Biosignal measurements for Neurophysiological tests aimed to determine new beverage responses

Stiliyan Georgiev
Validation – Vision Analysis Team
Visteon Electronics Bulgaria
Sofia, Bulgaria
stilliyan@gmail.com

Stanimir Andonov
Department of Economics, Industrial Engineering and Management,
Faculty of Management
Technical University of Sofia
Sofia, Bulgaria
stanimir.andonov@tu-sofia.bg

Georgi Tsenov
Department of Fundamentals of Electrical Engineering,
Faculty of Automatics
Technical University of Sofia
Sofia, Bulgaria
gogotzenov@tu-sofia.bg

Valeri Mladenov
Department of Fundamentals of Electrical Engineering,
Faculty of Automatics
Technical University of Sofia
Sofia, Bulgaria
valerim@tu-sofia.bg

***Abstract*—The main aim of this work is to present a test methodology framework for neuromarketing evaluation of drinks and tastes by obtaining statistically significant conclusions from test focus groups neurophysical reaction. In the past decade there was high rise of affordable and easy to use sensors for biosignal measurements, that provide data in real time at any place. This is the case for electroencephalographic signals (EEG) that can be measured from the human skull and galvanic skin response (GSR) and pulse, that can be measured from a finger. The human brain activity and neurophysiological reaction to external stimuli can be measured and represented to some extent with EEG, GSR and pulse. With feature extraction from the raw signals and detection of informative features that are user independent, we can perform simple classifications process and apply the measured brainwaves in variety of applications. In this paper we present the application of EEG brainwaves, paired with GSR and pulse for recognition of the degree of response variation in a test group in order to determine the test group preferences.**

Keywords—biosignal feedback, electroencephalography, feature extraction, neuromarketing, signal processing.

I. Introduction

In the past, and in many instances up to now, the determination of either whether a product/taste/marketing material is good or bad was either determined individually with experts or obtained with focus groups given a set to questions to answer. In the past decade a new technology emerged in the mass market, that were available only in hospitals and laboratories, that allows easy measurements and recordings of multichannel biomedical data. Also, in the past decade huge advancements were made in the field of big data and deep learning neural networks, paired with huge advancement in computational power, that allows the processing of huge amounts of big biosignal datastreams in real time in order to determine relevant features paired to the test person neurophysiological reaction. This approach of using biosignal feedback gave birth to a new approach for testing marketing material called neuromarketing and it brings together neuroscience and marketing. It uses the power of new technologies to study the brain and the physiological responses of the entire human body while exposed to certain controlled stimuli. The purpose is to measure the subject's response to certain marketing stimuli. In most cases, the brain responses measured by these techniques do not occur consciously and one cannot control them. Therefore, these data can be considered more indicative and reliable than data obtained from interviews, focus groups and other traditional techniques.

Usually, the neuromarketing is an attempt to uncover the unconscious reactions of consumers to various marketing stimuli by companies by obtaining group human reactions to brands and any associations related to them, also to company logos, slogans, entire advertising clips and campaigns, and respectively to the tangible or intangible products offered by the companies on the market. So, for example, through the use of electroencephalography and other techniques, researchers may discover that a given stimulus elicits the same response in the brains of the subjects participating in the study and that this response is associated with a desired behavior (e.g., trying something new). A marketing campaign that uses this stimulus to elicit this behavior can be said to be based on neuromarketing, although no specific subject studies have been conducted in this case.

This same methodology can be applied when a company wants to promote new product line of food or drink and trying to adopt to certain demographic. For instance, in the past companies like The Coca Cola Company, Pepsico and many others are changing the ingredients of the main product like Coca Cola or Pepsi, or introducing new products like Mirinda, Sprite, etc. and these companies wanted to appeal to the mass market with claims that they're product is better or best in order to sell more of it. Usually there are several varieties of the same drinks marked with numbers and with tests from focus groups and questionnaires the samples with most positive answers in the answered question boxes are chosen as the final product to be offered in the final product. The problem with using questionnaires in this field is that sometimes a test person from the focus group may not know what are his/her preferences and provide false results, while by using directly measured data from the brain reaction with EEG, paired with GSR and pulse, we can quantify with appropriate feature set the sincere reaction of the test subject to the external stimuli. This can lead to approach very similar to the one applied in the neuromarketing, so we have decided to develop a procedure to extract the results for new product drink taste reaction taken directly from the neurophysiological reaction and not only with questionnaire.

This paper is organized as follows. In Chapter 2 are presented the neurometric and biosignals that are measured and what relevant features are obtained from them. In Chapter 3 is presented the methodology for drink taste evaluation and results, followed by Conclusion, Acknowledgement and References sections.

II. NEUROMETRIC AND BIOSIGNALS USED

The category of biometric techniques, also called biometrics, consists of measurement techniques with a special emphasis on the physiological changes in the organism of the test subject participants. Biometric measurement methods investigate cognitive processes without recording brain activities [1].

Biometric techniques are: galvanic reaction of the skin (skin conductance); electromyography; tracking eye movements; reaction times; pulse rate; analysis of facial expressions; frequency analysis of the voice.

Neurometrics, on the other hand, refers to measurement techniques that have a particular focus on blood flow and neuronal activity in the brain. Neurometric techniques are: electroencephalography; magnetoencephalography; functional nuclear magnetic resonance [2]; positron emission tomography (PET) [3] and Functional near-infrared spectroscopy (FNIRS) [4].

The easiest to obtain and analyze from the biometrics are the skin conductance response and the pulse, while from the neurometrics it’s the electroencephalography.

The skin conductance response, also known as the electrodermal response (or as "galvanic skin response"), is the phenomenon that the skin momentarily becomes a better conductor of electricity when either external or internal stimuli occur that are physiologically arousing. The GSR is performed by measuring the conductance of the skin as a result of an electric current being carried across the surface of the skin. The basic principle is that the level of activation of a person's sweat glands during a change in emotion will fluctuate, and this physiological stimulation will lead to a change in electrodermal activity. Arousal is a broad term referring to overall activation, and is widely considered to be one of the two main dimensions of an emotional response. Measuring arousal is therefore not the same as measuring emotion, but is an important component of it. Arousal has been found to be a strong predictor of attention and memory. For measuring it we use an in house build sensor that is attached to a finger with 128 Hz signal sample rate, transmitting the recorded data to PC with USB interface.

The pulse measures the hearth beats per minute and is measured in BPM. Heart rate data is relatively easy to record and analyze. Breathing rate is an indicator that correlates with heart rate, but respiratory rate measurements are much more complicated, so heart rate measurement is usually preferred over respiration rate measurement. When the heart rate increases, this is seen as an expression of an increased level of arousal. Heart rate can vary from person to person due to various physiological and psychological factors such as body temperature, mental stress and sleep deprivation. Typically, researchers are primarily interested in analyzing changes in heart rate over time (heart rate variability) to detect changes in heart rate from a set baseline. The great advantage of heart rate measurement is that it is easy and inexpensive to perform and the measurements are highly reliable. As with measuring the galvanic response of the skin, measuring heart rate can tell us how excited a subject's nervous system is by exposure to certain stimuli. For measurement of this biosignal type we have used a smartwatch with pulse measurement functionality and transferring the data to PC wirelessly by utilizing Bluetooth connectivity.

Electroencephalography (EEG) is a recording of the brain's bioelectrical activity. EEG signal detection is done with usage of electrodes, which are placed on the scalp in order to detect electrical activity in the human brain. The neural cells in the human brain communicate by electrical impulses at all instances of time. This activity is monitored in form of brainwaves. EEG signals can be separated into several waveband classes-based frequency range. α band waves are ranging between 8 and 13 Hz in frequency, and between 30 and 50 μV. This brainwave type is useful to trace mental effort because of its higher amplitude. β band waves ranging between 14 and 30 Hz in frequency, and between 5 and 20 μV in amplitude. Beta waves can be measured from frontal and central regions of the brain. The central beta wave can be blocked by motor activity and operation of the planning to make a move. θ band waves are ranging between 4 and 8 Hz in frequency, with an amplitude of less than 30 μV. Theta waves are associated with access to unconscious materials, creative thinking and deep meditation. Furthermore, there is a link between emotions such as disappointment and frustration. δ band waves are ranging between 0.5 and 3 Hz in frequency, and between 100 and 200 μV and the final archetype is γ band waves, ranging between 31 and 50 Hz in frequency, and between 5 and 10 μV and are used to detect high cognitive activities. The International 10-20 system is used to record the spontaneous EEG. In this system the electrodes are located on the surface of the scalp as shown in Fig. 1.

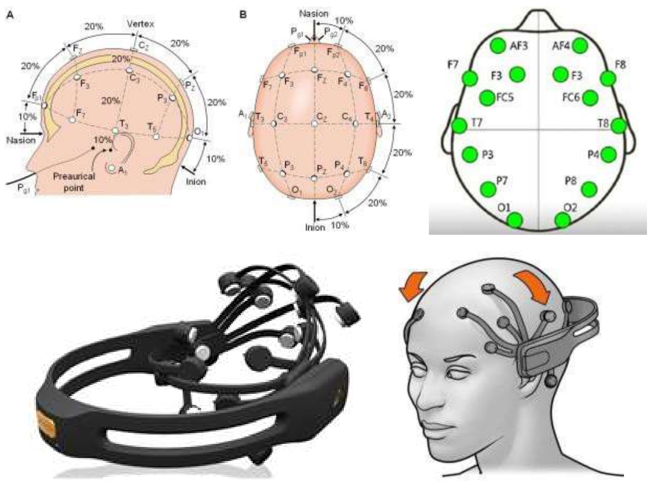


Fig. 1. The EEG 10-20 system of electrode placement and Emotiv EPOC+ EEG headset system electrode placement

The electrode placement positions are determined by dividing the skull into perimeters by connecting few reference points on human head. From these points, the skull perimeters are measured in the transverse and median planes. Electrode locations are determined by dividing these perimeters into 10% and 20% intervals. The “Emotiv EPOC” + is an EEG Headset with 14 channels of EEG data that we use and the measure data is send via Bluetooth interface wirelessly to PC, sampled in 2048Hz and downsampled to 128Hz resulting in 64Hz baseband. Based on the cognitive load the cognitive index is presented:

$$\partial = 100\left(\frac{\in b - \in t}{\in b}\right) \quad (1)$$

where ∂ is the cognitive index, $\in b$ is the base-line intermission of band power, and $\in t$ is the task internal of band power. Measurement of cognitive load is typically consisting bands extraction, features extraction and classification.

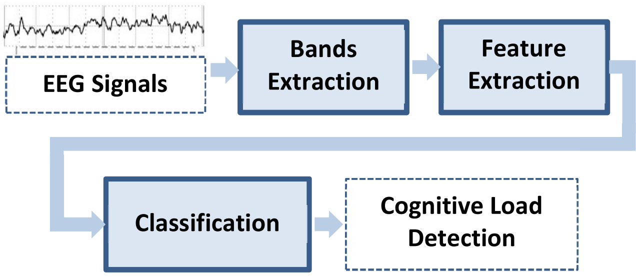


Fig. 2. The EEG signal processing and detection chain

From the measured EEG a relevant feature extraction on the raw signals can be performed as shown on Fig. 2. The most relevant features observed from researchers related to attention and concentration are in the Theta and EEG Alpha baseband. Clinical research from Klimesch [5], [6], [7] showed that the volume of power of Theta and Alpha frequency range in EEG is certainly associated with cognitive performance and memory in specific, if a binary dissociation amid absolute and event-related fluctuations in alpha and theta wave is considered and shows that alpha activity can be accepted as marker for attention and the theta EEG activity can be accepted as marker for memory. The reduction the EEG alpha activity for a given time window may indicate a moment of increased attention attraction to external stimuli and respectively, the time moments where the EEG theta activity increases may be perceived as moments that will be memorized better. So based on this as an analysis tool the Alpha and Theta and their combination of Theta/Alpha are going to be used. Also, the use of EPOC+ EMOTIV EEG devices provides the opportunity to use six archetypal feature classes of emotion measurements. They are calculated using a deep learning neural network classifier trained and tuned by utilizing data from thousands of different test subjects and are obtained from the raw EEG data and represent an estimate of some mental states, i.e., derived directly from the participants' measured brain activity. The six emotional states that can be measured with the neural network are Stress, Engagement, Interest, Excitement, Focus and Relaxation. In order to have a comparison between results from person to person and from different periods of time, due to skin conductivity/resistance or electrodes being not wet enough, resulting in varying voltage levels and signal quality the features are normalized and scaled in the range between 0 and 1. Stress/tension is a measure of comfort. High stress may result from the inability to perform a difficult task, causing test subjects to feel overwhelmed and fear negative consequences for failing to meet the demands of the task at hand. In general, a low to moderate level of stress can improve performance, while a higher level tends to be detrimental. Engagement feature is felt as alertness and consciously directed attention to task-relevant stimuli. This archetypal class measures the level of "immersion" in the given task at the particular moment and is a combination of the attention and concentration parameters and contrasts with boredom. Engagement is characterized by increased physiological arousal and beta waves along with suppressed alpha waves. The greater the attention, focus, and workload, the greater the parameter discovery output for that archetypal class. Interest feature class represents the degree of attraction or aversion to the current external stimuli, environment or activity and is often referred to as Valence. Low scores on the interest parameter indicate strong aversion to the given task, and high interest indicates strong affinity with the task, while mid-range scores do not interfere with either liking or disliking the external stimuli. Excitement feature class is a marker for the level of sensation of physiological arousal with a positive value. It is characterized by activation of the sympathetic nervous system, resulting in a number of physiological responses, including pupil dilation, eye dilation, and stimulation of sweat glands, increased heart rate and muscle tension, and inhibition of digestion. In general, the greater the increase in physiological arousal, the greater the output for the detection of this parameter. The detection of the Excitement parameter is tuned to provide results that reflect short-term changes in arousal over periods of just a few seconds. Focus is a measure of the level of sustained attention to a particular task. Focus measures how intense attention was, as well as the frequency with which the test subjects paid attention between the different tasks at hand. A high level of task switching is an indication of poor focus and distraction. The final feature Relaxation is an assessment measure of the test subjects' level of ability to stop thinking and concentrate on a specific task and recover to a state of rest, for example a trained mediators such as yoga instructors can have extremely high relaxation scores.

By combining some of the bio-signals connected to measurements and quantifications of neurophysiological reactions, based on external stimuli with feature extraction a test procedure can be made that statistically can extract preference data, determined from measurements of statistically significant enough focus group.

In the scientific literature, there are many studies in which, with the help of EEG and biometrics, a person's reactions to stimuli in visual and auditory modalities are studied. The accumulated information is already adapted for neuromarketing purposes to evaluate the impact of various print, television, radio and Internet advertisements [8], [9], [10], [11], [12], [13]. The situation is different with the taste modality, where the research is few and the results are practically not tied to the goals of neuromarketing [14], [15], [16]. Therefore, the aim of the present work is the creation and validation of an experimental test set-up for recording and processing the neurophysiological body response to taste stimuli for neuromarketing needs and context.

III. METHODOLOGY FOR DRINK TASTE EVALUATION AND EXPERIMENTAL RESULTS

With use of the signals and features described in the previous chapter setup environment for conducting an experiment can be made, based on the presumption that when a drink is sipped, a neurophysiological response should occur in the test subjects. For the purposes of the experiment, the following methodology and toolset have been prepared for each respondent test subject. For the test we use four different drink types not yet introduced to the market, Pant yellow and green (Drinks 1 and 2 with lemon and apple tastes), Forest fruits (Drink3) and Pear (Drink4) to be tested on focus group with size of eight and mixed gender and age variance (Fig.3).

Fig. 3. The test setup and tested drinks

We also use an eye tracking hardware and software. As initial step the respondents read the three concepts and their eye movements are tracked, then the unprovoked response with EEG, pulse and skin conductance are measured and recorded. Then the first drink is given to be drinked and recording of EEG, pulse and skin conductance is performed. After this step the respondents drink alone and wait 10-15 seconds between sips. Then the second drink is given and again the biometrics are recorded. After this step respondents drink alone and wait 10-15 seconds between sips. These steps are repeated by following third and fourth beverage similar drink and biometrics data recording procedures. Because the drinking process (picking up the bottle, sipping and returning the bottle to the table) causes signal artifacts, for analysis the recording from 2s to 7s after the bottle was returned to the table was used (Fig. 4).

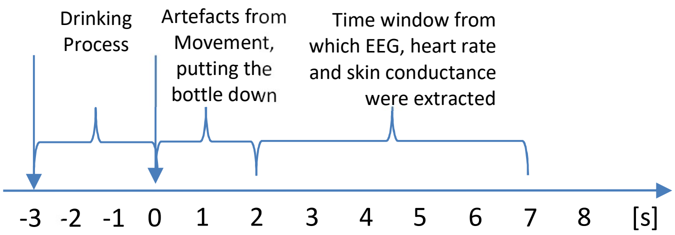


Fig. 4. Time interval for which the signals analysis has been made.

Finally, a semi-structured interview is conducted with each respondent.

The aggregated sum of the recorded EEG data by alpha and theta baseband frequencies and the theta/alpha ratio produced the following results as presented on Fig. 5.

From these results the conclusions can be made that Forest fruits and Pear drinks are attracting more attention with higher interest and conscious analysis of tastes.

The recorded aggregated biometric data from the pulse and skin conductivity are given in Fig. 6, while the aggregated data from the whole test data set based on the six informative features obtained with the pretrained deep neural network from EMOTIV are presented on Fig.7.

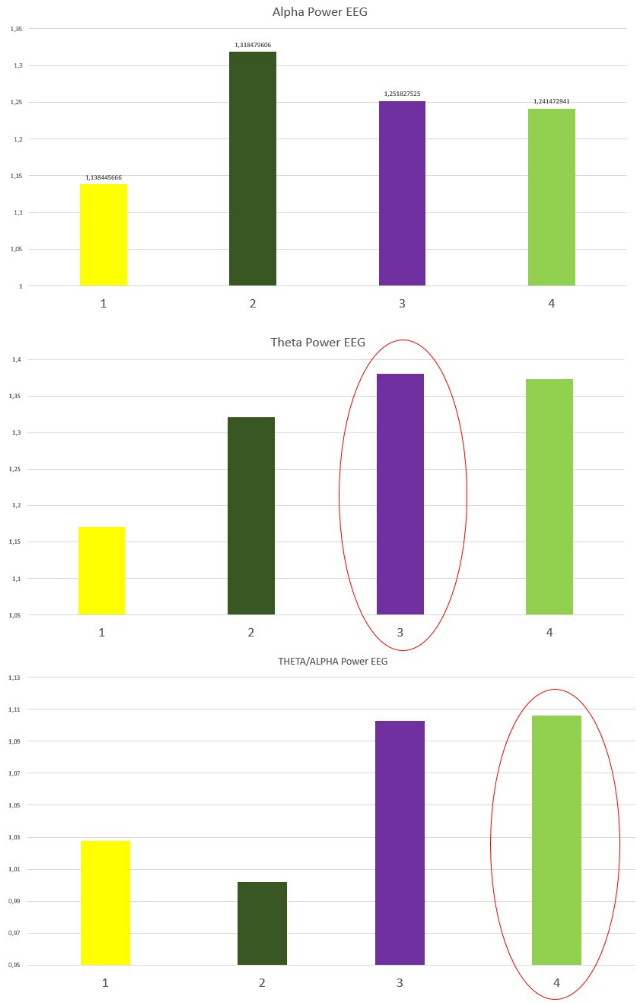


Fig. 5. Alpha, Theta and Theta/Alpha EEG Power levels

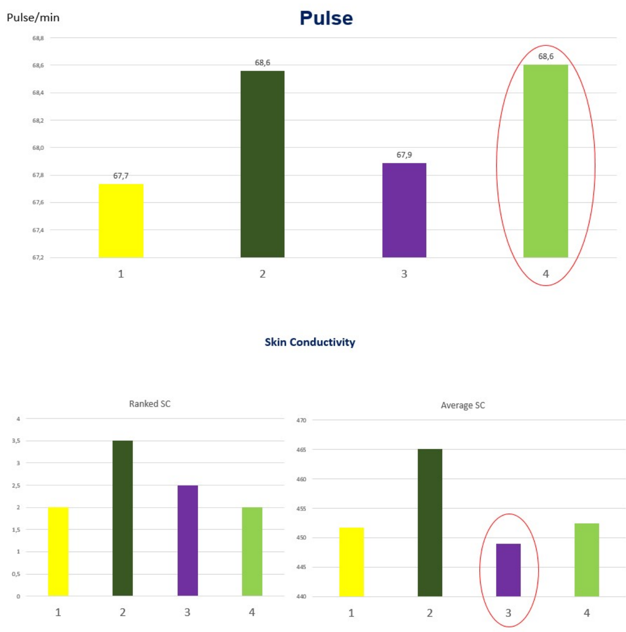


Fig. 6. Aggregated biometric data results from Pulse and GSR

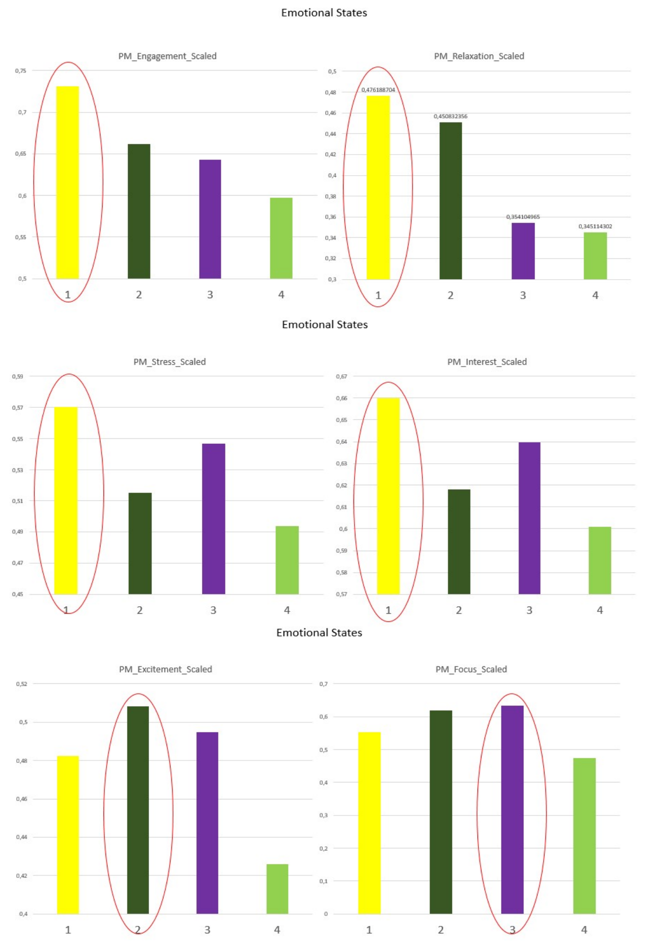


Fig. 7. Aggregated results from the six emotional states used

From these results the conclusions that can be made are that by galvanic skin response the Forest fruits drink wakes the person up, by the resulting pulse level there is a similar response between drinks 1 and 3, and 2 and 4, resulting in Pant2 (apple) and Pear increase the pulse and are tonic, Pant1 (lemon) and Forest fruits are refreshing. When combining the measured results (Perceptual data) with the test subject response from the scale from 1 to 10 we get the following data and preference shares in Table 1.

TABLE I.

Perceptual Data - Average score each brand achieves on each attribute from your sample of respondents.

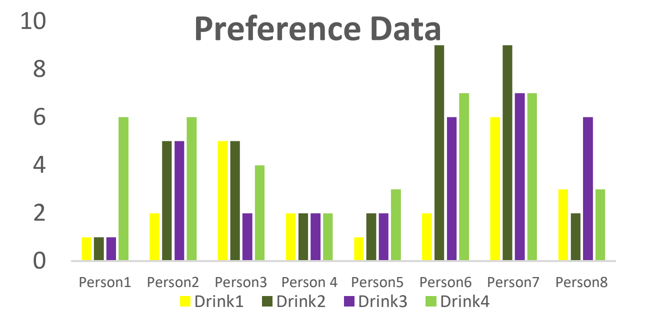
Brands/Attributes	Drink1	Drink2	Drink3	Drink4
Pulse [1/min]	67.7	68.6	67.9	68.6
GRS [rel. units]	452	465	449	453
Alpha [µV^2]	1.14	1.32	1.25	1.24
Theta [µV^2]	1.17	1.32	1.38	1.37
Ratio Theta/Alpha	1.03	1.00	1.10	1.11
Engagement	0.73	0.66	0.64	0.60
Excitement	0.48	0.51	0.49	0.43
Stress	0.57	0.51	0.55	0.49
Relaxation	0.48	0.45	0.35	0.34
Interest	0.66	0.62	0.64	0.60
Focus	0.55	0.62	0.63	0.47

Preference Data - Preference score obtained by each brand from each respondent.

Brands / Respondents	Drink1	Drink2	Drink3	Drink4
Person1	1	1	1	6
Person2	2	5	5	6
Person3	5	5	2	4
Person 4	2	2	2	2
Person5	1	2	2	3
Person6	2	9	6	7
Person7	6	9	7	7
Person8	3	2	6	3
Mean average	2.75	4.375	3.875	4.75
Standard deviation	1.714	2.997	2.204	1.854

Preference shares recovered by the model

Items / Preference Shares.	Drink1	Drink2	Drink3	Drink4
Preference shares recovered by the model	19.78%	26.35%	20.58%	33.30%



We have found correlation between the conscious preferences, obtained by means of interview and questionary and the unconscious physiological response expressed in heart rate, and emotional state Stress and Interest (r =-0.9656, p=.034 for interest; r=-0.9454, p=.055 for Stress and r=0.9098, p=.090 for heart rate).

IV. Conclusion

In the present study we have created and validated examination set-up for taste stimuli analysis for neuromarketing needs. We have demonstrated that in taste sensory modality useful information can be obtained by analysis of bio-signals expressed a couple of seconds after the end of the actual physical impact of the stimulus.

Although the difference in the responses caused by the taste stimulation of the different drinks is small, it is a sufficient indicator of common neuromarketing issues, for example to answering the question, if we replace the chemical formula of one of the drinks, how close the subtle taste perception remains to that drink.

By using biometric data, we can perform aggregation of tastes and preferences in order to help companies select products that are more appealing to a wider audience.

More specifically, we have obtained the following insights:

- EEG activity in the alpha, theta frequency ranges, EEG-assessed emotional states, pulse rate, and skin conductance can be used for taste evaluation.

- Emotional states, stress, and interest, as well as heart rate, correlated most strongly with beverage preferences determined by questionnaires.

- The drink that was preferred the most was associated with the lowest levels of stress, while the least liked drink was characterized by the highest similarity of its EEG pattern to that in a state of stress.

- The drink with the lowest rating obtained from the conducted interviews is also the same, which has highest interest according to the annualized EEG activity.

- Also, we have found that more liked drinks raised heart rate by about 1 bpm compared to less liked ones.

The feedback we have received from the conducted interviews with the respondents we have concluded that the Berries drink wakes the person up better than the others included in the test, Apple and Pear drinks increase the pulse and are tonic, while Lemon and Forest fruits are refreshing.

ACKNOWLEDGMENT

This research was done at a Neurocomputers Laboratory of the Technical University of Sofia. The authors would like to thank the Research and Development Sector at the Technical University of Sofia for the financial support.

REFERENCES

[1] Dsouza Prima, “Recent Trends in Neuro Marketing – An Exploratory Study” , International Journal of Case Studies in Business, IT, and Education (IJCSBE), 6(1), 38-60, 2022, Available at SSRN: https://ssrn.com/abstract=4029197

[2] Moran Cerf, „Can Your Business Benefit from Neuromarketing?“, Kellogg Insight, , University Institution of Social Sciences, Printed PHD Thesis, Nov 3, 2014, https://insight.kellogg.northwestern.edu/article/can-your-business-benefit-from-neuromarketing.

[3] Muehllehner G., Karp J., Positron emission tomography, 2006, IOP Publishing Ltd, Physics in Medicine & Biology, Volume 51, Number 13, pp 117-137, DOI: https://doi.org/10.1088/0031-9155/51/13/R08.

[4] Sangtae A., Thien N., Hyojung J., Jae K., Sung J., Exploring Neuro-Physiological Correlates of Drivers' Mental Fatigue Caused by Sleep Deprivation Using Simultaneous EEG, ECG, and fNIRS Data, 2016, Journal Frontiers in Human Neuroscience, Vol. 10 ISSN=1662-5161.

[5] Klimesch W, Doppelmayr M, Stadler W, Pollhuber D, Sauseng P, Rohm D. Episodic retrieval is reflected by a process specific increase in human electroencephalographic theta activity.Neurosci Lett. 2001;302:49–52. doi: 10.1016/S0304-3940(01)01656-1.

[6] Klimesch W, Doppelmayr M, Russegger H, Pachinger T. Theta band power in the human scalp EEG and the encoding of new information. Neuroreport. 1996;7:1235–1240.

[7] Klimesch W, Doppelmayr M, Pachinger T, Ripper B. Brain oscillations and human memory: EEG correlates in the upper alpha and theta band. Neurosci Lett. 1997;238:9–12. doi:10.1016/S0304- 3940(97)00771-4.

[8] Alwitt, L, "EEG Activity Reflects the Content of Commercials," In Psychological Measures of Advertising Effects: Theory. Hillsdale, NI: Erlbaum Assoc, 1989.

[9] Rothchild, M ET AI,, "Brain Activity of the Processing of Television Commercials."Cotnmunication Research 13, 2 (1988).

[10] Ambler, T., S. Rose (2001). —A revolution in advertising research?, Strategic directions, 16-17.

[11] Rothchild, M,, and Y. J. HYUN. "Predicting Memory for Components of TV Commercials from EEG." Journal of Consumer Research 16, (1989): 472-78.

[12] Vecchiato G, Astolfi L, De Vico Fallani F, Cincotti F, Mattia D, Salinari S, Soranzo R, Babiloni F. Changes in brain activity during the observation of TV commercials by using EEG, GSR and HR measurements. Brain Topogr. 2010 Jun;23(2):165-79. doi: 10.1007/s10548-009-0127-0. Epub 2009 Dec 22.

[13] Rothschild M.L. and Yong J Hyun, (1990); Predicting Memory for Components of TV Commercials from EEG; Journal of Consumer Research: An Interdisciplinary Quarterly, vol.16, issue 4, pages 472-78

[14] Oliveira, J. H. C., & Giraldi, J. M. E. (2019). Neuromarketing and its implications for operations management: an experiment with two brands of beer. Gestão & Produção, 26(3), e3512. https://doi.org/10.1590/0104-530X3512-19

[15] McClure, S.M., Li, J., Tomlin, D., Cypert, K.S., Montague, L.M., & Montague, P.R. (2004). Neural correlates of behavioral preference for culturally familiar drinks. Neuron, 44, 379-387.

[16] Eroglu S., Tomris K. N.., “Traditional Market Research and Neuromarketing Research: A Comparative Overview” in book: Analyzing the Strategic Role of Neuromarketing and Consumer Neuroscience (pp.146-167), Publisher: IGI Global, 2020, DOI:10.4018/978-1-7998-3126-6.ch008.