Evaluating the Data Quality and the Uncertainty in Electroencephalogram Signals for a Neuromarketing Service which Computes Attentional Engagement

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Abstract— **Objective and quantitative data, which indicate when and how much moviegoers are engaged with movies is important for movie makers when creating a film. However, with the traditional method of a review questionnaire, it is difficult to determine precisely the degree to which moviegoers were engaged and when this occurred. To evaluate the Attentional Engagement (AE) precisely, we used electroencephalogram (EEG) on Japanese students who were watching the American movie *Iron Man*. We found a significant decrease in the EEG power in the low-alpha-frequency band while the participants watched film content evoking subjective higher attention. To use our results as reference data for a neuromarketing service, we suggest a procedure with criteria evaluating the quality level of data. According to this procedure, the EEG power values of AE for the movie *Iron Man* can serve as standard reference data with quality level of validated.**

Keywords-neuromarketing service; electroencephalogram; data quality; uncertainty; attentional engagement.

I. INTRODUCTION

Immersion, like flow, has been used to describe the degree of an experience of feeling deeply engaged with types of media such as novels, movies, computer games, and virtual reality. To enter engagement, the first stage of immersion, users (e.g., gamers, moviegoers, etc.) have to invest time, effort, and attention [1][2]. Objective and quantitative measurements are important for media makers to determine when and how much media users are engaged with media. Standard marketing techniques employed for movies thus far have involved the use of interviews and questionnaires after participants view a movie. While useful, it is difficult with these methods to determine precisely the degree to which they were engaged or when they became engaged. If technology, which can measure variations in media users' levels of engagement is developed, it would help media makers when designing media content to induce the intended level of engagement. Currently, the focusing of attention can be monitored by measuring associated changes in brain electrical activity by means of electroencephalogram (EEG) [3][4]. Thus, in principle, EEG measures have the potential to provide a more direct and objective method for gauging the intensity and nature of moviegoer engagement [5][6].

Recently, with neuromarketing technology, defined as the application of neuroscientific methods to analyze and understand human behavior in relation to markets and marketing exchanges, marketing-relevant human behaviour can be understood [7][8][9][10][11]. However, it is difficult to measure physiological signals compared to the ease with which subjective review questions can be given. Therefore, many researchers want to share physiological signal data. Hence, a neuromarketing service, which computes the Attentional Engagement (AE) of moviegoers by measuring physiological signals is necessary and important in film production. In addition, to ensure the reliability of the service, it is also important to evaluate the quality of the data. The issues and practices with regard to a data evaluation include accessibility in data collection, reproducibility of basic evaluations, consistency in relational analyses, and predictability in modelling [12]. The purpose of a measurement is to determine the value of the measurand, that is, the value of the particular quantity to be measured. In general, the result of a measurement is only an approximation or estimate of the value of the measurand and thus is complete only when accompanied by a statement of the uncertainty of that estimate. The uncertainty in the result of a measurement generally consists of several components which may be grouped into two categories according to the way in which their numerical value is estimated. These are A) those which are evaluated by statistical methods, and B) those which are evaluated by other means [13].

In the present study, to serve as a reference data for neuromarketing in film industry, we measured the AE of participants as they watched movies. To validate the reliability of the reference data, we suggested a procedure with criteria, which evaluates the quality level of reference data. Finally, we applied the procedure to the present reference data. The remainder of this paper is organized as following. Section II describes the experimental method including participants, movie and audio-video system as stimulus, experimental procedure, questionnaire, EEG recording, statistical analysis, and evaluating the data quality. Section III describes the results including self-report measure, the EEG response, evaluating the uncertainty, and accrediting the level of data quality. Conclusion and future work are discussed in Section IV.

II. METHOD

A. Participants

The participants recruited were 12 right-handed students from the University of Tsukuba (UT) in Japan. Potential participants were excluded if they reported any history of neurological problems, took within 6 hours caffeine or any drug related to arousal, and had already seen the movie *Iron*

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Man. Due to the approximate time of two hours required for the long experiment, measurement device errors (n=1), drowsiness (n=1) and severe eye blink noise (n=2) caused the data for some of the participants and related measures to be unavailable for use here. Therefore, only eight participants (7 females; mean age: 22.3 years, range 20-28 years) were analyzed to evaluate AE.

B. Stimulus

To avoid previous movie experience by the Japanese participants as much as possible, we played the American movie *Iron Man* (manufacturer: Marvel, year produced: 2008, running time: 2 hours 50 seconds), which was considered to be a typical American ‘superhero’ movie. It was played using a PC-based beam projector system (Epson EB series) with a 5.1 surround-sound system (Cambridge DTT-3500). The main story and the time information for Film segment 1 and 9 are shown in Table I, and the typical scenes are in Fig. 1 (refer to “*D. Self-report measures*”).

TABLE I. CONTENT STORY OF *IRON MAN*

Film ID[a]	Main story of each film content segment	Start (s)	End (s)
1	Tony Stark (the main character in the film) and his colleagues were telling indecent jokes.	50	147
9	Tony Stark was flying through the night sky with the successfully completed *Iron Man* suit.	3,598	3,720

a. Film ID is the segment number of film content

Figure 1. Typical scenes selected from *Iron Man*.

C. Experimental Procedure

Upon arrival, the participants were fully informed of the purpose of the experiment and its procedure, and all signed a consent form that was approved by the Institutional Review Board (IRB) of UT. They were then led to a small sound-attenuated room equipped with a 150-inch wide screen. The procedure of the experiment consisted of three sessions. The first session (baseline session) was done to measure the physiological signals of the participants during a five-minute baseline state. The second session (movie session) sought to measure physiological signals from participants while they watched the movie, and this session took approximately two hours. The third session (questionnaire session), which took place after the movie, evaluated how the participants felt while watching the movie.

D. Self-report measures

With the help of movie narrative and storytelling experts, 11 film-content segments were selected as relatively meaningful parts of the story from the full movie. After watching *Iron Man*, the participants took part in a questionnaire session. For each of the 11 film-content segments, the participants were asked to rate the affection and AE that they felt while watching the movie on a Likert scale ranging from 1 to 9. The subjective questionnaire for affection was prepared by adapting a questionnaire from the model devised by Russel [14]. Finally, we selected two film-content segments, one with the highest score and one with the lowest score, on subjective AE.

E. EEG recording and data analysis

Two-channel EEG signals (Fp1 and Fp2 according to the 10-20 system) for each of the three participants were recorded during the movie session using an MP150 system and AcqKnowledge software version 4.2 (Biopac, USA). To synchronize the physiological signals with the corresponding scene, we measured the changes in the luminance in the scenes with a photometer. By measuring the rapid changes in the levels of luminance, 35 s from the beginning of *Iron Man* was determined as the reference time at which to synchronize with the starting point of the EEG. We collected the EEG activity with a personal computer at a sampling rate of 1,000 Hz. The EEG traces were analyzed in one-second intervals with a step of 0.5 s (50% overlapped). The fast Fourier transform was then computed on 50%-overlapped groups of 1,000-sample Hanning windows for all artifact-reduced data segments to obtain the Power Spectral Density (PSD) for each segment in the approximately two-hour film. Next, the EEG power in the low-beta-frequency band (13-20 Hz) was calculated from the PSD for each one-second segment. EEG signals were analyzed for two film-content segments, i.e., those with the highest and lowest AE scores as determined from self-reports. To examine the changes in the EEG signals while the participants watched these two film-content segments, we selected two intervals in each film-content segment. The duration of each interval was set to 60 s. The mean values of each EEG signals were calculated over two 30-second overlapped 60-second-long intervals for the two film-content segments separately. To analyze the EEG signals, MATLAB S/W version 7 was used.

F. Statistical Analysis

For the two film-content segments selected corresponding to the highest and the lowest subjective AE scores, a paired-samples t-test was carried out for the self-report ratings (AE and affection). The EEG data were subjected to a two-way analysis of variance, with Film Content (the content segments with the lowest AE and the highest AE) and Interval (Interval 1: 0–60 s and Interval 2: 30–90 s from the beginning of each film-content segment) as repeated-measures factors. The eta-squared statistic (η^2), indicating the proportion between the variance explained by one experimental factor and the total variance, is reported. Statistical analysis was carried out using SPSS ver. 21.

G. Evaluating Data Quality

To ensure the reliability of the physiological data, which will be serviced for neuromarketing in movie industry, we established a procedure evaluating the credibility of the data (Table II).

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TABLE II. PROCEDURE USED TO EVALUATE THE DATA QUALITY

Standard Reference Data as validated (1 ~ 8)
1. Specification of quantity to be measured
Stimulus, Target users (Participants), Physiological signals, Measurand
2. Measurement method and procedure
Measurement method, Measurement procedure, Measurement index
3. Theoretical basis of the measurement index
4. Control of factor influencing to measurement
5. Uncertainty of measurement method
6. Uncertainty of values measured
7. Reproducibility
8. Consistency
Standard Reference Data as verified (9)
9. Predictability based on modelling
Standard Reference Data as Certified (10)
10. Overall evaluation by two specialists

This procedure includes multiple acceptance categories with differing acceptance criteria. If the data satisfy criteria items from 1 to 8, then it is qualified as Standard Reference Data (SRD) of validated: satisfy from 1 to 9, then qualified as SRD of verified: satisfy from 1 to 10, then qualified as certified.

III. RESULTS AND DISCUSSIONS

A. Self-report

As Fig. 2 illustrates, the participants reported the highest AE for Film Content 9 (7.75±0.97) and the lowest AE for Film Content 1 (5.21±1.16). The self-report ratings for AE (t=-7.61, p<0.001), valence (t=-4.88, p<0.001), and arousal (t=-4.50, p<0.01) were significantly higher in Film Content 9 compared to those in Film Content 1.

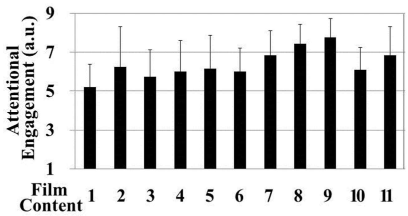

Figure 2. Self-report ratings of attentional engagement for 11 film-content segments in the movie *Iron Man*.

B. EEG Responses

To investigate the changes of the EEG signals while the participants watched Film Contents 1 and 9, we defined Interval 1 as being from 50 to 110 s for Film Content 1 and from 3,598 to 3,658 s for Film Content 9 and Interval 2 as being from 80 to 140 s for Film Content 1 and from 3,628 to 3,688 s for Film Content 9. We defined an attention index (EEG-attention) as the sum of the EEG powers in the low-beta-frequency band at Fp1 and at Fp2 because the low-beta-frequency band is known to be activated during attention. For EEG-attention, the main effect of the Interval was significant (F (1, 11)=5.23, p<.05, η^2=0.37), indicating that EEG-attention is higher in the second interval as compared to the first in the reaction to both Film Content 1 and Film Content 9. However, neither the main effect of the Film Content nor the Film Content by Interval interaction was significant. EEG-attention increased from 32.67±23.45 to 36.96±23.75 [ms^2] (t=-2.06, p=0.069), which was nearly significantly in the reaction to Film Content 9, and from 31.36±20.58 to 31.54±19.53 [ms^2] (t=-1.44, p>0.05) in the reaction to Film Content 1 (Fig. 3).

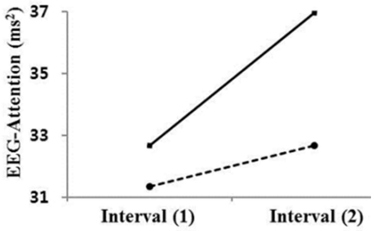

Figure 3. Attention index of the EEG (EEG-Attention). Dotted line denotes Film Content 1 and continuous line denotes Film content 9.

C. EvaluatingUncertainty

The Type A uncertainty of EEG power $u_A(P)$ for Interval 1 of Content segment 1 was calculated from (1). In the same way, the Type A uncertainty of EEG power $u_A(P)$ was calculated for each interval of Content segment 1 and 9, respectively, and summarized in Table III. The Type B uncertainty of EEG potential $u_B(V)$ is the sum of the uncertainty when amplifying the EEG potential using a voltage amplifier (2): $u_{Am\,p}(V)$, when digitalizing from the analog output of the EEG amplifier with a voltage range of 1 mV and with the quantization resolution B being 16 (3): $u_q(V)$, and when the fast Fourier transformation with a sampling frequency f_s of 1,000 (4): $u_{FFT}(V)$ [15]. The $u_{Am\,p}(V)$ was calculated from the expanded uncertainty of voltage amplifier $U_{Am\,p}(V)$, 0.042 V, which was calibrated by Korean national standard. The Type B uncertainty of EEG potential $u_B(V)$ was calculated from (5). The Type B uncertainty of EEG power $u_B(P)$ for Interval 1 of Content segment 1 was calculated from (6). The combined standard uncertainty of EEG power $u_C(P)$ for Interval 1 of Content segment 1 was calculated from (7). In the same way, the Type B uncertainty of EEG power $u_B(P)$ and the combined standard uncertainty of EEG power $u_C(P)$ were calculated for each interval of Content segment 1 and 9, respectively, and summarized in Table IV. The expanded uncertainty $U(P)$ of EEG power with coverage factor $\boldsymbol{k}$ being 2 for Interval 1 of Content segment 1 was calculated from (8). In the same way, the expanded uncertainty $U(P)$ of EEG power was calculated for each interval of Content segment 1 and 9, respectively, and summarized in Table IV. Finally, the EEG power values with expanded uncertainty are summarized in Table V.

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$$u_A(P) = \frac{s}{\sqrt{n}} = 7.07\ \mu V^2,\quad s = \sqrt{\frac{\sum_{i=1}^{n}(x_i - \bar{x})^2}{(n-1)}} \tag{1}$$

$$u_{Am\ p}(V) = \frac{0.042}{2} = 0.021\ \mu V \tag{2}$$

$$u_q(V) = \frac{a}{\sqrt{3}} = V_{range} \times \frac{2^{-B}}{2\sqrt{3}} = 1\ mV \times \frac{2^{-16}}{2\sqrt{3}} = 0.004\ \mu V \tag{3}$$

$$u_{FFT}(V) = \sqrt{\frac{u_q^2}{2f_s}} = \sqrt{\frac{0.004^2}{2\times 1000}} = 9.84 \times 10^{-5}\mu V \tag{4}$$

$$u_B(V) = \sqrt{u_{Am\ p}^2 + u_q^2 + u_{FFT}^2} = 0.021\ \mu V \tag{5}$$

$$u_B(P) = P\sqrt{\left(\frac{2u_B(V)}{V}\right)^2} = 2 \times 36.34\ \mu V^2 \times \frac{0.021\ \mu V}{5.79\ \mu V} = 0.27\ \mu V^2 \tag{6}$$

$$u_C(P) = \sqrt{u_A^2(P) + u_B^2(P)} = 7.08\ \mu V^2 \tag{7}$$

$$U(P) = k\ u_C(P) = 14.16\ \mu V^2,\ k = 2 \tag{8}$$

TABLE III. THE TYPE A UNCERTAINTY OF THE EEG POWER: $u_A(P)$

Participant ID	EEG Power values and Type A uncertainty [μV^2]			
	Content segment 1		*Content segment 9*	
	Interval 1	*Interval 2*	*Interval 1*	*Interval 2*
1	42.82	42.49	50.32	51.81
2	22.29	22.76	23.73	26.47
3	59.39	65.36	62.71	59.55
4	21.00	21.02	30.57	30.91
5	13.13	17.57	17.13	19.35
6	18.13	19.73	19.78	21.11
7	63.06	58.54	76.99	87.91
8	50.91	43.52	30.37	37.67
Average	36.34	36.37	38.95	41.85
Uncertainty Type A: $u_A(P)$	7.07	6.64	7.75	8.29

TABLE IV. THE EXPANDED UNCERTAINTY OF THE EEG POWER: $U(P)$

Items	Type B, combined, and expanded uncertainty for EEG power [μV^2]			
Segments in Film-content	*Content segment 1*		*Content segment 9*	
Intervals in Segments	*Interval 1*	*Interval 2*	*Interval 1*	*Interval 2*
Uncertainty Type B: $u_B(P)$	0.27	0.27	0.27	0.27
Uncertainty Combined: $u_C(P)$	7.08	6.65	7.75	8.29
Uncertainty Expanded: $U(P)$	14.16	13.30	15.50	16.58

TABLE V. THE EEG POWER VALUES WITH EXPANDED UNCERTAINTY

EEG Power value with uncertainty for attentional engagement [μV^2]			
Content segment 1		Content segment 9	
Interval 1	Interval 2	Interval 1	Interval 2
36.34 ± 14.16	36.37 ± 13.30	38.95 ± 15.50	41.85 ± 16.58

D. Accrediting the level of Data Quality

To assure the quality of the data for neuromarketing service, we evaluated the level of the reliability according to the procedure evaluating data quality (Table I). Because the EEG power values with the uncertainty from present study satisfy criteria items from 1 to 8 in Table VI, it can be served as SRD with quality level of validated.

TABLE VI. PROCEDURE USED TO EVALUATE THE QUALITY OF PRESENT DATA

Standard Reference Data as Validated (1 ~ 8)
1. Specification of quantity to be measured
Stimulus
- Genre/ Title: superhero film/ *Iron Man* - Producer/ Produced year: Marvel/ 2008 - Running time: 2 hours 50 seconds
Target users (Participants)
- Nationality: Japan - Gender/ Age/ Number of samples: 1 male (age: 20 years), 7 females (mean age: 22.3 years, range: 20-28 years)
Measurand observable: potential of EEG
Measurand to know: power of EEG
2. Specification of measurement method and procedure
Measurement method: EEG at Fp1 and Fp2 in 10-20 system
Measurement procedure: consists of three sessions (baseline session, movie session, questionnaire session)
Measurement index: EEG power in low-beta-frequency band for attentional engagement
3. Theoretical basis of the measurement index
EEG power in low-beta-frequency band is known to be activated during attention.
4. Control of factor influencing to measurement
To reduce noise, the impedance between electrodes was kept below 5 kΩ.
5. Traceability to national standard
EEG amplifier was calibrated by Korean national standard.
6. Evaluating uncertainty
Combined uncertainty of Type A and Type B was evaluated for EEG power.
7. Reproducibility
Reproducibility was satisfied during preliminary experiment.
8. Consistency
EEG index of attentional engagement consistent with the subjective self-report.
Standard Reference Data as Verified (9)
9. Predictability based on modelling
Modelling will be carried out as future work.
Standard Reference Data as Certified (10)
10. Overall evaluation by two specialists
Overall evaluation will be carried out as future work.

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In this study, we suggested an evaluation method with procedure to assure the reliability of the neuromarketing service data. As validated in credibility according to the procedure evaluating data quality, the present data as reference standard can be serviced to neuromarketing in movie industry. The data include as follows: information of stimulus and participants, raw signals of EEG, and EEG power in low-beta-frequency band for AE with traceable uncertainty.

IV. CONCLUSION AND FUTURE WORK

The present study sought to suggest an evaluation method, which will be used to assure the reliability of a physiological data for neuromarketing service. In conclusion, the method evaluating the reliability of EEG data from participants while watching American movie *Iron Man* results in successful application. The EEG power values with the uncertainty, which is traceable to a Korean national standard can be used as validated SRD for a neuromarketing service. This data can be serviced as reference standard to compute AE of moviegoers while watching the American movie *Iron Man*.

In the future, to enhance the reliability level of present data for neuromarketing service, it will be necessary to construct a model, which predicts the AE of participants while watching movies.

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