Analysis of Relationships between Combinations of Biological Signals and Subjective Interest

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***Abstract*—Interest greatly affects human behavior. Interest is often measured by a questionnaire or observational methods and is used for marketing or advertising purposes. However, there are some problems in the reliability of results of such conventional methods. We propose that using biological signals can help address these issues because such signals are associated with biological reactions to interest. This study describes an experiment and multiple linear regression analyses of the relationships between a viewer's interest in an infomercial and the viewer's biological signals such as electroencephalogram, hemoencephalography, blood volume pulse, skin conductance, and respiration. The subjective interests of viewers were measured by a questionnaire. A comprehensive index of interest based on the answer values was extracted by principal component analysis. We then constructed an individual regression equation to estimate the degree of interest from different combinations of biological signals.**

***Index Terms*—biological signal, infomercial movies, subjective interest**

I. Introduction

Interest has a great influence on our daily lives. It is interest that motivates people to become involved in things [1]. Therefore, it is very important to measure human interest, especially in marketing and advertising, which must adopt developmental strategies to respond to consumer behavior [2]. Conventionally, interests are measured using an observational method or a questionnaire method in these fields.

However, there is a reliability issue with measurement results analyzed by such methods. Using an observational method, there can be differences between estimations of an observed interest and a participant's subjective interest. Therefore, the precision of the measurement can be influenced by the observer's skill [3]. Similarly, using a questionnaire method, respondents may be unable to answer an estimation easily and honestly. In particular, a respondent can intentionally answer with an estimation that a researcher desires or one that is socially desirable [4].

We propose using biological signals to address these issues. The proposal is based on MacLean's "triune concept of the brain and behavior [5]." MacLean proposed that developing interest originates in the cerebral limbic system responsible for instincts and emotions, and that physiological indexes originate in the hypothalamic area responsible for life maintenance. The cerebral limbic system and hypothalamic area influence each other due to the close nerve fibers between them [6]. It is considered that biological signals change with changes in interest.

This study verifies the relationship between viewer interest and a combination of biological indexes when the viewer is watching a video. In particular, it describes the verification of relational expressions by estimating the degree of interest from biological signals using multiple regression analyses. The combination of biological indexes is used to verify the estimation accuracy using fewer biological signals, which reduces participant's burden.

II. Related Work

This section introduces work related to the relationship between mental activities and biological signals.

Relative to changes in biological signals with changes in emotions, Omata et al. developed a model that estimates the emotion of a viewer observing an emotional picture [7]. The model represents a decrease in the ratio of hemoencephalography (HEG) and an increase in the power value of alpha brain waves (electroencephalogram, EEG) when the viewer looks at a positive picture. Moriwaki et al. reported an increase in respiration rate when a viewer watches an animation that increases arousal. They also reported an increase in the power value of the high frequency of blood volume pulse (BVP) when a viewer watches an animation that lowers arousal [8].

Relative to estimation accuracy, Mikhail et al. reported an emotion estimation model that estimates the emotions of a person who creates a facial expression of delight,

Manuscript received April 24, 2015; revised June 24, 2015.

doi: 10.18178/ijpmbs.4.3.158-162

fear, anger, or sadness by classifying the brain waves using a support vector machine [9]. The accuracy rates were 51% for delight, 58% for fear, 53% for anger, and 61% for sadness.

In a study into the relationship between mental activities and biological signals, Mandryk *et al*. investigated the relationships between emotions and skin conductance (SC) and electromyogram (EMG) data on the cheeks and glabella of a user who played a video game [10]. The results showed that it is possible to estimate user arousal from SC, and that it is possible to estimate emotional valence from EMG data. Sakamoto et al. investigated the relationships between the results of questionnaires about emotional movies and biological signals [11]. The results showed that brain blood flow is useful for estimating emotional valence and that heart rate and the ratio of low frequency and high frequency (LF/HF) can be used to estimate multiple emotions. Mauri et al. investigated the relationships between State Trait Anxiety Inventory (STAI) scores for emotions and biological signals [12]. The results showed that SC and heart rate correlate closely with STAI scores.

III. Biological Signals

We measured brain waves (EEG), brain blood flow (HEG), blood volume pulse (BVP), SC, and respiration (RESP), which are considered closely related to human interest, to conduct experiments to verify the relationships between interest and biological signals. Moriwaki and Omata et al. established that emotional valences can be estimated from EEG, HEG, BVP, SC, and RESP [7], [8]. We have used ProComp INFINITI (Thought Technology Ltd.) to measure these signals.

Brain waves are weak electrical impulses generated by nerve cell activity in the brain. The waves are classified by the following frequency bands: theta (4-8 Hz), alpha1 (8-9 Hz), alpha2 (9-12 Hz), alpha3 (12-14 Hz), and beta (14-26 Hz) waves. The power values of the bands are calculated as physiological indexes. We attached an exploring electrode on Fp1 according to the international 10-20 system because a previous study has shown that mental activity is processed in the frontal lobe [13].

The HEG ratio is a relative ratio between the amount of oxygenated hemoglobin and the amount of reduced hemoglobin. The HEG ratio is calculated as follows

$$\mathrm{HEG} = \mathrm{RED}/\mathrm{IR} \times 200 \quad (1)$$

where RED is the absorptive powers of oxygenated hemoglobin and reduced hemoglobin during visible red light irradiation, and IR is their absorptive powers during near-infrared light irradiation. We attached a HEG sensor system (MediTech Electronic) to Fp2 according to the international 10-20 system.

RESP rate increases when a person is highly aroused or is performing exercise. RESP rate decreases when a person is relaxed. We attached a Resp-Flex/Pro (Thought Technology Ltd.) to the abdomen to monitor RESP rate.

BVPs are changes in vascular volume derived from a cardiac beat. BVP waves are classified by the following frequency bands: high frequency (HF, 0.15-0.4 Hz) and low frequency (LF, 0.04-0.15 Hz). The power values of HF and LF and the LF/HF ratio are calculated as physiological indexes. The LF/HF indicates the ratio of sympathetic nerve activity to parasympathetic nerve activity. We attached a BVP-Flex/Pro (Thought Technology Ltd.) to the left thumb to measure BVP.

The SC value indicates the electric conductivity of emotional sweating by eccrine glands in a participant's hand. We attached two SC-Flex/Pro electrodes (Thought Technology Ltd.) to a participant's left index finger and ring finger to sense electric conductivity between the fingers.

The values for brain waves, HEG, and SC are normalized as follows

$$Z=(X-\mu)/\sigma \quad (2)$$

with the values of the participant's normal signals, where X is the value from biological signals during the experiment, μ is the average value of the normal signals, and σ is the standard deviation from normal signals.

The indexes for RESP rate and BVP are normalized as follows

$$Z=X/Y \quad (3)$$

where X is calculated from biological signals during an experiment, and Y is calculated from normal signals.

IV. Experiment

We conducted an experiment to investigate the relationship between a viewer's interest and biological signals while watching videos of shopping programs. We compared viewers' subjective answers to a questionnaire regarding their interests with the viewers' objective physiological indexes calculated from the biological signals described above.

A. Experimental Environment

Fig. 1 shows the experimental environment. We used a 17-inch LCD to display an infomercial, a computer to render the movie and record the biological signals, and sensors to measure the signals.

The participant sat in a chair 30 cm from the table the LCD was placed on. The participant was instructed to place their left hand on the table and not move it while watching the video in order to reduce measurement noise.

Figure 1. A situation of an experiment.

B. Participants

The participants were seven college students aged 22-24. Only one participant was female.

C. Infomercial Videos

We used video files of shopping programs from an online shopping site (Nihonchokuhan Co. Ltd.) [14] as experimental stimuli to generate interest (or a lack thereof). We used videos for products that college students would likely be interested in, such as a bread-making machine, a rice cooker, and an all-purpose cleaner, as well as products that such students might not be interested in, such as a hairpiece, a sewing machine, and an electric hair clipper.

D. Questionnare

The question items about viewers' interests in products were related to "necessity," "impression," "favorability," "originality," "willingness," "regard," "clarity," "utility," "convenience," "fascination," and "reasonableness." We referred to previous studies [15]-[18] about interest to determine these question items. Each item was ranked on a five-point Likert scale.

E. Experimental Procedure

First, the participant's biological signals were measured and recorded for one minute while the participant sat quietly after attaching the sensors.

Then, the participant answered a questionnaire about a product by reading a leaflet with promotional material (including a picture) about the product prior to watching a video related to the given product.

The participant then watched an infomercial about the product for two minutes. During this time, their biological signals were measured and recorded.

Finally, the participant answered the same questionnaire for each product.

All participants performed the experimental procedure for all videos once according to a Latin square design. The answer values obtained after watching the videos were used for analyses.

V. Results and Analyses

Here, we describe multiple linear regression analyses between the physiological indexes and the answer values in two cases, i.e., using all indexes and using a combination of some indexes.

An objective variable of the regression analyses is a comprehensive answer value, i.e., a first component determined by principal component analysis of the answer values of the eleven question items.

Explanatory variables of the regression analysis are principal components determined by principal component analysis of the physiological indexes. The reason we conducted principal component analysis was to solve the multicollinearity of the multiple linear regression analyses.

A. Regression Analysis Using All Indexes

Equation (4) illustrates the relation between the comprehensive value as the first component and the answer values of all products of all participants. *A* of (4) is the coefficient matrix shown in Table I.

$$Comprehenshive\ value = A \begin{pmatrix} \text{"regard"} \\ \text{"impression"} \\ \text{"willingness"} \\ \text{"fascination"} \\ \text{"favorable"} \\ \text{"necessity"} \\ \text{"utility"} \\ \text{"originality"} \\ \text{"convenience"} \\ \text{"reasonable"} \\ \text{"clarity"} \end{pmatrix} \tag{4}$$

TABLE I. Coefficient Matrix *A* of (4)

Question item	Coefficient
Regard	0.38
Impression	0.38
Willingness	0.37
Fascination	0.37
Favorable	0.34
Necessity	0.32
Utility	0.29
Originality	0.23
Convenience	0.20
Reasonable	0.15
Clarity	0.15

$$The\ first\ component = B \begin{pmatrix} Power\ of\ \theta \\ Power\ of\ \alpha_1 \\ Power\ of\ \alpha_2 \\ Power\ of\ \alpha_3 \\ Power\ of\ \beta \\ HEG\ ratio \\ RESP \\ SC \\ Power\ of\ HF\ of\ BVP \\ \frac{LF}{HF}\ of\ BVP \\ Tne\ num.of\ BVP \end{pmatrix} \tag{5}$$

TABLE II. Coefficient Matrix *B* of (5)

Physiological indexes	Coefficient
Power of θ	0.42
Power of α_1	0.44
Power of α_2	0.44
Power of α_3	0.40
Power of β	0.42
HEG ratio	0.25
RESP	-0.05
SC	0.13
Power of *HF* of *BVP*	0.01
LF/*HF* of *BVP*	−0.09
The number of *BVP*	−0.05

Equation (5) illustrates the relation between the first principle component and the physiological indexes of all products of all participants. The *B* of (5) is the coefficient matrix shown in Table II.

The contribution ratio of the multiple linear regression equation using all physiological indexes and all answer values of all participants is 0.25, which is a low accuracy for a regression model. However, the contribution ratios of the individual multiple linear regression equation using all physiological indexes and all answer values of each participant range from 0.48 to 0.99. The ratios of six participants are 0.80 or greater; the highest ratio is 0.99.

B. Regression Analysis Using a Combination of Signals

This section describes the individual multiple linear regression equation using the answer values of each participant and the physiological indexes of a combination (two, three, and four indexes) of different biological signals.

Table III shows the combinations of four types of biological signals and the subjects' identifiers for contribution ratios of 0.5 or greater. In Table III, underlined identifiers indicate that the contribution ratios are 0.7 or greater.

TABLE III. COMBINATIONS OF FOUR TYPES OF BIOLOGICAL SIGNALS

Combination	Identifiers with contribution ratio of 0.5 or greater
RESP, HEG, SC, BVP	A, B, C, D, E, F, G
EEG, HEG, SC, RESP	A, B, C, D, E, F, G
EEG, HEG, SC, BVP	A, B, C, D, E, F, G
EEG, HEG, RESP, BVP	A, B, C, D, E, F, G
EEG, RESP, SC, BVP	A, B, C, D, E, G

Table IV shows the combinations of three types of biological signals and the subjects' identifiers for contribution ratios that are 0.5 or greater. In Table IV, underlined identifiers indicate that the contribution ratios are 0.7 or greater.

Table V shows the combinations of two types of biological signals and the subjects' identifiers for contribution ratios of 0.5 or greater. As above, underlined identifiers indicate contribution ratios of 0.7 or greater.

VI. DISCUSSION

We consider that the reason we could construct regression equations with high precision using the combinations of biological signals is that the biological reaction directionality of each participant was stable while the participant was interested in a video. In other words, we think that the decrease or increase of physiological indexes is consistent with the degree of change of the participant's interest.

In this experiment, the most stable signal was brain wave followed by BVP. The contribution ratios of six participants are 0.7 or greater in the combinations of two biological signals that include brain waves. In addition, the contribution ratios of all participants are 0.7 or greater in the combinations of three biological signals that include BVP.

The contribution ratio of the regression equation for all participants was low because the quality or magnitude of interest varies for different individuals.

TABLE IV. COMBINATIONS OF THREE TYPES OF BIOLOGICAL SIGNALS

Combination	Identifiers with contribution ratio of 0.5 or greater
EEG, HEG, SC	A, B, C, D, E, F, G
BVP, HEG, RESP	A, B, C, D, E, F, G
BVP, RESP, SC	A, B, C, D, E, F, G
BVP, HEG, SC	A, B, C, D, E, F, G
EEG, RESP, SC	A, B, C, D, E, F, G
EEG, HEG, RESP	A, B, C, D, E, F, G
EEG, BVP, SC	A, B, C, D, E, F, G
EEG, HEG, BVP	A, B, C, D, E, F, G
EEG, BVP, RESP	A, C, D, E, F, G
RESP, HEG, SC	B, C, D, G

TABLE V. COMBINATIONS OF TWO TYPES OF BIOLOGICAL SIGNALS

Combination	Identifiers with contribution ratio of 0.5 or greater
EEG, RESP	A, B, C, D, E, F, G
EEG, SC	A, B, C, D, E, F, G
EEG, BVP	A, B, C, D, E, F, G
EEG, HEG	A, B, C, D, E, F, G
HEG, BVP	C, D, E, F
BVP, SC	B, D, E, F
BVP, RESP	D, E, G
HEG, SC	B, D
HEG, RESP	B, G
RESP, SC	D

VII. CONCLUSIONS

Our regression equations for six of the seven participants can regress a degree of interest in a product in an infomercial video with an accuracy rate of 70% or greater using only two biological signals (including brain waves). In addition, our regression equations for all participants can regress a degree interest with an accuracy rate of 70% or greater using three biological signals including BVP (but not brain waves). These results suggest that we can reduce user burden during measurement of biological signals. To regress or estimate the degree of interest without brain waves is of particular importance.

In future, we plan to analyze time series variations of biological signals recorded in the experiment to verify the time series variations of participant interest in the videos. We also plan to use eye-tracking data to analyze fixation points to determine regions of the videos that attracted attention to improve the estimation accuracy of the regression equations.

ACKNOWLEDGMENT

This work was supported by the Japan Society for the Promotion of Science KAKENHI Grant Number 26350315.

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