IFSCC 2025 full paper (abstract reference number:IFSCC2025-1069)

"Impact of odor and scalp discomfort during oxidative hair coloring on consumer's mental state: Examination by EEG"

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1. Introduction

In society today, people are increasingly interested in the promotion of mental and physical health, and in the health promotion field, the effects of physical adornments such as cosmetics [1], hair coloring, and nail polish [2] are attracting attention [3]. Based on social psychological theories, physical adornments are regarded as an important contributor to the enhancement of physical and mental health by promoting positive self-evaluation via self-recognition, strengthening social identity, and raising self-esteem [4]. Among physical adornments, hair coloring is reported to cause positive psychological and physical changes in many people [5]. However, adverse effects, such as scalp discomfort(irritation) due to chemicals used in hair coloring, or the pungent odor are a concern[6]. Despite these well-known adverse effects, hair coloring is still widely performed [7]. Thus, there is a need to fully understand the effects of hair coloring and the associated adverse effects in the promotion of positive and pleasant beauty experience [8].

Many studies have reported adverse physical effects of oxidative hair coloring agents, but their pungent odor may also cause a psychological burden without physical symptoms. The olfactory system detects smells and social cues, influencing cognitive processing, emotions, and behavior through interactions with the neocortex and limbic system [9]. Pleasant scents promote relaxation, while unpleasant odors can cause stress and anxiety via conscious and unconscious mechanisms [10]. Olfaction also interacts with vision, taste, and somatosensation, leading to multisensory integration closely tied to emotions and memories. As the only sense directly connected to the limbic system, even slight differences in smell are immediately evaluated emotionally [11]. Thus, the emotional valence of hair coloring agents' smell likely strongly influences consumers' mental state during hair coloring.

This study aimed to investigate the effects of smell and scalp discomfort on emotional valence during hair coloring using the neurophysiological method of electroencephalography (EEG). Given that emotional responses in the brain are likely instantaneous during the application of hair coloring agent, high-temporal-resolution EEG was considered appropriate. To better understand the association between physical adornments and mental and physical state, it is important to gain basic knowledge for reducing the psychological burden of hair coloring and enhancing its utility. Here, mental state during hair coloring was objectively evaluated using EEG, and the effects of smells on emotional valence were also examined.

2. Materials and Methods

2.1. Participants

Participants were 14 healthy women (40.1±7.7 years old) with no orthopedic abnormalities and no visual or olfactory dysfunction. Inclusion criteria were healthy women aged ≥23 years and <50 years. Exclusion criteria were neurological disorders, psychiatric disorders, olfactory disorders, visual disorders, scalp disorders, allergy to hair coloring agents, and pregnancy or breastfeeding. This study was approved by the institutional review board of of our institution and was conducted in accordance with the Declaration of Helsinki. Informed consent was obtained from the participants after providing thorough verbal and written explanations of the objectives, content, and procedures of the study.

2.2. Protocol

This is a single-blind counter-balanced experimental study. We used EEG for objective neurophysiological evaluation and questionnaires for subjective psychological evaluation. Given that olfactory and emotional information is processed spatiotemporally in the brain [12], EEG with high temporal resolution is suitable for evaluating emotion recognition [13].

Participants completed a pre-task questionnaire, underwent EEG under four hair coloring step conditions (the resting, sniffing, application, and leave-on periods), and then completed a post-task questionnaire. A coloring agent was applied by a hair stylist, and color fixation occurred during the leave-on period. The sniffing period (90 s) was set to evaluate the effect of the odor only, and it was divided into the mixing phase (MP, 30 s) when the hair coloring agent was mixed by a stylist in front of the participant, and the smelling phase (SP, 60 s) when the participant sniffed the mixed hair coloring agent. The leave-on period was 7 min (Figure 1).

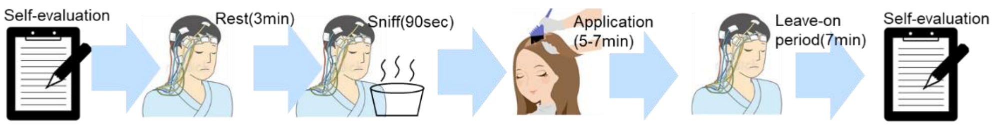


Figure 1. Experimental procedure.

Three hair coloring samples with different alkaline ingredients were used (no alkaline, monoethanolamine [MEA], and ammonia). The no alkaline sample (Sample 1) was used as a placebo of odor and scalp discomfort, and was prepared with a scent-free hair treatment agent. The MEA sample (Sample 2) was prepared as hair coloring formulation without ammonia, and ammonia sample(Sample 3) was prepared as the convientional hair coloring formulation having ammonia odor and potentially giving scalp discomfort. Two hair coloring formulation(Sample 2 and 3) were prepared without dye.

Each participant came for two sessions, with a 3-week interval between them. At each session, experimental tasks were performed for Sample 1. Then, Sample 1 was washed off and the tasks were performed for Sample 2 or 3. The order of Samples 2 and 3 was randomized, with Sample 2 used first for half of the participants and Sample 3 used first for the others.. The amount of coloring samples applied to the whole head by an experienced stylist was 100 g or 120 g, depending on the hair volume (Figure 2a,b).

Figure 2. (a) EEG electrode attachment; (b) Application of a coloring sample by a stylist.

2.2.1. Questionnaire Evaluation

Participants completed questionnaires for subjective psychological evaluation of mental stress due to smell and scalp discomfort. A 4-point scale was used to evaluate scalp discomfort (from “felt it very much” to “did not feel any”). For participants who answered that a “smell was detected,” a 4-point scale was used to evaluate smell discomfort (from “very unpleasant” to “not unpleasant”). Participants rated pleasantness and arousal on a 9-point scale to evaluate their mood before and after the experimental task under each task condition.

2.2.2. EEG Recording

An EEG system (PolymateV AP5148, Miyuki Giken) comprising passive electrodes and biosensors was used (sampling frequency: 1000 Hz). Following the international 10-20 system, electrodes were placed at Fp1, Fpz, Fp2, Cz, P3, and P4, with the reference electrode placed at the right earlobe. An active ground electrode was placed at the seventh cervical vertebra, and 2 more active electrodes were placed above and below the eye for electrooculography.

2.3. Data Analysis

EEGLAB (MATLAB R2022b) was used for independent component analysis to remove noise, such as that attributable to body motions during hair color application, myoelectric potential, eyeball movement, and blinking [14]. The siffing period (total 90 s) was divided into 3 sections, namely, the MP (30 s), the first half of the SP (SP1, 30 s) and the second half of the SP (SP2, 30 s). The application period was divided into Application 1 (first half) and Application 2 (second half) and the leave-on period was divided into Leave-on 1 (first half) and Leave-on 2 (second half), and 30-s electroencephalograms were extracted.

Power in the a frequency range (8-13 Hz), an indicator of mental state, was extracted by wavelet analysis [15]. Frontal alpha asymmetry (FAA) was used as an indicator of emotional valence [16]. Generally, increases in a power are thought to represent suppression of cortical activity [17], and the left and right frontal lobes are respectively thought to be responsible for regulation of approach behavior in a positive emotional state and avoidance behavior in negative emotional state [18]. When either the right or left frontal lobe become active, activity in the contralateral frontal lobe is suppressed, and the degree of this suppression is represented by a relative increase in a power [19]. We defined FAA as follows:

$$FAA = (lnFp2(\alpha) - lnFp1(\alpha)) \quad (1)$$

Also, parietal α power values at P3 and P4 were used as indicators of relaxation [20]. Natural logarithms of P3 and P4 power values, obtained by wavelet analysis, were averaged (equation (2)), and differences in parietal α power value from the resting state were calculated.

$$\text{Parietal } \alpha \text{ power value} = (lnP3(\alpha) + lnP4(\alpha))/2 \quad (2)$$

Wavelet coherence [21] was used to verify frontoparietal functional connectivity associated with hair coloring. The Fpz electrode was placed over the frontal lobe, which is involved in executive function and emotion processing [22], and the P3 and P4 electrodes were placed over the left and right parietal lobes, respectively, which are involved in processing of sensory information [23]. Then, the a coherence between Fpz and P3 and that between Fpz and P4 were obtained [24]. The Wavelet Coherence Toolbox for MATLAB [25] was used for wavelet coherence analysis. The Morlet wavelet was used for wavelet transformation with a range of scale from 0.5 s to 30 s. Calculated coherence values ranged from 0 to 1, with a value closer to 1 indicating greater phase synchronization of between 2 sets of time series data. Coherence values under each condition (MP, SP1, SP2, Application 1, Application 2, Leave-on 1, and Leave-on 2) were calculated for each hair coloring sample in this study.

To examine the effect of smell on emotional changes during coloring agent application, a support vector machine (SVM) predicting and classifying FAA during hair coloring (application and leave-on periods) was constructed using labeled FAA in the sniffing period [26]. Predicted negative FAA (right hemisphere dominance) and positive FAA (left hemisphere dominance) indicated Class 1 (unpleasant) and Class 2 (pleasant), respectively. Performance was validated by 5-fold cross validation with the dataset extended to the optimal sample number, which was determined using the bootstrap method. Performance indices used were accuracy [27], precision, recall [28], and F1 score [29].

Statistical analysis was performed using SPSS Version 27.0. The Shapiro-Wilk test was used to examine whether all datasets are normally distributed. FAA and parietal α power values were analyzed by two-way analysis of variance using stimulus conditions (Samples 1-3) and coloring step conditions (MP, SP1, SP2, Application 1, Application 2, Leave-on 1, Leave-on 2), and the Bonferroni test was performed post hoc. The significance level was set at 5%.

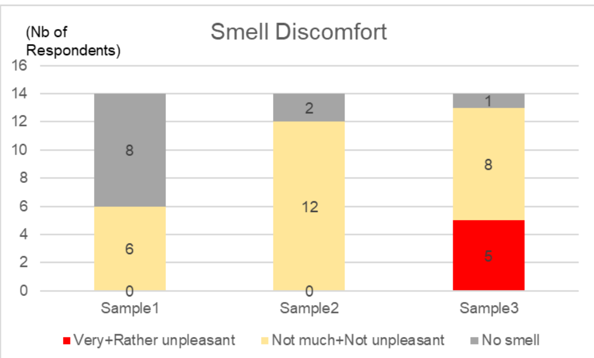
3. Results

Fourteen healthy women participated in this study, and there were no dropouts.

3.1. Effects of Sniff and Hair Coloring on Mental State

3.1.1. Self-Evaluation by Participants: Discomfort

More participants complained about discomfort due to smell and scalp irritation when Sample 3 (containing ammonia) was used than when Sample 1 (no alkaline) and Sample 2 (containing MEA) were used. On the other hand, slightly more participants reported scalp discomfort for Sample 2 than for Sample 1. For those who detected a smell, the smells of Samples 1 and 2 were both perceived as "not unpleasant."



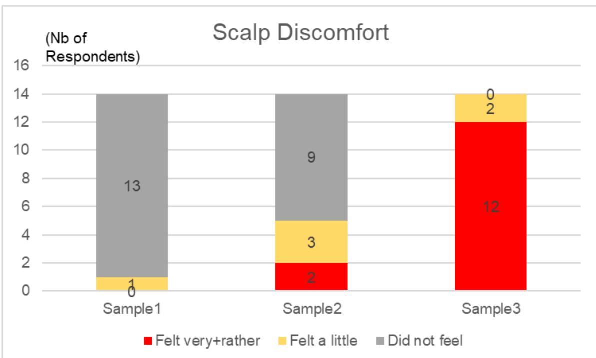


Figure 3. Self-evaluation of discomfort by participants.

3.1.2. Self-Evaluation by Participants: Mood

The pleasantness score for Sample 3 significantly decreased after the task compared with before (Figure 4). There was no marked change in the arousal score.

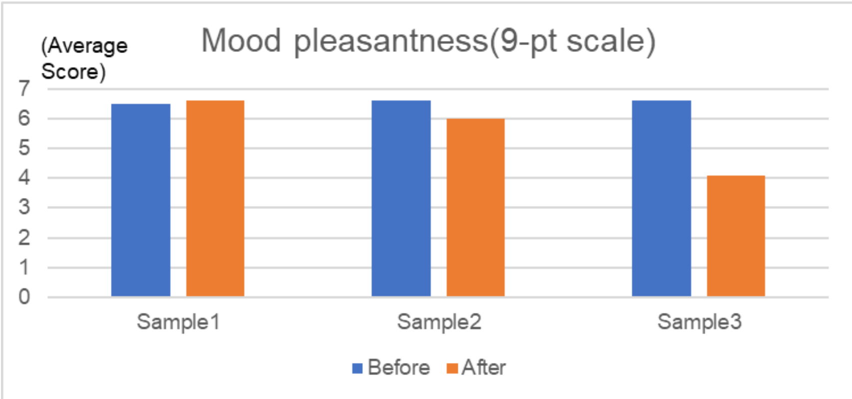


Figure 4. Self-evaluation of mood by participants.

3.1.3. Frontal Alpha Asymmetry

FAA scores in the sniffing period were positive for Sample 1 (0.09 ± 0.09 in MP, 0.11 ± 0.10 in SP1, and 0.10 ± 0.10 in SP2) and Sample 2 (0.23 ± 0.08 in MP, 0.23 ± 0.10 in SP1, and 0.22 ± 0.10 in SP2), but always negative for Sample 3 (-0.09 ± 0.10 in MP, -0.06 ± 0.09 in SP1, and -0.04 ± 0.09 in SP2). FAA scores were significantly lower when Sample 3 was used than when Samples 1 and 2 were used ($p < 0.05$). FAA scores changed from Application 1 to Application 2: from 1.39 ± 0.36 to 1.50 ± 0.15 when Sample 1 was used, from -0.18 ± 0.15 to0.74 ± 0.01 when Sample 2 was used, and from 2.94 ± 0.76 to 2.25 ± 1.79 when Sample 3 was used. The FAA scores in the application period were highest when using Sample 3, followed by Sample 1 and then Sample 2. FAA scores during the leave-on period were negative and significantly lower than those in the application period under all stimulus conditions. The FAA scores were particularly low when Sample 3 was used ($p < 0.05$) (Figure 5). Consdiering FAA as an indicator of emotional valence, these results were consistent with the self-evaluations for sniffing and the leave-on period, but not for the application period.

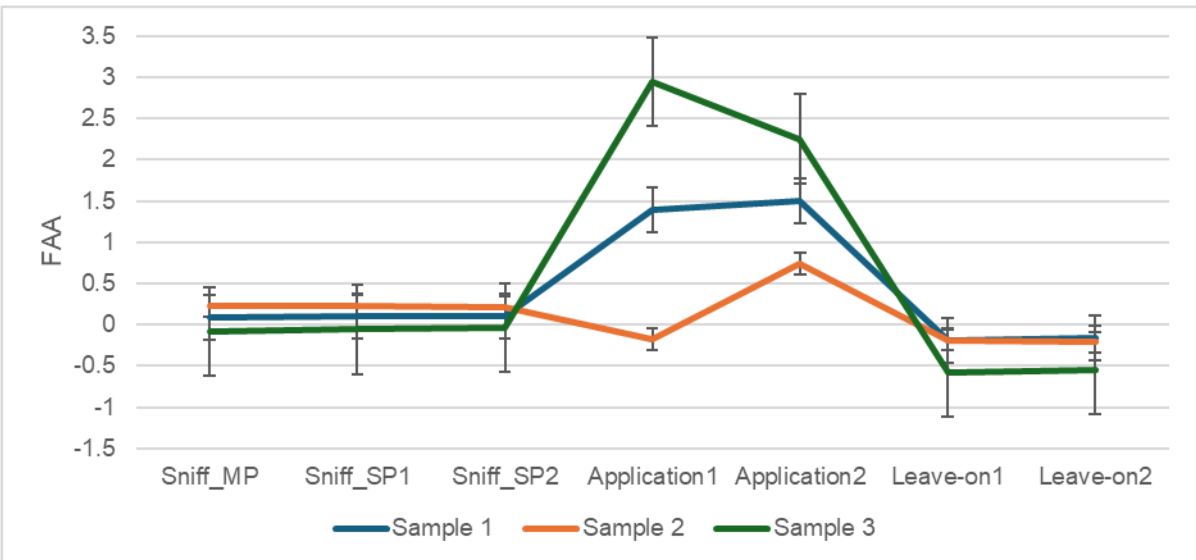


Figure 5. Changes in FAA over time.

3.1.4. Parietal α Power Values

Figure 6 shows parietal α power values in each coloring step condition. Two-way analysis of variance showed a significant main effect of the stimulus condition ($F(2, 26) = 48.2$, $p < 0.001$, $\eta p2 = 0.79$), a significant main effect of the coloring step condition ($F(6, 78) = 35.7$, $p < 0.001$, $\eta p2 = 0.73$) and significant interaction effect ($F(12, 156) = 8.4$, $p < 0.001$, $\eta p2 = 0.39$). In the sniffing period, parietal α power values were continuously negative when using Sample 3, and they were significantly lower than those when using Samples 1 and 2 (both $p < 0.05$). The values for Sample 2 also decreased during sniffing. During application, the values increased for all samples, while it was significantly lower when using Sample 3 than those when using Sample 1 and 2. During the leave-on period, the values were decreased regardless of the sample used, and the values for Sample 3 were the lowest ($p < 0.05$).

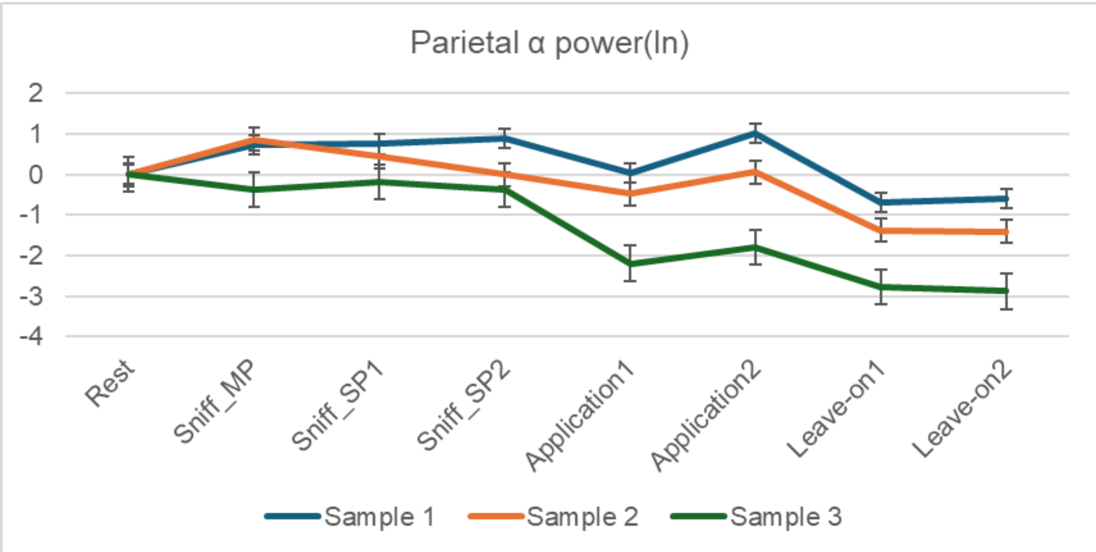


Figure 6. Changes in parietal α power values over time.

3.2. Frontoparietal Network

Fpz-P3 coherence and Fpz-P4 coherence were calculated to examine frontoparietal network. Table 1 shows mean coherence values under each stimulus condition and each coloring step condition. In the sniffing period, mean Fpz-P3 coherence values were continuously higher than mean Fpz-P4 coherence values under all stimulas conditions, and they did not change over time. On the other hand, in the application period and the leave-on period, mean Fpz-P4 coherence values were significantly higher than mean Fpz-P3 coherence values when Sample 2 and Sample 3 were used ($p < 0.05$, Table 1), showing right hemisphere dominance for frontoparietal functional connectivity for those samples.

Table 1. Mean coherence values under each stimulus condition and each coloring step condition.

Products	ch-ch	MP	SP1	SP2	Application1	Application2	Leave-on1	Leave-on2
Sample1	Fpz-P3	0.81	0.80	0.81	0.81	0.77	0.83	0.82
	Fpz-P4	0.75	0.76	0.74	0.80	0.82	0.81	0.82
Sample2	Fpz-P3	0.72	0.74	0.74	0.73	0.71	0.79	0.78
	Fpz-P4	0.66	0.67	0.68	0.88	0.92	0.94	0.93
Sample3	Fpz-P3	0.78	0.78	0.77	0.75	0.72	0.78	0.78
	Fpz-P4	0.72	0.71	0.71	0.93	0.94	0.96	0.94

3.3. Construction of SVM Models of Emotions Due to Smell

FAA during the application and leave-on periods were predicted by the SVM model constructed using FAA during the MP of the Sniffing period. Accuracy was 56-64% and 63-68% for predicting FAA in the application and leave-on periods, respectively. The model based on the labeled data during the SP also showed accuracy of 57-65% and 63-65% for predicting FAA in the application period and the leave-on period, respectively. In particular, the model based on the labeled data during the MP showed the highest accuracy (68%). For predicting class 1 (right hemisphere dominance, i.e., unpleasant), precision was 64%, recall was 100%, and F1 score was 0.78. On the other hand, for predicting class 2 (left hemisphere dominance, i.e., pleasant), performance was slightly low, with precision of 100%, recall of 28%, and F1 score of 0.44.

4. Discussion and Conclusion

This study aimed to investigate the effects of different olfactory and discomfort stimuli in hair coloring agents on mental state during hair coloring, by performing objective evaluations of neurophysiological indices of brain function using EEG and subjective evaluations using questionnaires.

First, FAA values in the sniffing period were negative, indicating right hemisphere dominance indicative of unpleasantness, only when using Sample 3 that contained ammonia. Also, parietal α power values were significantly lower when using Sample 3, and the level of relaxation was decreased over time when using Sample 2 that contained MEA. These results were more pronounced when the pungent odor of volatile ammonia is strong, supporting previous studies that showed induction of avoidance behaviors and stress responses by unpleasant odors [30]. Further, EEG data suggested that an unconscious psychological burden may be imposed even when the odor is weak and not appeared as uncomfortable in the subjective evaluation(e.g., Sample 2). This indicated the usefulness of real-time neurophysiological evaluation by EEG.

In the application period, pleasantness and increased relaxation were observed regardless of the sample used. When a hair coloring agent is applied by an experienced hair stylist, people feel tactile stimulation, similar to a massage having relaxing effects, in addition to olfactory stimulation and scalp discomfort, and this is thought to contribute to these increases [31]. On the other hand, during the leave-on period, unpleasantness and decreased relaxation level became prominent, especially when using Sample 3 that contained ammonia. Given that decreases in parietal α power values are associated with deactivation of default mode network, and possibly indicate increases in attention to anxiety and pain [32], our results suggest that stimulation by chemicals in hair coloring agents imposes odor and scalp discomfort as an intrinsic cognitive load.

Coherence analysis of the frontoparietal network showed high Fpz-P3 connectivity indicating left hemisphere dominance in the sniffing period, and marked increases in the Fpz-P4 connectivity indicating right hemisphere dominance during hair coloring. The right parietal lobe is specialized in detecting unexpected stimuli [33], suggesting that multisensory information including smell, touch, and pain (e.g., odor of and scalp discomfort by hair coloring agents) during hair coloring is possibly subject to higher order, parallel processing [34]. An SVM model constructed to test validity showed higher prediction accuracy for unpleasantness (right hemisphere dominance) caused by odor during hair coloring, indicating a particularly strong contribution of olfactory information when passive stimulation continues, as during the leave-on period. The low prediction accuracy found for pleasantness needs further investigation, including the limitations of SVM for directly assessing correlations and causal relationship [35].

In sum, this study that olfactory stimulation and scalp discomfort during hair coloring possibly influence the unconscious mental state before the conscious experience of emotions. Hair coloring is a physical adornment, but we need to pay attention to internal experiences while hair coloring is performed, in addition to the effects on appearance after hair coloring. To optimize plesantness of beauty experience, it is desirable to use a comprehensive approach considering both internal and external aspects. The findings of this study will contribute to the development of hair coloring agents and to improvement of the hair coloring process.

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