博士論文要旨 (2023 年度)

Exploring Prefrontal Activation Associated with Product Evaluation: Insights from Functional Near-Infrared Spectroscopy in Cosmetics Experience

理工学研究科博士課程後期課程 都市人間環境学専攻 平林　和恵

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1. Introduction

In the dynamic and highly competitive landscape of manufacturing industries, the exploration of consumer behavior is not just beneficial but it's essential. Industries, including cosmetics, thrive on their ability to align products with the rapidly evolving preferences and expectations of customers. To delve deeper into consumer behavior, it's crucial to explore the field of consumer neuroscience, also known as neuromarketing, which emerged in the early 2000s[1]. This interdisciplinary field combines neuroscience, marketing, and consumer psychology to offer deeper insights into consumers' decision-making processes and preferences[2]. Its rise is linked to the increased accessibility of advanced technologies like functional magnetic resonance imaging (fMRI) and electroencephalography (EEG), which enable scientists to study how the brain responds to the products and marketing stimuli[3,4].

Building on these advancements, this thesis aims to apply the principles of consumer neuroscience to understand the neural mechanisms of product evaluation by employing functional Near-Infrared Spectroscopy (fNIRS), a more movement-flexible and real-world applicable alternative to fMRI and EEG[5,6]. FNIRS has emerged as a valuable tool in consumer neuroscience, providing insights into the neural mechanisms during product experiences[7].

The current research landscape shows a notable scarcity of studies utilizing fNIRS in real-time product evaluation[8]. This gap highlights the necessity for the development of innovative product evaluation methods that not only analyze product evaluations by consumer but also delve into understanding the underlying neural processes. As industries, including cosmetics, continuously evolve and adapt to meet consumer needs, the application of such neuroscientific techniques becomes increasingly critical.

2. Scope of work

The primary aim of this dissertation is to provide the viability of fNIRS as a product evaluation method by validating and exploring prefrontal activation based on the correlation with subjective product evaluation scores.

- Examine the neural correlates of real-time evaluation of cosmetic products, using willingness-to-pay (WTP) as a measure of perceived value by replicating the previous results by Duncan et al. (2019). Validate and extend the existing knowledge, ensuring the reliability and applicability of our findings in the context of consumer neuroscience.

- Investigate the neural mechanisms behind the detection of incongruities in cosmetic products and their impact on WTP evaluations. This aspect focuses on understanding how pre-existing expectations about specific product features compare with the actual experience and how these discrepancies are processed in the brain.

Through achieving these aims, this dissertation intends to enrich the field of consumer neuroscience by demonstrating the utility of fNIRS as a valuable tool for analyzing consumer behavior, especially in the cosmetics market where the actual sensory experiences — such as sight, smell, and texture — influence product assessment.

Considering that, in the first study, with twenty-five healthy female frequent lipstick users, the experimental setup involved the application of an fNIRS device to measure brain activity, specifically targeting the right Dorsolateral Prefrontal Cortex (DLPFC), a region associated with value-based decision-making to replicate the results of previous study[8]. Specifically, the channel closest to the DLPFC, which previously reported to correlate with WTP[9] was identified by calculating the Euclidean distance from the MNI coordinates of each channel. The channel closest to the right DLPFC was Channel 38 (Figure 1).

During the experiments, participants were presented with six different lipstick prototypes, a shift from the previously studied powdery foundations, to maximize the variation of the subjective experience of the products and the associated brain activity, the most preferred color lipstick and a less preferred color lipstick were chosen for each participant, and each color of lipstick had three different textures (*Lo, Mid, and Hi*).

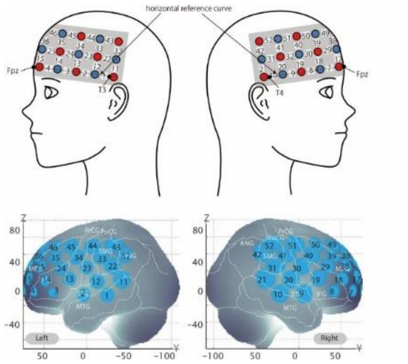


Figure 1 Virtual estimated 52 channel positions.

Each participant underwent a series of evaluation sessions where they were asked to use and assess the lipsticks (Figure 2). During these sessions, their willingness-to-pay (WTP) for each product was recorded as a quantifiable index of perceived value.

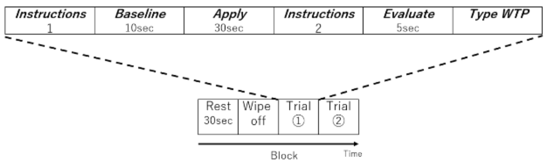


Figure 2 One block of the experimental design (Study 1).

Statistical analysis was employed to understand the intra-subject correlation between the neural activity of Channel 38 and the WTP score for each product in each participant.

The second study further expanded on the application of fNIRS in consumer neuroscience, specifically focusing on detecting incongruencies between product expectations and actual sensory experiences. Specifically, thirty healthy female frequent lipstick users examined six different lipsticks, varying in softness which is a key feature of lipstick product, to record their perceived softness ratings and WTP based on the valuation on their softness preferences.

The core of this experimental setup was the real-time measurement of brain activity using fNIRS to explore the areas involved in detecting the texture incongruity.

A critical aspect of our data analysis is the use of semi-partial correlation[10]. This statistical method was employed to discern the unique contribution of each texture variation to the observed brain activation patterns, effectively separating it from other confounding factors, which is WTP.

3. A Willingness-to-Pay Associated Right Prefrontal Activation During a Single, Real Use of lipsticks as assessed using Functional Near-Infrared Spectroscopy

The time series of the cerebral hemodynamic responses in frontal areas during lipstick application analyzed with the adaptive GLM[11] and the intra-subject correlation between the right DLPFC beta scores for the lipsticks and their respective WTP values conducted for each participant. The coefficient of each participant was converted to a Z score using Fisher's *r*-to-*z* transformation and one sample *t*-test was conducted for the average Z score of all participants. The results indicated that the group Z scores for Channel 38 which is the only channel differed significantly from 0 (mean Z = 0.239, the standard error of the mean = 0.091), ($t_{(24)} = 2.5$, $p = 0.03$*, $d = 0.65$). The group R, calculated using the inverse Fisher transformation, was 0.24.

4. Right Prefrontal Activation Associated with the Incongruency in Texture of Lipsticks During a Single Real Use as Assessed Using Functional Near-Infrared Spectroscopy

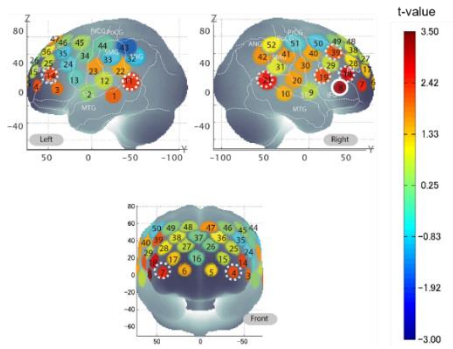
The same analysis procedure as the study 1 with adaptive GLM was applied for the time series of the hemodynamic responses and the incongruency scores of softness were calculated to understand the distance from the optimal softness. The intra-subject correlation between the beta scores during application of the lipsticks and their respective incongruency score for each participant were acquired using semi-partial correlation analysis, controlling for the effects of WTP. The results of the mean *Z* in the group significantly differed from 0 in multiple channels shown in Table 1.

Table 1 Channels of the results of the mean Z in the group significantly differed from 0

Channel	MeanZ	*t*	*p*	*d*
4	0.30	2.19	0.04	0.42
7	0.24	2.46	0.02	0.47
8	0.31	3.16	0.004	**0.61**
11	0.24	2.36	0.03	0.45
14	0.31	2.27	0.03	0.44
18	0.33	2.88	0.01	0.55
19	0.28	2.18	0.04	0.43
21	0.20	2.54	0.02	0.50
39	0.19	2.12	0.04	0.41

Based on the power analysis, only Channel 8 had a reasonable effect size for the results of one-sample *t*-test (mean $Z = 0.31$, the standard error of the mean= 0.51), [$t_{(26)} = 3.15$, $p<0.01$, $d = 0.61$)]. Channel 8 covered right-Inferior Frontal Gyrus (IFG) from the results of the MNI coordinates (x=58.0, y=36.3, z=0.7, SD=8.3) (Figure 3).

Figure 3 Intra-subject correlation between each 52



channels and the difference from optimal softness

5. Conclusions

The results from both studies highlight the effectiveness of using fNIRS in understanding consumer behavior of cosmetics experience. Study 1 replicates our previous study by showing the significant positive intra-subject correlation between the right DLPFC activations during lipsticks use and their respective WTP values. This study suggested the right DLPFC can be a potential brain-based personalization or product selection process biomarker.

Study 2 indicated the significant positive semi-partial correlation between the right DLPF activations during lipsticks use and their respective WTP values. This highlighted the potential of fNIRS to provide brain-based insights into consumer behavior and decision-making in the context of cosmetics products. Study 2 further revealed that when the texture of lipsticks doesn't match what customers expect, the right IFG has higher activations during the cosmetics use. This analysis indicates that our brains pay close attention to whether a product meets our expectations or not.

In conclusion, these studies show us how our brain responds to different aspects of cosmetic products and how this can affect our buying choices. Understanding these neural responses can help in creating cosmetics that better meet customer expectations and improve their overall experiences.

References

1. Ramsøy, Thomas Z. ; Neurons Inc. (2015).
2. Plassmann, H., Ramsøy, T. Z. & Milosavljevic, M. ; *J. Consum. Psychol.* **22**, 18–36 (2012).
3. Ariely, D. & Berns, G. S. ; *Neurosci.* **11**, 284–292 (2010).
4. Alvino, L., Pavone, L., Abhishta, A. & Robben, H. ; *Front. Neurosci.* **14**, (2020).
5. Kopton, I. M. & Kenning, P. ; *Front. Hum. Neurosci.* **8**, (2014).
6. Çakir, M. P., Çakar, T., Girisken, Y. & Yurdakul, D. ; *Eur. J. Mark.* **52**, 224–243 (2018).
7. Meyerding, S. & Mehlhose, C. ; *J. Bus. Res.* **107**, 172–185 (2020).
8. Kawabata Duncan, K., Tokuda, T., Sato, C., Tagai, K. & Dan, I. ; *Front. Hum. Neurosci.* **13**, (2019).
9. Plassmann, H., O'Doherty, J. & Rangel, A. ; *Neurosci. Off. J. Soc. Neurosci.* **27**, 9984–9988 (2007).
10. Tabachnick, B. G. & Fidell, L. S. ; Boston, MA: *pearson* (2013).
11. Uga, M., Dan, I., Sano, T., Dan, H. & Watanabe, E. ; *Neurophotonics* **1**, 015004 (2014).