. Berger, H. (1929). Über das elektroenkephalogramm des menschen. *Archiv für psychiatrie und nervenkrankheiten*, *87*(1), 527-570.
8. Davidson, R. J. (1998). Anterior electrophysiological asymmetries, emotion, and depression: Conceptual and methodological conundrums. *Psychophysiology*, *35*(5), 607-614.
9. Coan, J. A., & Allen, J. J. (2004). Frontal EEG asymmetry as a moderator and mediator of emotion. *Biological psychology*, *67*(1-2), 7-50.
10. Ekman, P., & Davidson, R. J. (1993). Voluntary smiling changes regional brain activity. *Psychological Science*, *4*(5), 342-345.
11. Davidson, R. J., Ekman, P., Saron, C. D., Senulis, J. A., & Friesen, W. V. (1990). Approach-withdrawal and cerebral asymmetry: emotional expression and brain physiology: I. *Journal of personality and social psychology*, *58*(2), 330.
12. Harmon-Jones, E., Gable, P. A., & Peterson, C. K. (2010). The role of asymmetric frontal cortical activity in emotion-related phenomena: A review and update. *Biological psychology*, *84*(3), 451-462.
13. Pesaran, B., Pezaris, J. S., Sahani, M., Mitra, P. P., & Andersen, R. A. (2002). Temporal structure in neuronal activity during working memory in macaque parietal cortex. *Nature neuroscience*, *5*(8), 805-811.

14. Bauer, E. P., Paz, R., & Paré, D. (2007). Gamma oscillations coordinate amygdalo-rhinal interactions during learning. *Journal of Neuroscience*, *27*(35), 9369-9379.

15. Engel, A. K., Fries, P., & Singer, W. (2001). Dynamic predictions: oscillations and synchrony in top–down processing. *Nature Reviews Neuroscience*, *2*(10), 704-716.

16. Boksem, M. A., & Smidts, A. (2015). Brain responses to movie trailers predict individual preferences for movies and their population-wide commercial success. *Journal of Marketing Research*, *52*(4), 482-492.

17. Christoforou, C., Papadopoulos, T. C., Constantinidou, F., & Theodorou, M. (2017). Your brain on the movies: a computational approach for predicting box-office performance from viewer's brain responses to movie trailers. *Frontiers in neuroinformatics*, *11*, 72.

18. Luck, S. J., & Kappenman, E. S. (Eds.). (2011). *The Oxford handbook of event-related potential components*. Oxford university press.

19. Nunez, P. L., & Srinivasan, R. (2006). *Electric fields of the brain: the neurophysics of EEG*. Oxford University Press, USA.

20. Holroyd, C. B., & Coles, M. G. H. (2002). The neural basis of human error processing: Reinforcement learning, dopamine, and the error-related negativity. Psychological Review, 109(4), 679–709.

21. Hillyard, S. A., Hink, R. F., Schwent, V. L., & Picton, T. W. (1973). Electrical signs of selective attention in the human brain. *Science*, *182*(4108), 177-180.

22. Polich, J. (2007). Updating P300: an integrative theory of P3a and P3b. *Clinical neurophysiology*, *118*(10), 2128-2148.

23. Carretié, L., Martín-Loeches, M., Hinojosa, J. A., & Mercado, F. (2001). Emotion and attention interaction studied through event-related potentials. *Journal of cognitive neuroscience*, *13*(8), 1109-1128.

24. Cuthbert, B. N., Schupp, H. T., Bradley, M. M., Birbaumer, N., & Lang, P. J. (2000). Brain potentials in affective picture processing: covariation with autonomic arousal and affective report. *Biological psychology*, *52*(2), 95-111.

25. Folstein, J. R., & Van Petten, C. (2008). Influence of cognitive control and mismatch on the N2 component of the ERP: a review. *Psychophysiology*, *45*(1), 152-170.

26. Bago B., Frey D., Vidal J., Houde O., Borst G., De Neys W. (2018). Fast and slow thinking: Electrophysiological evidence for early conflict sensitivity. *Neuropsychologia*, 117 , pp. 483-490.

27. Silberstein, R. B., & Pipingas, A. (1995). Steady-state visually evoked potential topography during the Wisconsin card sorting test. *Electroencephalography and Clinical Neurophysiology/Evoked Potentials Section*, *96*(1), 24-35.

28. Hasson, U., Nir, Y., Levy, I., Fuhrmann, G., & Malach, R. (2004). Intersubject synchronization of cortical activity during natural vision. *science*, *303*(5664), 1634-1640.

29. Hasson, U., Furman, O., Clark, D., Dudai, Y., & Davachi, L. (2008). Enhanced intersubject correlations during movie viewing correlate with successful episodic encoding. *Neuron*, *57*(3), 452-462.

30. Dmochowski, J. P., Bezdek, M. A., Abelson, B. P., Johnson, J. S., Schumacher, E. H., & Parra, L. C. (2014). Audience preferences are predicted by temporal reliability of neural processing. *Nature communications*, *5*(1), 1-9.

31. Barnett, S. B., & Cerf, M. (2017). A ticket for your thoughts: Method for predicting content recall and sales using neural similarity of moviegoers. *Journal of Consumer Research*, *44*(1), 160-181.

32. Ohme, R., Reykowska, D., Wiener, D., & Choromanska, A. (2010). Application of frontal EEG asymmetry to advertising research. *Journal of economic psychology*, *31*(5), 785-793.

33. Vecchiato, G., Astolfi, L., Cincotti, F., Fallani, F. D. V., Sorrentino, D. M., Mattia, D., ... & Babiloni, F. (2010, June). Patterns of cortical activity during the observation of Public Service Announcements and commercial advertisings. In *Nonlinear biomedical physics* (Vol. 4, No. S1, p. S3). BioMed Central.

34. Vecchiato, G., Astolfi, L., Fallani, F. D. V., Cincotti, F., Mattia, D., Salinari, S., ... & Babiloni, F. (2010). Changes in brain activity during the observation of TV commercials by using EEG, GSR and HR measurements. *Brain topography*, *23*(2), 165-179.

35. Vecchiato, G., Toppi, J., Astolfi, L., Fallani, F. D. V., Cincotti, F., Mattia, D., ... & Babiloni, F. (2011). Spectral EEG frontal asymmetries correlate with the experienced pleasantness of TV commercial advertisements. *Medical & biological engineering & computing*, *49*(5), 579-583.

36. Guixeres, J., Bigné, E., Ausín Azofra, J. M., Alcañiz Raya, M., Colomer Granero, A., Fuentes Hurtado, F., & Naranjo Ornedo, V. (2017). Consumer neuroscience-based metrics predict recall, liking and viewing rates in online advertising. *Frontiers in psychology*, *8*, 1808.

37. Smidts et al., Personal communication.

38. Wittenbraker, J. and Venkatraman, V. (2019). Ipsos Dynamic Decision Making Model, *Scientific Report, Global Science Organization*, Ipsos.

39. Baldo, D., Venkatraman, V., & Timpone, R. (2020). Building an Ipsos Emotion Ground Truth Database, *Scientific Report, Global Science Organization*, Ipsos.

Scientific POV on EEG in Consumer Neuroscience