Human
TECHNOLOGY

ISSN: 1795-6889

https://ht.csr-pub.eu

Volume 20(3), December 2024, 676–700

INCREASING ENERGY AWARENESS THROUGH EFFECTIVE ADVERTISING MESSAGES – A NEUROPHYSIOLOGICAL APPROACH TO ENGAGEMENT STUDY

Bartłomiej Piwowarski
University of Szczecin
Poland
ORCID 0009-0007-5666-4761

Abstract: *The article presents the application of neurophysiological measurements when evaluating the effectiveness of advertising messages aimed at increasing energy awareness. The study focused on two commercials promoting pro-ecological behaviors. The level of audience engagement was analyzed using the engagement index (EI), which was determined based on EEG studies. The results suggest that appropriately designed scenes (surprising, humorous situations, longer rather than shorter ones, etc.) could increase engagement. Continuous upward trend in engagement, confirmed by the time analysis of EI, validated the alignment of the advertisement design with models of advertising impact on the audience. The study demonstrated that EEG is an effective tool for assessing audience reactions to advertisements, which can lead to more effective advertising campaigns promoting pro-ecological behaviors.*

Keywords: *energy awareness, social advertising, engagement, neurophysiological measurement, EEG (Electroencephalography)*

DOI: https://doi.org/10.14254/1795-6889.2024.20-3.12

INTRODUCTION

Energy constitutes a critical factor in sustainable development. It is linked to nearly all (economic, social, and environmental) dimensions of this development. It significantly influences the achievement of sustainable development goals, from eliminating poverty and hunger worldwide through providing healthcare, education, and industrial development to combating climate change and its impacts (Munasinghe, 2004; Stankevičienė & Borisova, 2022; UN General Assembly, 2015). One of the Sustainable Development Goals (SDGs) directly addresses energy issues. This goal (SDG 7) provides for access to affordable, reliable, sustainable, and modern energy for all (McCollum et al., 2017). For this to be achieved, however, large-scale efforts must be undertaken to ensure an effective energy transition, particularly towards renewable energy sources. Here, another important task relates to reductions in energy waste, as they positively impact the natural environment (e.g., combating global warming). Finally, improving energy efficiency saves money for both individual households and the economy. The potential for changes in this area is evident across all sectors of the economy, along with a wide range of possible actions (Creutzig et al., 2015; Cullen et al., 2011; Edenhofer, 2015; Moriarty & Honnery, 2019). High energy efficiency comprises many factors that can be grouped into two overarching categories. The first concerns issues related to broadly understood technology, while the second pertains to the energy awareness of users (consumer behavior).

Technological aspects of improving energy efficiency focus on enhancements within available technology. Some solutions are well-known and proven through years of application, while others are novel, innovative, and less familiar. This pertains to technologies available on both the supply and demand sides. In the first case, these are technical solutions (as well as management procedures) implemented by network operators, energy distributors, or manufacturers of consumer products. The second case includes all actions and technical devices that can be implemented on the customer (consumer) side (Y. Chen & Liu, 2021; National Academy of Engineering, 2009). Examples of solutions that increase energy efficiency include: building and using more efficient transmission and distribution systems (Melhem, 2013; National Academy of Engineering, 2009), converting surplus heat to electricity (Q. Chen et al., 2016; Energy & others, 2014), using renewable energy sources (Kolosok et al., 2021; Salameh, 2014; Streimikiene, 2022, 2024), using energy-efficient appliances (Stoffels & Vielhaber, 2016; Waris & Hameed, 2020) and many others. The energy efficiency assessment and consumption by various devices, buildings, systems, etc., is becoming increasingly reliable and more accessible. Multiple models (Bermeo-Ayerbe et al., 2022; Drobyazko et al., 2021; Mo & Zhao, 2021), standards, policies, recommendations, certificates, norms (Asdrubali & Desideri, 2019; *Energy Efficiency*, 2019; European Commission, 2020; Poveda-Orjuela et al., 2019; uit het Broek et al., 2020), etc., are being developed.

Issues related to the energy awareness of energy consumers are more critical and, at the same time, more accessible to assess. They concern every person using various energy-consuming devices daily, whether at home, work, school, traveling, or on vacation. It must be unequivocally stated that even the most advanced technology will not solve the problem of energy waste. Therefore, it becomes necessary to raise awareness and change the behavior of energy users to be more economical and environmentally friendly. People tend to take energy for granted. Many are unaware that they can significantly influence energy consumption reduction. Even if some advocate for energy efficiency, they do not necessarily change their behaviors in this regard. As the International Energy Agency notes, the global improvement in energy efficiency is the slowest in 10 years (International Energy Agency, 2020). Hence, it is essential to intensify efforts to increase energy awareness. These efforts must be multifaceted, reach a broad audience, and be effective. Various approaches, often called energy efficiency interventions, are currently being used worldwide. The main assumptions of these interventions are based on several fundamental principles: people will change their behavior if they understand the problem, know what to do, or realize that it is in their best interest (Kollmuss & Agyeman, 2002; Ro et al., 2017).

Interventions are conducted on a micro-scale (households), a macro scale (policies, regulations), and a multi-level scale (both micro and macro combined). They are mainly focused on providing consumers with information, feedback, and specific actions that encourage energy savings (Jacobsen et al., 2012; McAndrew et al., 2021; Juhasz et al., 2023). The most commonly used intervention tools include information and education (training, workshops); financial mechanisms (tariffs, rewards) (Abrahamse et al., 2005; Ó Broin et al., 2015); visualizations of energy consumption and displaying selected feedback information on meters, displays, smartphones, tablets, etc. (Morganti et al., 2017; Murugesan et al., 2015; Schultz et al., 2015); using games and gamification to engage consumers in saving behaviors (Morganti et al., 2017); and energy audits and home retrofits (Ehrhardt-Martinez et al., 2010; Karlin et al., 2014; Lazowski et al., 2018). Interventions using feedback and specific encouraging actions are more costly and limited in terms of personnel. On the other hand, general informational activities can be directed to a broad audience. These are standard methods of raising energy awareness conducted by various governmental and international institutions, energy producers, and manufacturers of devices and other material goods. Informational messages are often delivered through social campaigns, video advertisements, computer games, posters, leaflets, websites, etc. Mass media, such as television, radio, the Internet, and the press, are disseminated. However, the effectiveness of both informational activities and feedback interventions can vary. Poorly prepared informational and feedback interventions may result in only minor and temporary changes in energy savings. After the intervention ends, a return to normal (previous) usage may occur (Bird & Legault, 2018).

The effectiveness of the informational message presented to users largely depends on its construction. It should attract attention, arouse interest, engage emotions, and be memorable. It should provide reliable, specific information delivered convincingly and attractively. Furthermore, it should be tailored to and reach a particular target audience. Repetitive information presentation schemes are sometimes used, but they only sometimes prove effective.

Moreover, frequently repeated solutions become commonplace and fail to meet their original objectives. Good practices are often not applied when designing informational (advertising) messages. For example, website information architecture is usually low, and overall usability discourages users from seeking information. In the case of video advertisements (often social), the storyline can be irritating, and the advertising slogan fails to evoke any emotions, interest, or engagement and needs to be more memorable and effective. While more extensive advertising campaigns typically involve a multi-level message design process that includes surveying potential audience opinions, various methods and techniques for research and testing are used depending on the form of the informational message. These typically boil down to declarative forms (surveys, interviews), where the evaluation is verbally communicated. However, such studies still need to answer emerging emotions, perceptions, attention focus, and other factors. These factors can be crucial when analyzing the reception of designed messages, which are the primary information form. Expecting changes in human behavior and building energy awareness is more accessible with practical information.

The article aims to present the potential of using neurophysiological measurements to assess engagement in the reception of advertising messages intended to increase energy awareness. The essence of the studies described is to demonstrate that using brain electrical activity measurements (EEG) and determining an engagement index based on them can provide added value in research on the applicability of advertising impact models on the recipient and the design of advertising messages. Engaging consumers in advertising messages is desirable regardless of the adopted model. However, it is difficult to measure and assess, partly due to the emotional nature of this phenomenon and the dynamic nature of advertising messages. The presented research results show that neurophysiological studies offer high accuracy in assessing the level of engagement (e.g., at the level of film frames or thematic scenes). Such a methodological approach is also considered more objective than other declarative assessment methods. This may be significant in evaluating the effectiveness of advertising messages, which in practice is supported by models that assess advertising's impact on the recipient. Ultimately, this allows for a better understanding of how advertising influences consumer behavior and decisions. The subject of the study comprises two natural advertising spots (videos) aimed at promoting pro-ecological behaviors. The research method involves measuring the brain's electrical activity (EEG), based on which an engagement index was determined. It analyzes the level of engagement allowed to verify the effectiveness of the advertising messages and relates the obtained results to the defined phases in advertising impact models.

The article consists of five parts. Section 2 discusses the concept of advertising impact models on audiences. Section 3 describes the research experiment, the group of subjects, and the methods, algorithms, and analyses used. Section 4 presents the research results, and the following section discusses them. The final part of the article contains concluding remarks and practical implications of the research.

ADVERTISING IMPACT MODELS ON AUDIENCES

Messages aimed at increasing energy awareness often take the form of videos or are purely informational. In the first case, these are typically social advertisements and educational videos, while in the latter case, they consist of various leaflets, posters, internet information, press articles, etc. The design of informational or advertising messages varies depending on their form. The primary goal is to achieve maximum effectiveness. The result is to generate consumer interest and convince them to purchase a product or, for example, change their habits (social advertisements). Therefore, many methodological approaches have been developed to describe the impact of advertising messages on audiences. The most well-known advertising impact models include AIDA and models based on this framework:

AIDAS (S-Satisfaction), AIDAL (L-Loyalty), and AIDCAS (C-Conviction, L-Loyalty). Other well-known models include DAGMAR, DIPADA, FCB, Lavidge-Steiner, ACALTA, EKB, and Ray's (Chakravarty & Sarma, 2022).

The choice of a marketing impact model determines the type and conditions of building the message. Often, the model specifies the technology used for implementation, the type of advertisement, or the type of media. The fundamental idea of any advertising impact model is to attract attention, generate interest, stimulate desire, and prompt specific action, such as purchasing products or changing habits (Koziara, 2017). The most well-known advertising impact models are presented in Table 1. They differ in the defined phases of the process or the evocation of specific affective and cognitive states in the audience.

Table 1. Selected Advertising Impact Models on Audiences.

Model Name	Phases	Literature
AIDA	Attention, Interest, Desire, Action.	(Ullal & Hawaldar, 2018) (Dharti Narwani, 2023) (Universitas Bakrie, Jakarta - Indonesia & Sukma Wijaya, 2012)
DAGMAR (**D**efining **A**dvertising **G**oals for **M**easured **A**dvertising **R**esults)	Unawareness, Awareness, Comprehension, Conviction, Action.	(X. Chen, 2023) (Egede, 2013)
DIPADA	Definition, Identification, Proof, Acceptance, Desire, Action	(Furnham, 2008)
FCB	The FCB grid takes into account four factors: Thinking, Feeling, as well as High and Low involvement.	(Vaughn, 1980)
Lavidge-Steiner	Awareness, Knowledge, Liking, Preference, Conviction, Purchase.	(Lavidge & Steiner, 1961)
ACALTA	Awareness, Comprehension, Attitude, Legitimation, Trial, Adoption.	(Chakravarty & Sarma, 2022)
EKB (**E**ngel-**K**ollat-**B**lackwell)	Need recognition, Information search, Evaluation of alternatives, Purchase decision, Outcome analysis.	(Longart et al., 2016) (Srivastava et al., 2021)

Analyzing the various models, it is evident that an essential role of the advertising message is to build an emotional (Rejer et al., 2024) and intellectual bond and engage the audience in purchasing a product or adopting or changing habits (Kovacic, 2014). The stronger the bond created, the more the advertised goods will be entrenched in the audience's consciousness (Otamendi & Sutil Martín, 2020).

For the models listed in Table 1 (regardless of the number and type of stages), three phases of the advertising message can be distinguished: the cognitive, affective, and conative phases (Barry & Howard, 1990). The cognitive phase is the stage of awareness where the advertising message is entrenched in the consumer's consciousness. The clarity of the brand, products, and promoted habits is tested by comparing them with other advertisements. If the respondent identifies the advertisement among competing messages, it indicates strong retention in the audience's consciousness. In the affective phase, the attitude towards the advertised item is shaped. Research in this phase focuses on determining how the advertising message translates into decisions made. The conative phase aims to prompt the audience to take action that aligns with the advertisement's message (such as purchasing a product, using a service, or changing habits). Research in the conative phase focuses on the audience's behaviors after viewing the advertisement (Barry & Howard, 1990).

The models in Table 1 structurally describe methods for building positive relationships with the audience. Viewer engagement in advertising content interacts with the message and the audience. The message encourages action, such as following the advertised product online or on social media, using loyalty programs, imitating behaviors, and developing certain habits. This approach initiates building loyalty and trust towards products, services, etc. In practical terms, this can translate into repeat purchases or specific behaviors.

The fundamental goal of social advertising related to energy conservation is to convey information and evoke a specific emotional response. This can prompt the audience to take action in line with the message (Kotler & Lee, 2008). Advertisements that elicit emotions and provoke reflection are more effective in promoting changes in the attitudes and behaviors of the audience. Numerous studies confirm that viewer engagement in receiving the advertisement significantly impacts its effectiveness. In particular, a high level of engagement leads to deeper processing of the advertisement content (often subconsciously), enhancing understanding and retention of the message (Heath, 2001). Various studies have also shown that advertisements with high viewer engagement are more persuasive and influential (Akarsu & Serdar, 2023; Kim et al., 2017; Borawska et al., 2023). Increasing viewer engagement, especially in the early phases of impact models, can be achieved using techniques such as storytelling, well-known or engaging actors, or introducing interactivity (Edson Escalas, 2004). Advertisements that draw the audience into the storyline and action of the message at the interest-evoking stage have a higher chance of effective communication (Green & Brock, 2000). Therefore, designing advertisements with the highest possible level of engagement in the initial phases of impact models seems crucial to achieving the intended goals. This is practically independent of the adopted model (AIDA, DAGMAR, FCB, Lavidge-Steiner, etc.).

A critical issue is the method of studying or assessing engagement. Generally, three approaches can be distinguished: self-assessment questionnaires, behavioral measurement during tasks, and physiological measurement (Rejer et al., 2024). Each has its advantages and limitations. Self-assessment questionnaires are simple to conduct and analyze. They provide information about subjective feelings and opinions but can be distorted by subjective biases and are susceptible to manipulation (conscious or unconscious). Behavioral measurement is more objective than questionnaires and allows for the observation of behaviors in real-time. It requires specialized equipment, and data analysis is more complex and time-consuming. Physiological measurement has several significant advantages. It enables an understanding of emotional and cognitive reactions to advertisements. Since the measurement occurs at the level of changes in the human nervous system, it is considered the most objective. It records even the most minor physiological reactions a person cannot control. However, such studies require specialized equipment, software, and expert knowledge (Giombi et al., 2022).

Physiological measurement (EEG) was used to study engagement in social advertisements to increase energy conservation awareness. The results will allow for a precise analysis of consumer reactions to these advertisements. Achieving greater engagement in the reception of the advertising message increases the chances of a lasting change in attitudes and the campaign's effectiveness. This is particularly true for complex advertising messages and products that require greater involvement in the decision-making process. Therefore, consumer engagement in the reception of the advertisement significantly impacts the effectiveness of advertising impact models.

MATERIALS AND METHODS

Participants

In the study, 30 individuals participated, out of which data from 29 respondents (14 women and 15 men) were included in the analysis. The measurements from one person were excluded due to technical issues in signal registration (poor quality of EEG signals). The participants were between 19 and 51 years old, with an average age of 29.38 years and a standard deviation of SD=10.67. One participant was left-handed, while the others were right-handed. The study included both students and working individuals. All participants were healthy and voluntarily took part in the study. They all signed consent forms to participate in the experiment and have their data processed for research purposes. Participants were informed about the study procedure (without revealing specific details about the experiment's content) and the measurement equipment used. The research experiment used the principles outlined in the Declaration of Helsinki (2013 version) (World Medical Association, 2013). The Bioethics Committees reported to and approved the study at the Regional Chamber of Physicians in Szczecin.

Research Protocol and Stimuli

The research protocol included 12 advertisements, one film, and additional significant screens for physiological measurement. All participants were shown a 30-minute documentary film interrupted by two commercial breaks. Each break contained six advertisements, both commercial and social. Each ten advertisement was 30 seconds long, while the two lasted 60 seconds each. The structure of the research protocol is presented in Figure 1.

EEG baseline	Film (part I)	Advertising block (no. 1)	Film (part II)	**Advertising block (no. 2)**	Film (part III)
SCREENS	VIDEO	AD1 ÷ AD6	VIDEO	**AD1 ÷ AD6**	VIDEO

Figure 1. Research protocol used in the experiment.

The advertisements analyzed in the study were placed in the second commercial break, each lasting 30 seconds. Both ads had a social message related to the necessity of saving electricity and developing good habits.

First Advertisement (referred to as Ad1):

- Advertiser: Energa (*Energa - Po Prostu Włącz*, 2012).
- Objective: This ad aimed to increase awareness about the efficient use of electricity and encourage potential customers to take advantage of Energa's offerings. The company promotes itself as the most eco-friendly energy provider in Poland. The advertisement emphasizes that saving energy involves simple tasks like turning off unnecessary lights, televisions, or computers. The main characters in this spot are animals: a canary, a dog, and a cat. In various scenes, these animals turn off power sources.

Second Advertisement (referred to as Ad2):

- Advertiser: Polish Ministry of Environment (*Wyłączamy Prąd, Włączamy Oszczędzanie*, 2012).
- Objective: This ad was part of an educational campaign on energy saving. Its goal was to raise awareness and rationally shape attitudes and habits about using electrical and thermal energy. The actors in this ad are a couple (a woman and a man) who discuss the linguistic and emotional aspects of turning power on and off.

To analyze the advertisements, both were divided into one-second frames and thematic scenes. The first and second advertisements were split into five scenes each. These scenes are briefly labeled as S1 (scene 1), S2 (scene 2), etc.

Scenes of Ad1 (with seconds in parentheses indicating the duration of each scene):

- S1 – A man and a woman walking around the apartment (0÷2; 9; 20);
- S2 – A canary flying out of its cage, sitting on the TV remote, and turning off the TV with its beak (3÷8);
- S3 – A dog lying on the couch, looking at the overhead light, then jumping onto a cabinet and turning off the light with its paw (10÷19);
- S4 – A cat looking at an open laptop, jumping onto the table, and closing the laptop; additionally, the narrator's voice informs that the animals are setting an example of saving energy and that everyone can save energy (21÷28);
- S5 – The energy provider's logo with a voice-over encouraging viewers to take advantage of their offer (29÷30).

Scenes of Ad2:

- S1 – A couple (woman and man) cuddling in bed at night (0÷3);
- S2 – The woman tells the man he should have turned off the TV, and the man points out that it should be said "turned off" instead of "switched off," leading to a discussion about the correct terminology (4÷17);
- S3 – The man turning off power-consuming devices, with the narrator's voice in the background stating the Ministry of Environment's position that it's not about what you turn off, but about what you save (18÷23);
- S4 – A screen with a light switch and the text and voice message of the advertisement "Turn off the power, turn on the savings" (24÷27);
- S5 – The man returning to bed (28÷30).

At the beginning of the measurement procedure, graphic stimuli were displayed on the computer screen to focus attention and establish a reference point (baseline). The neurophysiological reactions of the respondents were determined based on the brain activity signals obtained during this phase. Subsequently, the process of displaying stimuli, which were the advertising spots, began.

Research Apparatus

The measurement of brain electrical activity was conducted using a portable 8-channel g.Nautilus system from g.tec. The wet measurement electrodes were positioned according to the international 10-20 standard at the following locations: Fp1, Fp2, F3, F7, Fz, F4, F8, and Cz. The ground (GND) electrode was placed on the surface of the head, and the reference electrode was attached to the left earlobe (ear clip). To place the electrodes, g.GAMMAcap[2] caps in two sizes (medium and large) were used. Before starting the measurement process, the impedance at the electrode-skin interface was checked, maintaining an upper limit of 10 kΩ. The brain activity was recorded at a frequency of 500 Hz. Noise level: < 10.6 μV RMS between 1 and 30 Hz.

A multi-step procedure was applied to preprocess the EEG signal, consisting of several stages: data import (.hdf5 format), filtering, electrode localization, event import, checking for bad channels and possibly their interpolation, removing eye artifacts, re-referencing the data, dividing the signal into epochs, removing epochs containing data with remaining artifacts (Piwowarski et al., 2021). A fifth-order Butterworth filter [2-30 Hz] was used to filter out frequency ranges irrelevant to the study, allowing for the removal of high-frequency noise, e.g., muscle artifacts (above 30 Hz) and the elimination of slow drifts (below 2 Hz). The electrode localization step involved loading and verifying channels' correct placement and order according to the established locations during the measurement. A procedure was implemented to extract events from the recorded signal to import an event definition file and set processing parameters. Since the entire EEG signal was processed, extracting specific segments, i.e., individual advertisements, was necessary. Time markers (events) were used for this purpose to identify the start and end of each ad (videos in .mp4 format), as well as other important moments in the study (e.g., technical issues reported by the researcher during the measurements or behaviors of the subjects). A complete measurement environment was developed, which included preparing the research project (defining stimuli, primarily advertisements), displaying them to the subjects, and recording events (a separate .xls file was created for each subject). This was done by a team of researchers working within the cognitive neuroscience laboratory. The measurement and recording of the EEG signal began after pressing the start button, after which the stimuli (advertisements) automatically appeared on the screen. Pressing the start button generated the first event, and its timestamp was recorded with an accuracy of 1 millisecond. In both analyses, each advertisement's start caused subsequent events, and their timestamps were recorded in the file. The recorded EEG signal (containing time markers) was synchronized with the events saved in the file using a dedicated function in the EEGLAB toolbox. The next step involved actions aimed at identifying the wrong channels. Bad channels can occur, for example, due to poor electrode contact with the scalp, resulting in a low signal-to-noise ratio. In the described study, the main focus was on analyzing the correlation of signals from adjacent channels, flat signals, and the level of high-frequency noise. Two bad channels were identified in total, each in two different subjects (Fz and F4). The probable cause was either an insufficient amount of conductive gel applied to the measurement electrodes or its partial leakage during the EEG measurement. After additional visual identification of bad channels for the entire recorded signal, it was decided to remove these two channels (for the two subjects). The removed channels were interpolated based on other valid channels. The interpolation was performed following the ICA procedure described below.

Various methods were applied for artifact removal. In the first step, ocular artifacts were identified and subsequently removed. For this purpose, Independent Component Analysis (ICA) and the Infomax algorithm were applied (Makeig et al., 1996). The use of ICA allowed for extracting independent components of signal sources, including artifacts of ocular origin. Due to the relatively small number of measurement electrodes (which translates into a similar number of extracted components), it was decided to remove only one component – the component corresponding to ocular-origin disturbances. Ocular artifacts are relatively easy to identify, and ICA analysis effectively identifies this noise source (even with a small number of applied electrodes). The ICA procedure was conducted in the EEGLAB toolbox and had a semi-automatic character. Independent components were extracted automatically using the ICLabel classifier. The decision to remove components was made after a visual analysis of the obtained components using topographic head maps. Other components were not removed due to the higher likelihood of removing brain activity signals in the remaining components.

The next stage of the preprocessing procedure involved re-referencing the EEG data. During signal recording, the data were registered with reference to the electrode placed on the left earlobe, a commonly used practice due to the good signal quality and noise suppression obtained. However, such referencing is not the most optimal solution at the data analysis and interpretation stage. It is not recommended to use only one earlobe, as this approach is unbalanced and tends to lower activity in the homologous hemisphere of the considered earlobe. Therefore, a re-referencing process was applied, using the linked earlobes as the reference.

The final stage of the preprocessing procedure involved removing other artifacts. To eliminate other artifacts, the continuous EEG signal was divided into epochs (1-second time windows). The criteria for marking artifacts in the defined epochs were signal amplitude exceeding $\pm 75\mu V$ and a trend slope between epochs exceeding $\pm 10\mu V/s$, with R-squared=0.3. Epochs identified with artifacts were removed. The cleaned signal was then subjected to analysis. EEG signal processing was performed using Matlab, EEGLAB, FieldTrip toolboxes, and custom scripts.

Analysis of Measurement Data

The primary measure derived from the processed EEG signal and subjected to analysis was GFP (Global Field Power). The GFP measure corresponds to the spatial standard deviation of the average EEG amplitude (at each time point) from all eight measurement electrodes simultaneously (Skrandies, 1990). To more precisely determine the frequency band ranges for all study participants, the Individual Alpha Frequency (IAF) was calculated (Corcoran et al., 2018). Based on the IAF, the alpha, beta, and theta bands were defined in the study. This was done using the formula IAF ± x, where x is the number determining the start and end of the band in Hz. The alpha range was defined as [IAF-2 Hz ÷ IAF+2 Hz], the beta range as [IAF+2 Hz ÷ IAF+14 Hz], and the theta range as [IAF-6 Hz ÷ IAF-2 Hz]. The extraction of bands was carried out using the Discrete Fourier Transform (DFT) and bandpass filtering. The GFP value was calculated using the following formula:

$$GFP = \frac{1}{N}\sum_{i=1}^{N} x_{\vartheta_i}(t)^2, \quad (1)$$

where: ϑ is the considered EEG band,
N is the number of electrodes,
i is the electrode index,
x represents the EEG sample at a time *(t)*, filtered within the related EEG band (ϑ) and for the specific channel i.

Sampling was performed in frames of 51 samples in length. To calculate the GFP, the middle value of the frame (EEG sample) was taken, and then the frame was shifted by 1. This procedure was repeated for the subsequent frames created in this way.

Using the GFP measure, an Engagement Index (EI) was calculated, which was based on the recorded changes in brain activity in the beta, alpha, and theta bands, according to the following formula (Cartocci et al., 2019):

$$EI = \frac{GFP\beta}{GFP\alpha + GFP\theta}. \quad (2)$$

The methodological assumptions of this index are based on the premise that an increase in beta activity is associated with an increase in alertness and engagement in a cognitive task. Conversely, increased alpha and/or theta frequency activity reflects decreased alertness and engagement (Cartocci et al., 2019; Coelli et al., 2015; Lelis-Torres et al., 2017; Pope et al., 1995).

The value of the EI index was normalized (z-score) for each time point of the advertisement (1 second) using the mean value and standard deviation of the EI values obtained for the baseline (the initial screen of the study) (Cartocci et al., 2019):

$$Normalized\ index\ (z - score) = \frac{index\ value -\ mean\ value\ (baseline)}{standard\ deviation\ (baseline)}. \quad (3)$$

Various methods were used for statistical analyses. The between-group differences were examined using the Student's t-test with Welch's correction, the non-parametric U Mann-Whitney test, the non-parametric Kruskal-Wallis test, and the Dunn-Bonferroni post-hoc test. Additionally, Pearson correlation and linear regression were applied.

RESULTS

The Engagement Index (EI) values determined from the EEG measurements were analyzed for consecutive time points (every 1 second) and the identified thematic scenes. This approach allowed for verifying the impact of both advertisements (Ad1, Ad2) on the audience in the context of the assumptions and defined phases of the various models (AIDA, DAGMAR, etc.). The analysis conducted with 1-second accuracy enabled the assessment of how the level of engagement changed over time. The thematic scenes provided additional information about the effectiveness of the advertisement's script, including the storyline, actors, actions, and dialogues.

The distribution of aggregated EI values for the entire group of respondents for advertisement Ad1 is shown in Figure 2.

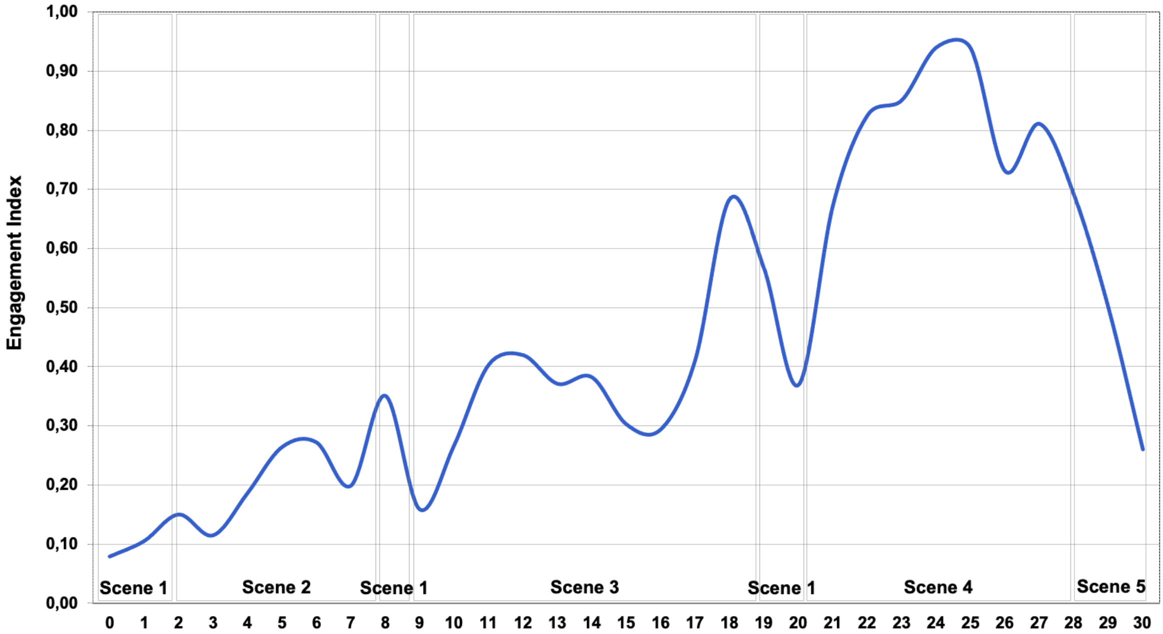

Figure 2. Engagement index (EI) values over time for advertisement Ad1.

The obtained EI results indicate a gradual increase in engagement levels, starting from an EI=0.079 at the beginning of the advertisement to a maximum value of EI=0.939 at the 24-second mark. Between these time points, local peaks in engagement can be observed (e.g., at 6s, 8s, 12s, 18s), followed by declines in EI values. After reaching the highest engagement level (24s), there was a sharp decline to an EI value of 0.260 in the last second of the advertisement. To better understand the reasons for changes in engagement during the ad, it is necessary to examine the thematic scenes closely. The highest EI values were achieved for scene S4, where the leading actor is a cat. This scene begins with a camera close-up of the cat (21s, EI=0.672) staring at something. The cat then runs towards the table, jumps on it (24s, EI=0.939), and closes the laptop (26÷27s, EI=0.731÷0.811). The second highest engagement is in scene S3, featuring a dog. The first peak of engagement in this scene occurs when the dog raises its head and stares at the ceiling lamp (12s, EI=0.419). The second, significantly higher peak of engagement in this scene happens when the dog jumps onto the cabinet and turns off the light with its paws (18÷19s, EI=0.683÷0.566). In scene S2, where a bird turns off the TV using a remote, an increase in EI value can also be observed (8s, EI=0.351). Compared to scenes S4 and S3, the engagement level is relatively small. The final scene of the advertisement (S5), containing the logo and information about the energy provider, is marked by a significant drop in engagement level compared to the preceding scene, indicating a general decline in interest in this part of the advertisement.

When analyzing the engagement index distribution over the second advertisement's duration (Ad2), significant differences can be observed compared to those in Ad1 (Figure 3).

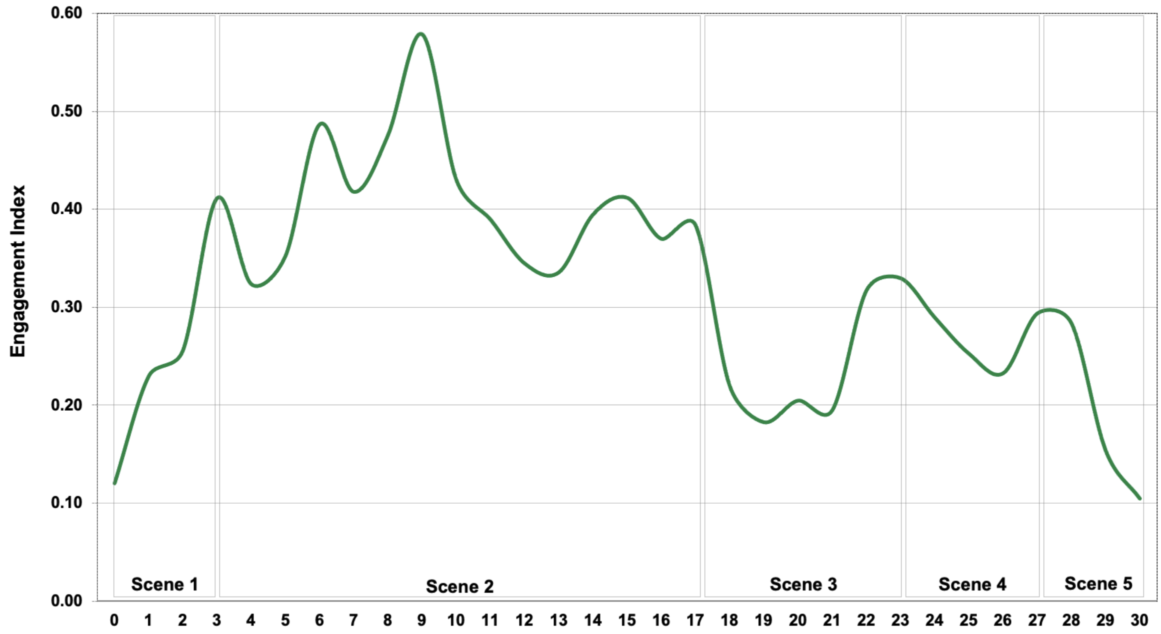

Figure 3. Engagement index (EI) values over time for advertisement Ad2.

From the beginning of this advertisement, the EI values increase dynamically, reaching the first peak at 3 seconds (EI=0.411), the second at 6 seconds (EI=0.487), and then the maximum for the entire clip at 9 seconds (EI=0.579). From this point, engagement levels decrease, noting small, local increases around 15÷17 seconds (EI=0.412÷0.384), 22-23 seconds (EI=0.317÷0.329), and at 27 seconds (EI=0.294). In the context of increasing engagement, significant scenes are S1 and part of scene S2. In the 3-second scene S1, a woman and a man lie in bed, cuddling each other. This segment triggers the rise in engagement, which continues through the first 6 seconds of scene S2. During this period, a conversation (a minor argument) occurs about turning off the TV (the woman) and switching off the TV (the man). The prolonged discussion causes a decrease in EI values. In scene S3, the man turns off electrical devices while the narrator's voice delivers a message from the Ministry of Environment. Turning off the radiator at the end of this scene causes a slight increase in engagement. The end of scene S4 (a screen with a message about saving power) and the beginning of S5 result in a temporary rise in EI values, after which the last seconds of S5 lead to a decline.

Besides analyzing the engagement levels at individual time points (every 1 second), a generalization for the entire advertisement can be made. This will help determine which advertisement is more engaging overall. The average EI values calculated for Ad1 and Ad2 are presented in Figure 4.

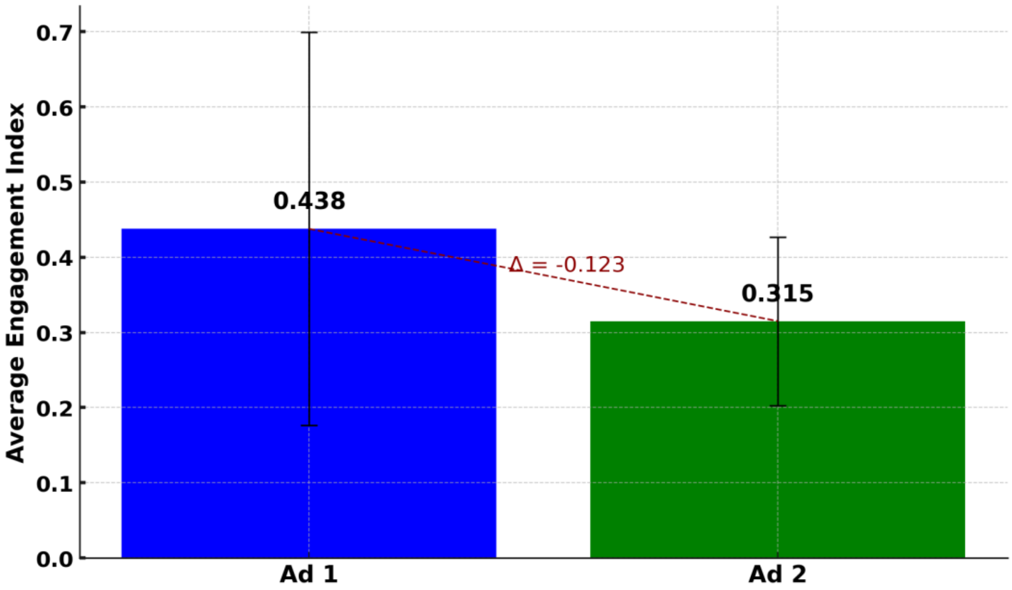

Figure 4. Comparison of average Engagement Index (EI) values for Ad1 and Ad2.

The average Engagement Index (EI) value for advertisement Ad1 is EI=0.438, while for advertisement Ad2 it is EI=0.315. This indicates that Ad1 generates a higher average engagement than Ad2. The difference between these averages is -0.123 (the average EI for Ad2 is lower than the average EI for Ad1 by this amount). The error bars, showing the standard deviation for each advertisement, differ significantly. For Ad1, the standard deviation is higher (SD=0.261) than for Ad2 (SD=0.112), suggesting more significant variability in engagement.

Two tests were used to test the significance of the differences between the average EI values for both advertisements: the Student's t-test with Welch's correction and the non-parametric U Mann-Whitney test. This approach was taken because the data distribution (Shapiro-Wilk test) for one of the groups (Ad1) was not typical: Ad1 (p=0.022), Ad2 (p=0.982). Levene’s test (p=0.0005) indicated that the assumption of homogeneity of variances was not met. The result of the Student's t-test (with Welch's correction) suggests that the difference in average engagement index values between Ad1 and Ad2 is statistically significant t(60)=2.40, p=0.019. The non-parametric U Mann-Whitney test did not significantly differ between the EI values for Ad1 (Med=0.371) and Ad2 (Med=0.323), U=583.0, p=0.151. Considering the results of both tests, it can be concluded that the differences between the average EI values for both advertisements are noticeable. However, verifying statistical significance would require a more extensive data set.

The variability in engagement, visible in the standard deviations, may indicate different audience reactions to the advertisements at various intervals. Therefore, further analyses were conducted at the level of the identified scenes in both advertisements (Figure 5).

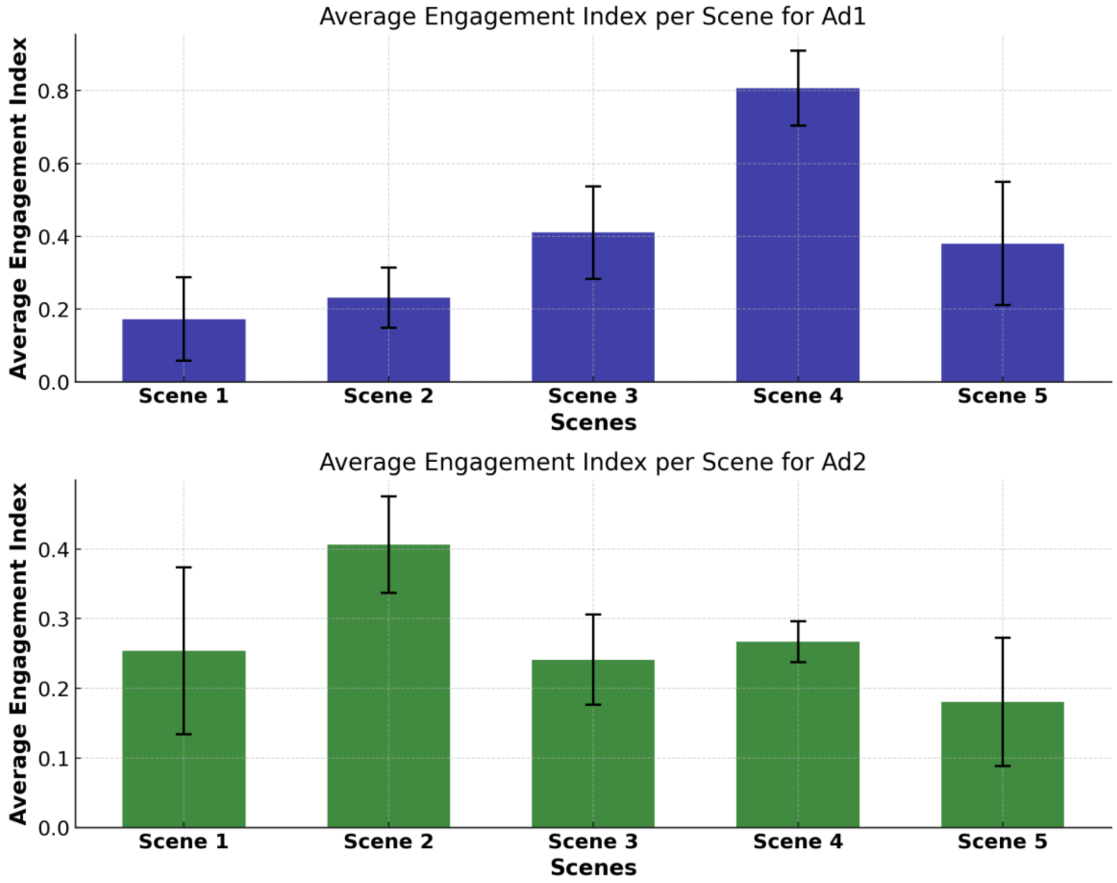

Figure 5. Comparison of average Engagement Index for different scenes in video advertisements: Ad1 and Ad2.

Analyzing the average EI values for the scenes in Ad1 suggests that the initial scenes did not elicit high engagement: S1 (EI=0.173) and S2 (EI=0.231). A more significant increase in engagement is observed for S3 (EI=0.410), with the highest engagement occurring in S4 (EI=0.807). Engagement decreases in S5 (EI=0.380) but remains relatively high. Therefore, scenes S3 and S4 proved particularly effective in increasing engagement.

For Ad2, scene S1 (EI=0.254) generates relatively high engagement, indicating a reasonably practical capture of viewer attention at the beginning of the ad. The significant standard deviation for this scene (SD=0.120) indicates considerable participant engagement variability. An apparent increase in engagement is seen in S2 (EI=0.407), suggesting that the content in this scene was more exciting and engaging. Subsequent scenes show a decline in engagement: S3 (EI=0.241) and S4 (EI=0.267), with the lowest value in S5 (EI=0.180).

The next step was to check whether the differences in average EI between the scenes could be considered statistically significant. Since the EI values for all scenes did not follow a normal distribution, the non-parametric Kruskal-Wallis test was used. The lack of normal distribution for Ad1 was observed in scenes S2 (p=0.029) and S4 (p=0.018) and for Ad2 in scene S1 (p=0.035). The Kruskal-Wallis test showed statistically significant differences in engagement levels between scenes for both Ad1 ($H(4)=22.34$, $p<0.001$) and Ad2

(H(4)=14.67, p=0.005). The Dunn-Bonferroni post-hoc test identified which scenes these differences occur between (Table 2).

Table 2. Results of Dunn-Bonferroni tests for engagement levels in advertisement Ad1 and Ad2.

Advertisement (Ad1)			**Advertisement (Ad2)**		
Scenes		p-value	Scenes		p-value
Scene 1	Scene 3	0.001	Scene 1	Scene 2	0.032
Scene 1	Scene 4	0.000	Scene 2	Scene 3	0.046
Scene 1	Scene 5	0.035	Scene 2	Scene 4	0.022
Scene 2	Scene 3	0.003	Scene 2	Scene 5	0.018
Scene 2	Scene 4	0.000			
Scene 2	Scene 5	0.037			
Scene 3	Scene 4	0.000			
Scene 4	Scene 5	0.001			

The Dunn-Bonferroni test results for advertisement Ad1 showed statistically significant differences in viewer engagement levels between several pairs of scenes. Scenes S1 and S2, which exhibited the lowest average engagement index values, significantly differed from S3, S4, and S5. Similarly, scenes S2 and S4 compared to S5 and S3 and S4 showed significant differences.

For advertisement Ad2, the variation in EI levels between scenes was more minor. Scene S2 stood out, with statistically significant differences in engagement compared to the other scenes (S1, S3, S4, S5). This suggests that S2 contains elements that capture viewers' attention and engage them more. No significant differences were found between the other scene pairs.

Pearson's correlation was applied to examine the relationship between the duration of individual scenes and the level of engagement (EI) in viewing them (separately for Ad1 and Ad2) (Figure 6).

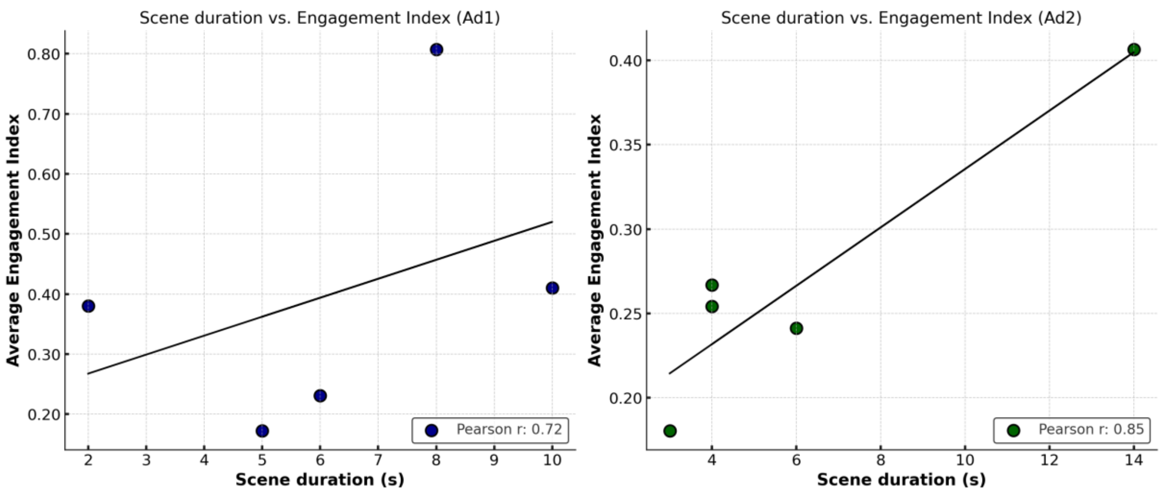

Figure 6. Correlation between scene duration and Engagement Index for advertisements Ad1 and Ad2.

For advertisement Ad1, there is a moderate positive correlation between scene duration and the average engagement index, r(3)=0.72, p=0.12. This suggests that more extended scenes in Ad1 are associated with higher engagement levels (EI), although this relationship is not statistically significant at the 0.05 level. For Ad2, an even stronger positive correlation was found between scene duration and engagement index, r(3)=0.85, p=0.03. This strong positive correlation indicates a statistically significant relationship between scene duration and engagement, suggesting that more extended scenes significantly increase viewer engagement.

Linear regression analysis was applied to investigate the relationship between the total duration of advertisements and viewer engagement. By interpreting the regression coefficients, we can better understand the impact of time on engagement. Identifying trends in EI values helps determine whether engagement increases or decreases as the advertisement progresses. Figure 7 shows the linear regression of the Engagement Index (EI) as a function of time for ads Ad1 and Ad2 (scatter plot and regression line).

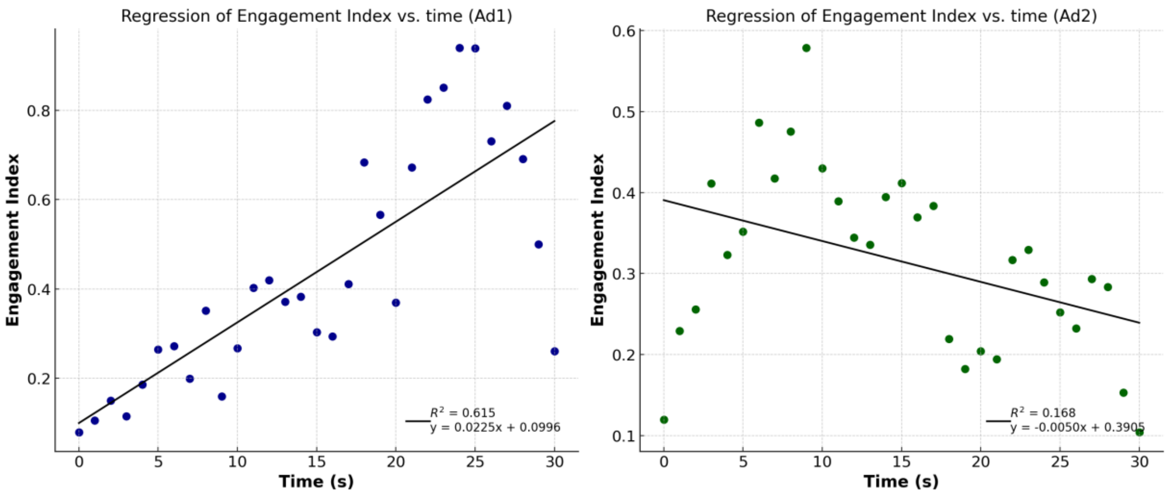

Figure 7. Linear regression of Engagement Index as a function of time for advertisements Ad1 and Ad2.

For advertisement Ad1, the linear regression equation is described by the formula y=0.0225x+0.0996. The positive value of the coefficient B=0.0225 indicates a positive relationship between time and engagement level (EI). This means that the longer the advertisement runs, the greater the viewer engagement. The linear regression model (R^2=0.615, p<0.01) explains 61.5% of the variance in the engagement index. Therefore, the duration of the advertisement is a robust and significant predictor of engagement in Ad1. For advertisement Ad2, a downward trend in viewer engagement can be observed throughout the ad. The formula y=-0.0050x+0.3905 describes the regression equation. The slope coefficient B=−0.0050 indicates that the EI decreases by an average of 0.0050 units for each subsequent second of the advertisement. The regression model (R^2=0.168, p=0.022) explains 16.8% of the variance in the engagement index. This means that the duration of the ad is a weak predictor of viewer engagement in Ad2. The application of the linear regression model thus allows for a better, more precise understanding of the dynamics of viewer engagement in the context of advertisement duration.

DISCUSSION

The study aimed to determine whether measuring brain activity could be effectively used to assess audience engagement with advertising content. According to models of advertising impact on audiences, successive phases of an advertising message should elicit specific reactions, such as attracting attention, generating interest, stimulating desire, or prompting action (purchase, behavior change) (Koziara, 2017). Engaging viewers in the reception of the message is, therefore, one of the critical elements of effective advertising (Zennifa et al., 2018), given the limitations of engagement assessment methods based on self-assessment questionnaires or behavioral measurements, which rely on the performance of specific tasks, (Zennifa et al., 2018) neurophysiological measurement (EEG) was chosen for this study.

The measurement of audience engagement with the advertising content using EEG enabled an objective capture of reactions to two different advertising spots. The first advertisement (Ad1) was broadcast by the electricity provider Energa. The Polish Ministry of Environment aired the second advertisement (Ad2). Advertisement Ad1, promoting energy saving through simple daily actions such as turning off the TV, turning off lights, or closing the laptop, showed a higher level of engagement (EI index) among viewers compared to advertisement Ad2. The higher engagement for Ad1 may be due to more engaging, unusual, and humorous elements, such as animals performing everyday tasks. The obtained results align with published research (Green & Brock, 2000; Heath, 2001), indicating that humor, surprising situations, and elements related to the audience's daily lives can significantly increase the effectiveness of advertising messages. Other studies suggest visual elements and actions that evoke emotions can enhance viewer engagement (Edson Escalas, 2004; Kim et al., 2017). Scenes involving the cat closing the laptop and the dog turning off the light can be considered such actions.

The analysis of the Engagement Index (EI) values for advertisement Ad1 indicates a gradual increase in viewer engagement, reaching its peak 5 seconds before the end of the advertisement. This pattern of increasing engagement is consistent with advertising impact models such as AIDA and Lavidge-Steiner. In the AIDA model, an ad should attract the viewer's attention at the beginning (Attention), then build interest (Interest), followed by desire (Desire), and finally prompt action (Action). Ad1 effectively captures attention and gradually builds interest and engagement, leading to a rise in EI as the advertisement progresses. Similarly, the Lavidge-Steiner model posits that a consumer moves through several stages from awareness (Awareness) to purchase (Purchase). Ad1 effectively supports this process by enhancing viewer engagement at each stage.

In contrast to Ad1, advertisement Ad2 showed a declining trend in viewer engagement as the advertisement progressed. The initial increase in engagement in Ad2, related to the couple's interaction in bed, was short-lived and did not sustain throughout the ad. In advertising impact models like DAGMAR, an advertisement should transition smoothly from unawareness (Unawareness) to action (Action), maintaining viewer engagement. The decline in engagement in Ad2 suggests that the ad needed to meet these assumptions, which may affect its effectiveness in capturing and retaining audience attention.

The analysis of engagement in individual time segments showed that more extended scenes in Ad1 (i.e., S3 – 9 sec. and S4 – 7 sec.) were associated with higher levels of engagement. These two longer scenes allowed for creating a more complete narrative, which helps the viewer better understand the content of the message. The viewer has more time to engage with the presented message and identify with the characters and the situation depicted in the advertisement. By delving into the storyline, the viewer is more inclined to reflect on the message, which strengthens engagement. These conclusions are consistent with literature suggesting that longer, well-designed scenes can increase engagement through deeper information processing by viewers (Cartocci et al., 2019). In Ad2, a downward trend in engagement was observed as the ad progressed. Despite the fact that Ad2 had one long scene (S2 – 13 sec.), it can be said that it ultimately did not fulfill the expected role. It can be inferred that it was not designed well enough, as after an initial increase in engagement, it caused a subsequent decline. This led to a loss of attention, likely due to information overload, boredom, or message distraction, ultimately resulting in lower audience engagement. In Ad1, more extended scenes involving animals were more effective in maintaining viewer attention, aligning with advertising impact models that emphasize sustaining interest and engagement throughout the advertisement (Barry & Howard, 1990).

EEG as a method for measuring engagement enabled objective and precise capture of audience reactions at a neurophysiological level, consistent with previous research highlighting the advantages of physiological measurements. EEG allows for recording subtle changes in brain activity that are inaccessible through other research methods. The proposed methodological approach to studying audience engagement in ad reception is crucial in the context of advertising impact models. As is known, audience engagement with an advertisement affects the way in which viewers process information and respond to the advertising message. Depending on the level of engagement, the mechanisms of advertising action and its effects can vary significantly. The level of audience engagement determines how effectively the advertisement influences their decisions, attitudes, and behaviors. Different advertising models, however, emphasize the importance of this factor in different ways.

CONCLUSIONS

The conducted research focused on increasing energy awareness through effective advertising communication. A vital element of the study was using neurophysiological measurements, specifically electroencephalography (EEG), to assess audience engagement. Two advertisements promoting pro-environmental behaviors were analyzed. The aim was not only to understand how effectively the advertisements could capture attention and engage viewers but also to identify which elements of the message had the most significant impact on engagement. Additionally, the study examined how the level of engagement could influence different phases in selected advertising impact models.

The research findings suggest that using neurophysiological methods to measure engagement can be an effective tool for analyzing the impact of advertising messages on viewers. These studies can contribute to developing more effective communication strategies in social and commercial campaigns, potentially leading to more sustainable consumer behaviors. Organizations promoting appropriate behaviors and shaping energy awareness can use these research results to optimize their advertising messages. This approach can also be effectively applied in other education and social awareness areas, such as ecology, safety, and health.

The proposed methodological approach to measuring audience engagement using EEG is an added value to advertising impact models. It provides objective data on brain responses, allowing a better understanding of which elements of the message truly capture attention and engage the audience. Traditional models rely mainly on subjective data (declarations, observations), whereas EEG offers deeper insights into cognitive and emotional processes occurring in real time. This makes it possible to precisely tailor social ads, such as those promoting energy awareness, to elicit greater engagement and lead to desired attitude changes. EEG also helps assess which moments in the ad have the most significant impact on the audience and which are emotionally engaging. As a result, neurophysiological measurement supports the creation of more effective advertising messages that are better suited to the audience and more effectively influence their attitudes and behaviors.

It is important to note that the study had its limitations. Firstly, the number of participants was relatively small (although sufficient for this type of research), which may affect the generalizability of the results. Additionally, the study focused on a randomly selected group of respondents, which may limit the ability to extrapolate the findings to a broader population. However, the presented methodological approach (research experiment, processing, and analysis of physiological data) can be applied to various research problems. The research could also be expanded to focus on the long-term effects of advertising campaigns. It would be valuable to analyze whether and how lasting changes in energy awareness and behaviors occur among viewers.

IMPLICATIONS FOR RESEARCH, APPLICATION, OR POLICY

The research findings suggest that applying neurophysiological methods for measuring engagement can effectively analyze the impact of advertising messages on viewers. These studies can contribute to developing more effective communication strategies in social campaigns (and commercial ones as well), which can lead to more sustainable consumer behaviors. Organizations that promote appropriate behaviors and shape awareness (including energy awareness) can use the research results to optimize their informational messages. The proposed methodological approach can be practical in advertising spots and other areas related to education and awareness, such as environmental, safety, or health awareness.

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Authors' Note

Funding: Co-financed by the Minister of Science under the "Regional Excellence Initiative".

All correspondence should be addressed to
Bartłomiej Piwowarski
Department of Decision Support Methods and Cognitive Neuroscience
University of Szczecin
Cukrowa 8, 71–004 Szczecin, Poland
bartlomiej.piwowarski@usz.edu.pl

Human Technology
ISSN 1795-6889
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