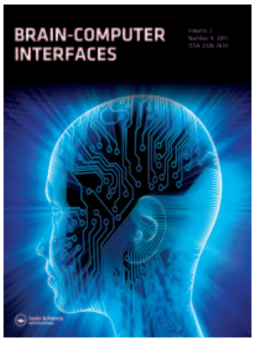

Brain-Computer Interfaces

ISSN: 2326-263X (Print) 2326-2621 (Online) Journal homepage: http://www.tandfonline.com/loi/tbci20

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Brain-Computer Interfaces, 2015
Vol. 2, No. 4, 186–192, http://dx.doi.org/10.1080/2326263X.2015.1099091

EEG-based neurocinematics: challenges and prospects

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(*Received 31 March 2015; accepted 19 September 2015*)

Neurocinematics is an emerging research discipline that studies audiences' cognitive and affective responses to cinematic stimuli. To date, functional magnetic resonance imaging (fMRI) has been the most widely used research tool for neurocinematics studies; however, recent studies have shown that electroencephalography (EEG) can also be a promising tool for neurocinematics studies thanks to its excellent temporal resolution. In this article, after discussing challenges and prospects for EEG-based neurocinematics, we introduced two potential film-rating indices named 'empathy index' and 'reactivity index' as examples of EEG-based neurocinematic markers. Preliminary experiments showed that the new indices have the potential to be used as promising tools for film evaluation.

Keywords: neurocinematics; cognitive film theory; inter-subject correlation; affective computing; electroencephalography (EEG)

1. Introduction

Recent advances in neuroimaging technology allowed researchers to investigate the neural mechanisms underlying human emotion, leading to the popularization of affective neuroscience. Neurocinematics was introduced as a branch of affective neuroscience by Hasson et al., [1,2] aiming to provide novel filmmaking techniques by analyzing viewers' brain activities. In Hasson et al.'s studies,[1,2] the change in emotions during a film screening was observed utilizing functional magnetic resonance imaging (fMRI). They suggested a new approach called inter-subject correlation (ISC), which could measure how brains of different people are similarly activated. The newly suggested index, ISC, showed the possibility of being used as a new measure to evaluate films.

Although the fMRI-based neurocinematics studies provided a new way of evaluating films, several issues still need to be addressed for the practical application of neurocinematics. First, the experimental environments of the current fMRI-based neurocinematics studies are very different from the normal environment where viewers watch films in a theater. In the study by Hasson et al.,[2] study participants were lying on their backs in an MRI scanner feeling constrained and watched the film in an unnaturally small space, which might be inappropriate for eliciting natural emotions. Second, a viewer who is watching a film can have different feelings depending on who or how many people are with the viewer, but only one person can watch a film in the fMRI environment. Third, fMRI is relatively expensive compared to other neuroimaging modalities. In practice, testing a large number of subjects is generally required to evaluate the reliability of experiments. Lastly, fMRI is limited by its low temporal resolution, which could make it difficult to synchronize a scene in a film with a neuroimage obtained from fMRI. To address all these issues, Dmochowski et al. [3] used electroencephalography (EEG) as a new imaging modality to study neurocinematics. They suggested that EEG might be more suitable for investigating changes in brain activities during fast-changing movie scenes due to its higher temporal resolution. In the present article, we briefly reviewed recent EEG-based neurocinematics studies and discussed future prospects of this emerging discipline.

2. Movies as a useful tool to study human affective neuroscience

Traditionally, pictures have been the preferred stimuli to study human emotion. Specifically, the International Affective Picture System (IAPS) [4] has been extensively used in both fMRI- and EEG-based affective neuroscience studies. These static visual stimuli can be effectively used to investigate brain responses to discrete emotions such as happiness, sadness, fear, and anger [5] as well as to study the multidimensional emotion model composed of valence, arousal, and dominance.[6] Conventional EEG studies generally measured event-related potentials (ERPs) elicited by a specific kind of emotional picture. For example, early posterior negativity (EPN) and late positive potential (LPP) are well-known ERP components showing significant differences in both

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amplitudes and latencies when pictures eliciting different emotional states are presented.[7]

Although conventional ERP-based emotion studies provided valuable information on the neural substrate of human emotion, whether the study participants actually felt the designated emotions in the highly controlled experimental settings was still questionable. Note that the participants in the conventional ERP experiments were generally forced to stay immobile and look at fixation marks and pictures during the entire experiment. Furthermore, some studies have demonstrated that this highly constrained experimental environment might lead to a consistent activation of specific visuotopic areas and object-related regions, and thereby might inhibit the natural emotional process of the human brain.[2] To circumvent this issue, neuroscientists have started to use movie clips instead of static visual stimuli [8] as movies are thought to be able to evoke a variety of emotions more naturally than picture stimuli. Early studies generally used short movie clips edited to elicit specific emotions effectively, and analyzed the changes in EEG rhythmic activities after watching the clips [9–13] to classify different discrete emotions.

Recently, deviating from the conventional affective neuroscience studies, some studies attempted to develop novel EEG neuromarkers that can evaluate cognitive or affective states of audiences during movie screening, with the aim to apply neuroscience techniques to practical applications such as evaluation of movie trailers or TV commercials. Some representative examples of the EEG-neurocinematics studies are summarized in Table 1. Dmochowski et al. proposed a new signal decomposition method that extracts maximally correlated signal components from multiple EEG recordings.[3] A new index termed 'emotionally laden attention' was evaluated by computing intra- and inter-subject correlation coefficients in the component space, and was verified by screening three short movie clips twice. Interestingly, the peaks of intra-subject correlations (IaSC) appeared at crucial scenes, and disappeared when the movie scenes were scrambled. They additionally showed the ISC value was reduced when subjects watched the movie twice repeatedly. In another article,[23] the researchers further compared individuals' neural signals with not only their own preferences but also the preferences of a larger number of people. They developed an index termed 'neural reliability', which was computed based on the components analysis approach proposed in [3], and compared it with various indices such as frequency of tweet, viewership of TV show, and gratings of audiences who watched specific advertisements. Kong et al. [14] proposed a new index termed 'impression index' to track how impressed viewers were when watching commercial videos. The research group devised the impression index by combining memorization and attention indices. They improved global field power (GFP) [15] into general global field power (G^2FP) by giving different weighting to each EEG channel.[14] The results showed that the change in the developed index matched well with the results of a questionnaire asking which scenes were impressive in the videos. More recently, Lee et al. [16] proposed that global field synchronization (GFS), which is known as an index reflecting human cognitive processes, might be used to track emotional arousal changes during video watching. They hypothesized that emotional processing may distract from cognitive processes, thereby leading to reduced overall functional connectivity of the brain during emotional processing. The scenes identified as most impressive or memorable in the questionnaire study matched well with the local minima of the grand-averaged GFS waveforms, suggesting that their approach can potentially be applied to the evaluation of cultural content or broadcasting products.

Despite these promising results, many issues still remain to be addressed and new approaches need to be introduced for commercialization of this field. In the next section, we discuss current limitations of EEG-based neurocinematics and provide prospects for this emerging discipline.

Table 1. Representative EEG-based neurocinematics papers.

Article	Clips	Approach	Findings
Dmochowski et al., 2012	Three 6-min movie clips	Component analysis and inter-subject correlation (ISC)	Correlated components of EEG occur with emotionally arousing moments of the films
Kong et al., 2013	Six 30-s commercials	General global field powers (GFP) of specific electrodes	Change of proposed impression index matched well with impressive scenes in advertisements by interview
Lee et al., 2014	Two 5-min video clips (positive and negative)	Global field synchronization (GFS) among multiple EEG channels	Change of GFS reflects emotional arousal well
Dmochowski et al., 2014	Broadcast of television shows ('The Walking Dead') and twenty 30-s Superbowl advertisements	Component analysis and inter-subject correlation (ISC)	Neural reliability of small group is significantly regressed with not only their own preferences but also preferences of a larger group

3. Issues and prospects

EEG is believed to be less reliable in determining detailed emotional processing of audiences than fMRI due to its lower spatial resolution. To enhance the overall reliability of emotion recognition, recent studies have attempted to use physiological signals simultaneously recorded with EEG [17–20]. Eventually, these attempts might yield a more reliable neurocinematic index. The photoplethysmogram (PPG), skin conductance, skin temperature, pupillary response, and electromyography (EMG) are representative examples of the physiological signals that have been being used for the recognition of human emotion or brain states. It is noteworthy that electrooculography (EOG), which is regarded as producing artifacts contaminating frontal EEG signals, has the potential to be used as a new biomarker of attention [21] during movie screening.

Another limitation of the current EEG-based neurocinematics is the large individual variability, which has not been discussed extensively to date. For example, individual preferences for film genres might be different according to personal characteristics such as political inclination, personality, gender, age, professional occupation, and culture. Hammann and Canli suggested that differences in personality, dispositional affect, sex, and genotype could give different modulation of neural bases of emotion processing in prefrontal, limbic, and other brain regions.[22] Accordingly, prior to applying neurocinematics methods to a larger number of people, the influence of individual characteristics on the EEG-based movie evaluation results should be demonstrated.

Further studies in neurocinematics may answer some fundamental questions regarding the film by providing objective indices related to the audience's emotion. The following are some examples. (1) Does the degree of immersion or empathy change when watching a film together with other people in comparison to watching it alone? (2) Is the degree of audience immersion affected by the film format, such as 2D, 3D, 4D, or IMAX formats? (3) Can the emotional response of an individual to cinematic stimuli be influenced by the surrounding people (e.g. a partner whom the individual dislikes)? It is expected that recent development of wearable EEG technology might allow for simultaneous recording of EEG data from a large number of individuals watching the same movie in a cinema. In order to acquire clean EEG signals in the theater environment, advanced signal-processing techniques to detect and remove unwanted artifacts contaminating EEG signals, such as motion artifacts, eye movements, and other bio-signals, need to be introduced in future studies.

The EEG-based neurocinematics studies should be eventually applied to the film industry. In particular, the tracking of the emotional index during movie screening is expected to be used for film-editing processes. During the film editing, the film producer should place various scenes or shots into the appropriate places [23,24] because appropriate positioning of scenes and shots contributes significantly to viewers' emotional responses such as attention, reaction, and immersion.[25] Accordingly, time-resolved tracking of such emotional responses via neural signals can help the film-makers to arrange scenes or shots into the most appropriate places so as to maximize the audience's response.

Rating a film from the perspective of audiences is crucial because it can be a barometer of its box-office success. Currently, movies are generally rated via online movie information sites such as the Internet Movie Database (IMDb; http://us.imdb.com) as well as via evaluation by professional film critics. However, the online rating scores can be easily manipulated by some viewers' intentionally distorted scoring, which is often associated with the distributors and marketers in the film industry. Therefore, it is expected that EEG-based film-rating indices can be used as auxiliary tools to enhance the overall reliability of the current film-rating systems. In Dmochowski et al.'s study,[26] the authors demonstrated that their 'neural reliability index' evaluated for 12 subjects could predict the subjective ratings from a large audience with surprisingly high accuracy, demonstrating the great potential of the 'brain' indices in the film industry.

4. Examples of new 'brain' indices: empathy index and reactivity index

In this paper, we preliminarily tested two new 'brain' indices, which were devised to measure the empathy and reactivity of audiences during movie screening. The two indices were named 'empathy index' and 'reactivity index', respectively. The empathy index was defined as how much the collective audience feels empathy with the subjects of the film (e.g., sadness, happiness, etc.). To develop this index, 25 subjects participated in the offline experiments. The EEG data were acquired while the participants were watching two short video clips (approximately 4–5 min long) designed to elicit two different emotion types (anger and sadness). The detailed information on the experiments can be found in the supplementary document file. The participants scored each clip from 1 to 10 based on how strong an emotion they felt from the clip (1 was the lowest score and 10 the highest score). To develop a new index, 10 subjects were selected for each clip and were divided into two groups based on the scores. A group scoring low (GSL) was composed of subjects who scored low while a group scoring high (GSH) was composed of subjects who responded with high scores (Table 2). The reason for grouping in this way was because the individuals in the GSH commonly felt the 'intended' feelings (anger and sadness). In other words, the video clips were not effective in eliciting the 'intended' feelings to the individuals in the GSL. Accordingly, we had expected that higher ISC would be obtained in the GSH and low ISC in the GSL. We first evaluated the temporal change in EEG power of a high beta (22–30 Hz) frequency band at Fp1, based on the reports that prefrontal beta activity is closely associated with both cognitive and emotional processes.[27] The ISC value between a pair of subjects was evaluated using a Matlab® toolbox called Hermes™ (http://hermes.ctb.upm.es/), when a classical correlation was evaluated and a surrogate test was applied to assess the statistical significance. We then generated a binary connectivity network by selecting connections satisfying the following two conditions: correlation larger than 0.2 ($r > .2$) and p-value less than .05 ($p < .05$). Figure 1 shows the network diagrams of the ISC results, where each node represents a subject and nodes are connected only when the ISC between nodes is high enough. The degree of empathy was quantified using a mean nodal degree,[28] a representative graph-theoretical measure. As expected, many nodes were connected with each other in the GSH, while fewer nodes were connected in the GSL (see Figure 1). The calculated mean degree was 2.0 and 0 with the GSH and GSL, respectively, in the 'anger' clips, and 2.4 and 1.2 in 'sadness' clips (Table 3), showing the possibility that the ISC of left prefrontal beta activity may be an influential candidate index for 'degree of empathy'.

In addition to the empathy index, we developed another index to quantify the reactivity of audiences. In some genres of movies such as action, horror, and thriller movies, the reactivity of audiences is regarded as an important factor to evaluate the possibility of success for the movie.[29] To develop a new index named the 'reactivity index', EEG data were recorded from 24 subjects consisting of 12 male and 12 female subjects during movie screening. A representative Korean thriller movie, 'The Chaser' (2008), was selected as the test movie. Details of the data acquisition and data processing can be found in the supplementary document file. We hypothesized that the time-resolved EEG features related to emotion such as frontal alpha asymmetry would fluctuate more widely and more frequently with female subjects rather than males because 'The Chaser' includes a lot of extremely cruel and violent scenes. To quantify the overall degree of fluctuation of the EEG features, Teager's energy operator was adopted,[30] which can consider both the variation and frequency of time-series. Two groups were assigned based on sex, and the reactivity index was computed by integrating the Teager's energy over time. Our results showed that the reactivity index of the female group was significantly higher than that of the male group (p = .023, Wald-Wolfowitz runs test), as expected, which demonstrates that our new reactivity index might be potentially used as a promising index to quantify the emotion variation of audiences.

The above two indices named 'empathy index' and 'reactivity index' may be used for rating films. The degree of empathy aroused by the film can be a good reference for film-makers who want to maximize audiences' empathy. The 'reactivity index' is expected to be effectively used for evaluating horror or thriller movies as mentioned before. It would be also interesting to see differences of empathy and reactivity among various sub-groups, e.g., between male and female audiences, and among different generations. These results could also be effectively used to determine the target audiences of a film before the promotion of the film starts.

The above two indices are just examples of the potential 'brain' film-rating indices, which still need to be further validated through a series of additional experiments with a variety of audiences. There have been many EEG features that correlate cognitive or emotional states of the

Table 2. The score values of two participant groups (GSH and GSL). The participants scored each of two different clips from 1 to 10 based on how strong an emotion they felt from the clip.

	Group scoring high (GSH)		Group scoring low (GSL)	
Emotional Type of Clip	Participant no.	Score	Participant no.	Score
Anger	1	10	6	6
	2	10	7	6
	3	10	8	6
	4	9	9	5
	5	9	10	6
	Average	**9.6**	**Average**	**5.8**
Sadness	1	10	6	7
	2	10	7	7
	3	10	8	6
	4	9	9	6
	5	9	10	5
	Average	**9.6**	**Average**	**6.2**

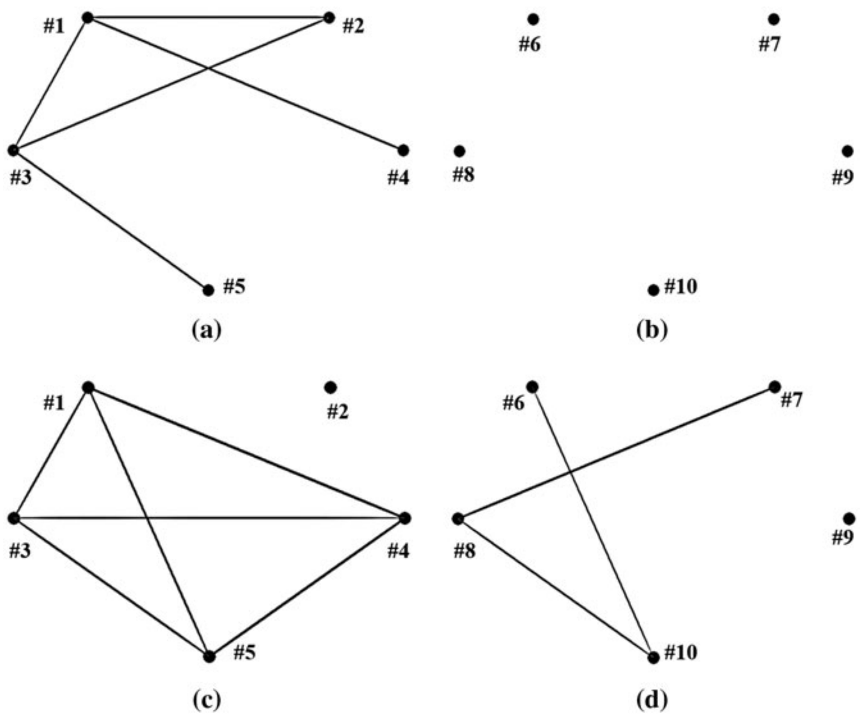

Figure 1. The inter-subject correlation (ISC) diagrams of a group scoring high (GSH) and a group scoring low (GSL), where five nodes represent each subject: (a) ISC diagram for GSH ('anger' video); (b) ISC diagram for GSL ('anger' video); (c) ISC diagram for GSH ('sadness' video); (d) ISC diagram for GSL ('sadness' video). As seen in the figures, many nodes are interconnected in GSH, but relatively fewer nodes are interconnected in GSL.

Table 3. The empathy index evaluated for two types of movie clips, 'anger' and 'sadness'. The inter-subject correlation of high beta band power of Fp1 was evaluated, and the empathy index was then defined as the mean degree of the binary connectivity network. GSL and GSH represent a group scoring low and a group scoring high, respectively.

	Empathy index (no unit)	
Emotional type of video clip	**Group scoring high (GSH)**	**Group scoring low (GSL)**
Anger	2	0
Sadness	2.4	1.2

human brain, such as event-related synchronization/desynchronization (ERS/ERD),[31] the power spectral density (PSD) of theta, alpha, beta, gamma, and sensorimotor rhythms,[32–38] frontal EEG asymmetry,[39,40] and cross-frequency coupling.[41] It is expected that advances in passive BCI technology,[42] which studies new EEG features to decode individual brain states, would also contribute to the development of new techniques that can enhance the reliability of EEG-based neurocinematics.

5. Conclusion

In this short review article, we briefly reviewed the current state-of-the-art of EEG-based neurocinematics, and discussed the grand challenges and prospects of this emerging technology. Furthermore, we suggested two new 'brain' film-rating indices that might be potentially used for EEG-based neurocinematics studies. Neurocinematics is a fascinating area not only for neuroscientists but also for film-industry professionals as it has the potential to provide a new way for objective evaluation of films. However, many issues still remain to be addressed for the commercialization of EEG-based neurocinematics, such as large individual variability, absence of detailed questionnaires, and incomplete wearable EEG technology, which need to be studied further in future studies.

Acknowledgements

This work was supported in part by the IT R&D program of MSIP/KEIT (KI10045461, Development of cultural contents evaluation technology based on real-time biosignal of multiple subjects) and in part by a National Research Foundation of Korea (NRF) grant funded by the Korean government (MSIP) (No. 2014R1A2A1A11051796).

Disclosure statement

No potential conflict of interest was reported by the authors.

Funding

National Research Foundation of Korea10.13039/501100003725 [Grant Number No. 2014R1A2A1A11051796]; MSIP/KEIT [Grant Number KI10045461].

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