Ph. D. Thesis
박사 학위논문

Effects of odor stimuli on self-face perception depending on sex, BMI, and self-esteem: an event-related potential study

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Department of Brain and Cognitive Sciences

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Advisor: Professor Cheil Moon

Co-advisor: Professor Chang-Hun Lee

by

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A thesis submitted to the faculty of DGIST in partial fulfillment of the requirements for the degree of Doctor of Philosophy in the Department of Brain and Cognitive Sciences. The study was conducted in accordance with Code of Research Ethics[1]

11. 23. 2020

Approved by

Professor Cheil Moon (Signature)
(Advisor)

Professor Chang-Hun Lee (Signature)
(Co-Advisor)

[1] Declaration of Ethical Conduct in Research: I, as a graduate student of DGIST, hereby declare that I have not committed any acts that may damage the credibility of my research. These include, but are not limited to: falsification, thesis written by someone else, distortion of research findings or plagiarism. I affirm that my thesis contains honest conclusions based on my own careful research under the guidance of my thesis advisor.

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Sun Ae Moon

Accepted in partial fulfillment of the requirements for the degree of Doctor of Philosophy.

11. 23. 2020

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ABSTRACT

Our face is the most powerful tool for socializing. It conveys a great deal of information about ourselves. For this reason, we regularly check our own reflections in the mirror in everyday life. Previous studies have revealed that context and sensory stimuli alter face perception and evaluation. However, it is unclear how external sensory stimuli change neural processing of self-face perception and evaluation. This study investigated how odor alters self-face perception and evaluation using the mean amplitude of event-related potentials (ERP) and post-survey ratings. Thirty participants showed differences in the mean ERP amplitudes in the frontal region of the left hemisphere after the onset of self-face perception when exposed to a pleasant odor (lavender) or an unpleasant odor (isovaleric acid). The responses also differed depending on sex, body mass index (BMI), and self-esteem. The self-face perception and evaluation response were more sensitive to odors in females than in males. Participants with high BMI or high self-esteem showed little difference between the presented odors. Interestingly, the neural modulation patterns in response to both odors were isovaleric acid–like in the high-BMI group but lavender-like in the high-self-esteem group. These results indicate that accumulated feelings toward the self or sensitivity to the odor stimuli may produce different self-face perceptions and evaluations. The results will help us understand the modulation of neural activity patterns by odors during self-perception and evaluation. Furthermore, they demonstrate distinct responses to odor stimuli according to individual features such as sex, BMI, and self-esteem. This study could be used to develop neuro-cosmetics or enhance social well-being.

Keywords: Odor, Self, Face, ERP, EEG, Sex, BMI, Self-esteem

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Ⅰ. Introduction

1.1 Overview of this study

During self-face processing, we sometimes perceive our face reflected in a mirror perceive. Also, when we see an identification picture for a passport, we may be surprised by the photo's face shape. Self-face recognition errors have been reported not only in prosopagnosia patients but also in healthy participants [1]. We can perceive our own face only indirectly, through reflections in a mirror, photos, or descriptions from other people [2]. This means that even though our face is the same, the perceived self-face image is not fixed, and is influenced by external situations or moods in daily life.

We live in an environment with a variety of stimuli, and our responses vary from person to person. However, it is unclear what factors modulate our self-face perception processing and how. In this study, I used neuroimaging to characterize the modulatory effects of external stimuli and differences in responses depending on individual features during self-face perception processing.

Among various external stimuli, odor stimuli are highly related to emotions. Subjectively valenced odor stimuli could evoke positive or negative emotions such as happiness and surprise or anger and disgust [3]. Since odor hedonic perception is known to modulate the physiological and psychological states of people [4, 5], odor stimuli have been studied for their stress-relief effects [6, 7] and alleviation of mood-related symptoms [8] using psychophysiological methods. In particular, recent studies [9-13] have shown that odor stimuli affect perception and evaluation processing of the face. The effects of odors on social relationships have been studied for a long time because olfaction is an

important sense in social life of humans and other animals. However, most research on odor effects in relation to faces has been limited to perception and evaluation of others' faces. This research direction is probably due to the idea of spraying perfume to be perceived as attractive by others. Through this study, I suggest the use of perfume for the well-being of the self

If simply spraying perfume makes our face seem more attractive, we may meet people with joy and create more active social relationships. A previous study has reported that when women wear clothes that they feel are attractive, men feel attractiveness of the women's neutral facial expressions to a greater extent than when women wear clothes that they find unattractive or comfortable, even though the clothes are not visible in the photo [14]. This indicates that other people can notice what we feel attractive about ourselves. Thus, self-related subjectively valenced odor may greatly affect our social relationships. There is much advertising about odor effects in the industry, however more research is needed to support scientifically the industrial use of odors. In the past, cosmetics manufactured using high technology was the best. However, nowadays, people want to get special experience with cosmetics such as enhancing self-esteem for inner beauty. Therefore, developing neuro-cosmetics is needed based on scientific evidence to help people to be more beautiful both inside and outside, and also to improve social relationships.

The purpose of this study is to understand how odor stimuli modulate our self-face perception and evaluation depending on differences in sex, BMI, and self-esteem **(Fig 1.1).** I tried to reveal how and when odors influence our self-face processing. To identify the crucial time window, I used electroencephalograms (EEGs), which have high temporal resolution [15]. Although functional magnetic resonance imaging (fMRI) has a good spatial resolution, it is difficult to use it to examine neurocognitive

processes because of low time resolution. In addition, since fMRI measurements is performed while the person is lying down, the settings are different from our daily experience of odors. Among EEG analysis techniques, I chose the event-related potential (ERP) to obtain the neural patterns after viewing self-face. Because ERP analysis uses a repeated averaging process, it reduces noise and allows to obtain specific event-related neural patterns with a millisecond resolution [16]. To check the effects of odor during self-face processing, I used a priming paradigm:, I presented the odor first and then allowed the participants to passively view their self-face as the target. Participants inhaled air, lavender, and isovaleric acid during odor presentation periods. This paradigm has been used to reveal how olfactory stimuli affect the processing of visual modality [10, 17-19]. Owing to this experimental paradigm, I could separate neural activity directly triggered by odor stimuli from that during self-face neural processing. Thus, I could measure which time window and brain regions are affected by odor stimuli during self-face neural processing.

In this study, among various internal factors, I focused on differences in sex, BMI, and self-esteem. There are well-known sex differences in behavior patterns, e.g. when looking in the mirror. However, the differences in neural activity patterns have not yet been probed. Previous studies have revealed that males show asymmetric neural activity during face coding [20-22]; however, for the self-face, there is no such study, as far as I know. Behavioral studies have also reported changes in self-face perception caused by high BMI or obesity [23, 24]. In the brain, neural activity differences in frontal regions have been reported between obese and normal-weight persons [25, 26]. However, neural activity has not yet been reported during face coding and self-face processing. Self-esteem is also reported to be correlated with self-face evaluation [27]. The authors have revealed the brain regions

responsible for self-face evaluation and associated activity patterns depending on self-esteem. However, this research was conducted only with female participants and focused on comparing evaluations of self-, friends', and others' faces. Therefore, it is necessary to check the difference between the three factors that might affect self-face processing. Characteristic neural patterns could be helpful in understanding the association between the factors during self-perception and evaluation in the presence of odors.

To sum up, in chapter Ⅲ, I examined the self-face evaluation ratings and neural processing in the no-odor condition. These data will be used as the baseline in the analysis described in chapters Ⅳ and Ⅴ. I also verified the differences between groups (sex: males (n=17) vs. females (n=13), BMI: low (n=18) vs. high (n=12), and self-esteem: low RSES (n=17) vs. high RSES (n=13)). In chapter Ⅳ, I analyzed changes during self-face processing after lavender or isovaleric acid odor priming. I hypothesized that a pleasant odor (lavender) would positively enhance the self-face evaluation, and these behavioral patterns will be reflected in the ERP patterns. These patterns will be used to interpret the results in chapter Ⅴ. In chapter Ⅴ, I analyzed changes separately depending on the sex, BMI, and self-esteem during self-face processing after odor priming. The results will show the different responses to the odor depending on the three factors. This study could contribute to the understanding of the self. Furthermore, my results could have industrial applications or be used to enhance social well-being.

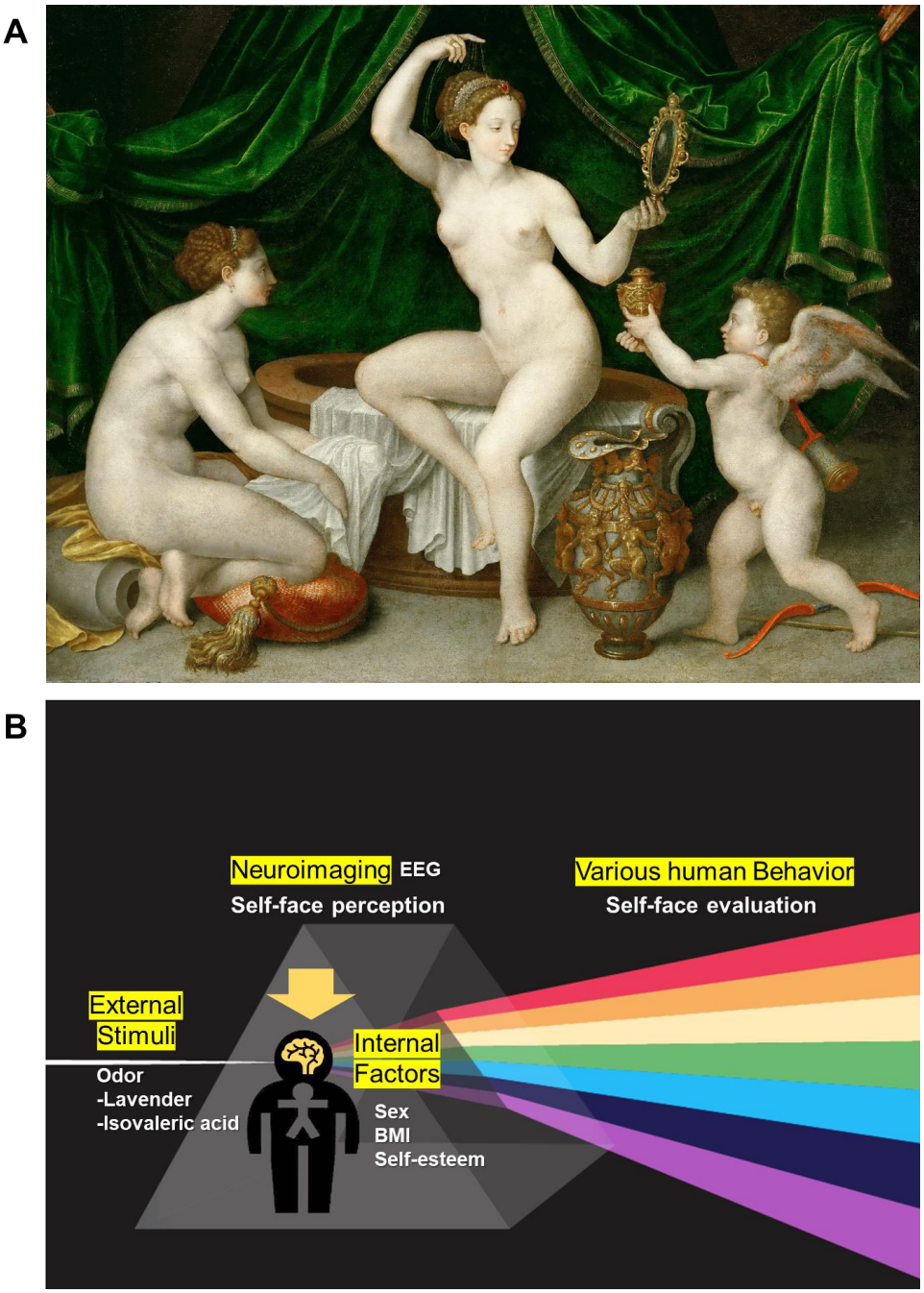


Fig 1.1 Graphical abstract

This study will use the neuroimaging technique to understand how and when external stimuli (odors) modulate self-face perception and evaluation, depending on internal factors (sex, BMI, self-esteem). (A) Cupid gives perfume to Venus while seeing her face in the mirror; Venus at her toilet, unknown author (School of Fontainebleau), public domain, via Wikimedia Commons. (B) Graphical abstract of the thesis.

1.2 Theoretical background of this study

1.2.1 Importance of making good social relationships

“The good life is built with good relationships." This sentence is the key conclusion from a 75-year longitudinal study of adult development at Harvard [28]. For our happy life, we make an effort to have good social relationships with others in our daily life. Social relationships, broadly defined, are the connections between people who have frequent interactions, including family members, friends, coworkers, and neighbors [29]. There are many studies on social relationships that affect health [30]. Fewer social network ties have been reported to increase the risks of diseases, including cardiovascular disease, stroke, infectious diseases, possibly dementia, and cancer [31, 32]. Therefore, studying social relationships is essential to our healthy and happy life.

1.2.2 Central roles of self-face perception processing in social relationships

'Self' is the first step toward understanding social relationships. The self is the foundation of all human behavior because it is the basic unit that makes up the interactions of an individual. Thus, it has been studied for many years [33].

Interestingly, only a few animals, including humans, can recognize the self in the mirror. Chimpanzees and orangutans could recognize their own reflections in the mirrors, but monkeys cannot [34, 35]. Elephants, dolphins, and some birds also showed the use of a mirror for investigating marked parts of the body [36-38]. This mirror self-recognition is considered as an indicator of self-awareness. The definition of *self-awareness* is being conscious of the self as an individual. Infants can recognize

themselves in a mirror at about 18 months of age in the same way that chimpanzees do [39]. Two-year-old infants can become aware of their gender (a boy or a girl); 4-year-olds can describe physical features and emotions. They can also predict the behavior of others and understand that others see and rate themselves just as they see and rate others [40, 41]. This means that self-perception is essential to understand others.

According to the *objective self-awareness* (OSA theory) by Duval and Wicklund (1972) [42], people tend to self-evaluate on the basis of broad social standards and norms. The OSA theory assumes that the self as a socially evaluable object [43]. The objective self-awareness could be enhanced when we look in the mirror [44], at photos, including those of our own face [45], and at a video camera that points to us [46]. In these situations, our behavior could be compared with our internal standards [42]. The *self-discrepancy theory* (1987) explains that we experience distress when we perceive a gap between our actual and ideal selves [47].

We live in an era when more and more people are posting selfies and updating status on social media. According to previous studies, these actions could impact *self-esteem*, which refers to positive or negative feelings about ourselves [48, 49]. Even in the online world, people want to build good connections with others by projecting themselves positively into society [33].

People tend to look in the mirror every morning to check their faces. We seem to know the importance of the information conveyed by the face. The face visually conveys our genetic, biological, and psychological features, including identity [50], gender [51], age [52], race/ethnicity [53], physical health [54, 55], and emotional state [56]. It also provides social information such as the first impression [57], sexual orientation [58], attractiveness [55, 59, 60], and personality [61] to other people. Therefore,

perception, evaluation, and further management of self-face are critical for our social communication [62].

1.2.3 Distinct neural patterns: self-face vs. non-self-face

In the brain, self-face and non-self-face are processed differently [63]. Interestingly, previous studies have demonstrated that self-face perception is distinct from, faster, and more accurate than non-self-face perception [63-65]. An ERP study has also shown that brain responses are increased by presenting deviant self-faces (but not by deviant non-self-faces), compared to the expected self-face [66]. This processing is associated with early changes in visual cortical signals.

fMRI studies have also shown that self-face processing activates specific brain regions compared to non-self face processing. The right hemisphere is known to play a role in discriminating between self and non-self [67, 68]. Recognition of self-face activates the 'mirror area,' which is a right hemisphere network that includes the inferior frontal gyrus, inferior parietal lobule, superior parietal lobule, and inferior occipital gyrus. Seeing self-face decreases activity in the 'default mode network,' which includes the precuneus, ventromedial prefrontal cortex, dorsomedial prefrontal cortex, and posterior superior temporal gyrus [69]. When viewing a non-self face, the default mode network is more active (but not activated in these regions) than when viewing the self-face [68]. These studies indicate that self-face perception is a more active neural process in the brain than non-self-face perception.

Another fMRI study [70] has revealed specific brain regions that show specific activation during negative self-face evaluation. The researchers presented self-face images during scanning fMRI (good images: posed for a photograph; bad images: deviant images from a video clip, for example, with eyes

totally or partly closed or the mouth unnaturally open). Then, the participants rated their embarrassment while viewing each face. The researchers could measure the brain regions activated during self-face recognition and evaluation, especially when participants felt embarrassed because their self-face was far from their mental representation of ideal self. Compared to the non-self-face, the self-face caused a significant increase in activation in the right prefrontal cortex, bilateral insular cortex, anterior cingulate cortex, and bilateral occipital cortex **(Fig 1.2)**. The study also revealed the role of the right prefrontal cortex in detail. The authors concluded that right precentral gyrus is involved in self-face recognition, and the embarrassment modulates the right middle inferior frontal gyrus (mIFG) activity [70].

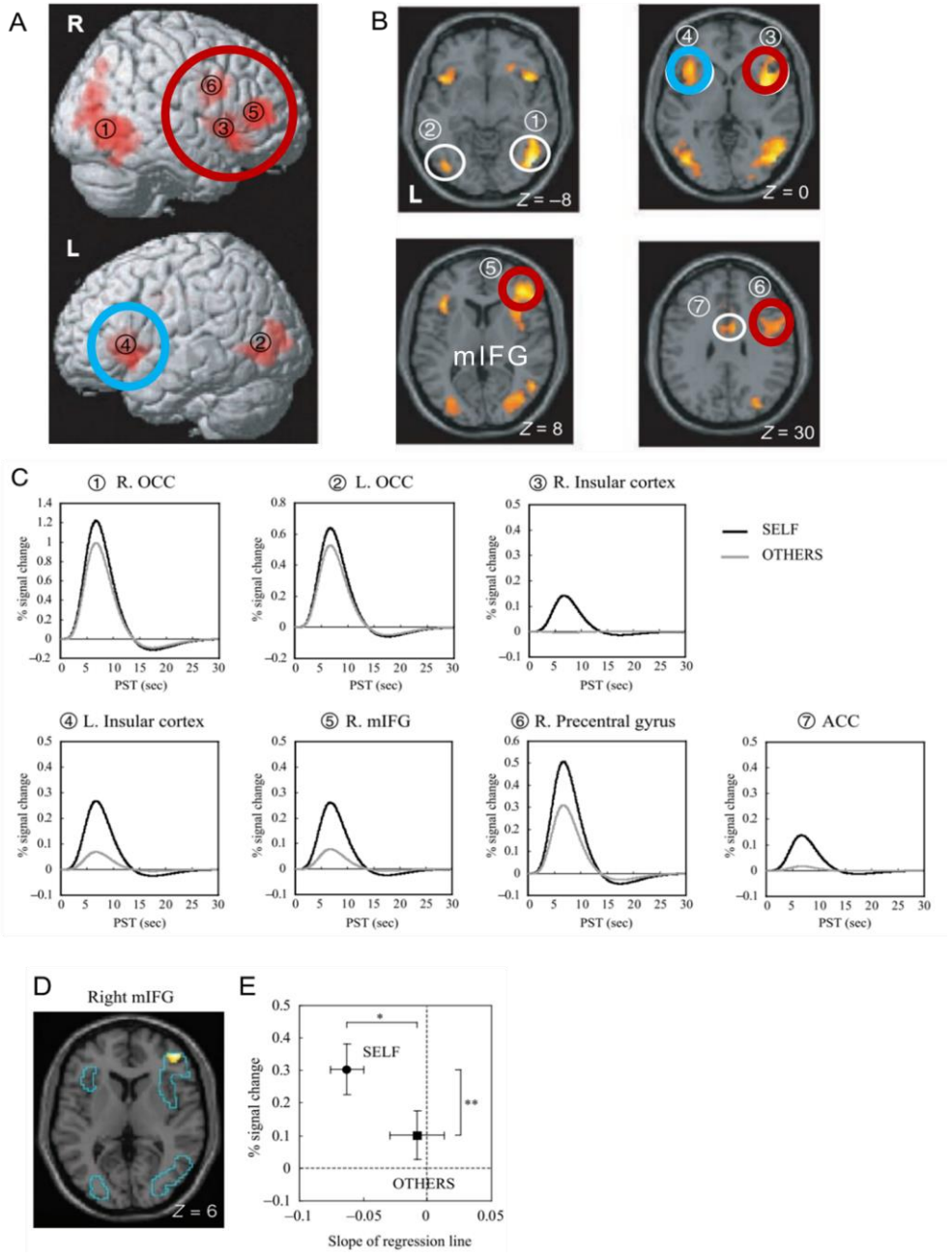


Fig 1.2 Brain regions: self-face vs. non-self face during negative self-face evaluation

Modified from Morita et al. (2008) [70]. (A, B) Self-face vs. non-self face contrast, marked brain regions were significantly activated. (C) Estimated hemodynamics plot in the marked regions. PST: poststimulus time. (D) Statistical parametric activation map (SPM) of the right mIFG. Blue line indicates areas of significant activation by self vs. non-self contrast. (E) The *x*-axis shows the slope of a regression line between the embarrassment ratings for each face and the right mIFG activation, the *y*-axis shows right mIFG percent signal changes. * $P < 0.05$, ** $P < 0.001$, paired *t*-test.

1.2.4 Odor stimuli

From the anatomical point of view, the odor could change face perception and evaluation. In the olfactory pathway **(Fig 1.3)**, the odor perception begins at the odorant receptors of olfactory sensory neurons in the olfactory epithelium. These neurons project to the glomeruli in the olfactory bulb and form synapses with mitral and tufted cells. The axonal projections of these cells pass through the lateral olfactory tract and then terminate in numerous regions such as the anterior olfactory nucleus, olfactory tubercle, anterior piriform cortex, posterior piriform cortex, amygdala, and entorhinal cortex. Then it is relayed to the orbitofrontal cortex (OFC) and the hippocampus [71]. Because of the structure of this olfactory pathway, odors modulate the amygdala, hippocampus, and OFC, which have important roles in emotional stimuli [71-73]. Interestingly, OFC can respond to reward stimuli and is also involved in the judgment of facial attractiveness [74, 75].

From the functional point of view, previous studies have reported that perception and evaluation of the face can be altered by contextual or sensory stimuli, although they are primarily mediated by visual sensation. Especially, odor affects face perception by modifying the interpretation of emotional facial expressions [9], hedonic evaluations including facial attractiveness [10], social judgment [12], and social preferences for the face [13]. Notably, pleasant odors positively modify face perception and evaluation, whereas unpleasant odors have a negative effect [10]. However, no studies have investigated how odors change self-face perception and evaluation.

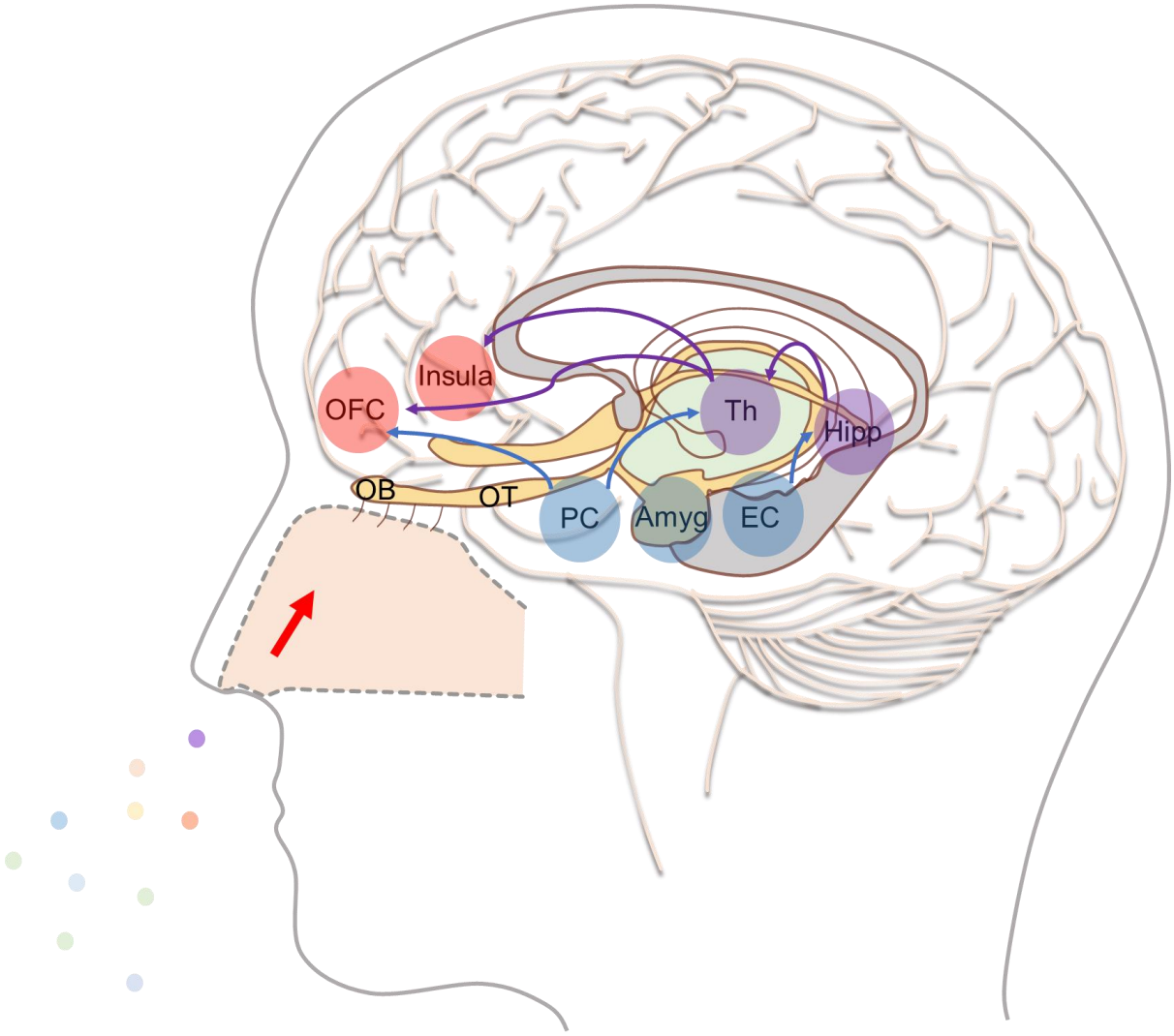


Fig 1.3 Olfactory pathway

Modified from Saive et al (2014) [76]. Odor stimuli are perceived through the following olfactory pathway. The primary olfactory cortex is shown in blue and the secondary olfactory cortex in red. OB: olfactory bulb, OT: olfactory tract, PC: piriform cortex, Amyg: amygdala, EC: entorhinal cortex, Hipp: hippocampus, Th: thalamus, OFC: orbitofrontal cortex

1.2.5 Sex, BMI, and self-esteem

Self-face perception and evaluation are variable and even distortable processes. The perception and evaluation of the self-face, but not the faces of other people, respond to external stimuli and might vary depending on the individual differences such as genetic differences, gender, appearance, and self-esteem. However, which factors might influence self-face perception processing is largely unknown. Only a few studies reported some clues about how individual variations affect self-face perception processing.

It is well known that self-evaluation is highly affected by our self-esteem. When people evaluate self-related information, they tend to evaluate it in a way that allows them to maintain their self-esteem. Typically, they rate the self more positively than others [77-79]; they even choose a morphed self-face, which is modified to be more attractive [80] and more trustworthy [81]. In a previous study, participants with high self-esteem showed a strong self-positivity response when a subliminal self-face was presented. They showed a faster response to positive words than to negative words following self-face primes [82].

An fMRI study [27] revealed self-esteem score–dependent neural correlates during positive self-face evaluation **(Fig 1.4)**. The researchers showed a positive correlation between self-esteem and activation in the posterior cingulate cortex and ventral tegmental area (PCC/VTA). The PCC might affect positive self-face processing by retrieving participants' positive self-image from the positive autobiographical memories. The VTA might process the self-face as a social reward because VTA is the main region of the reward system. Interestingly, the researchers have reported that VTA showed different responses during self-face evaluation according to self-esteem score [27].

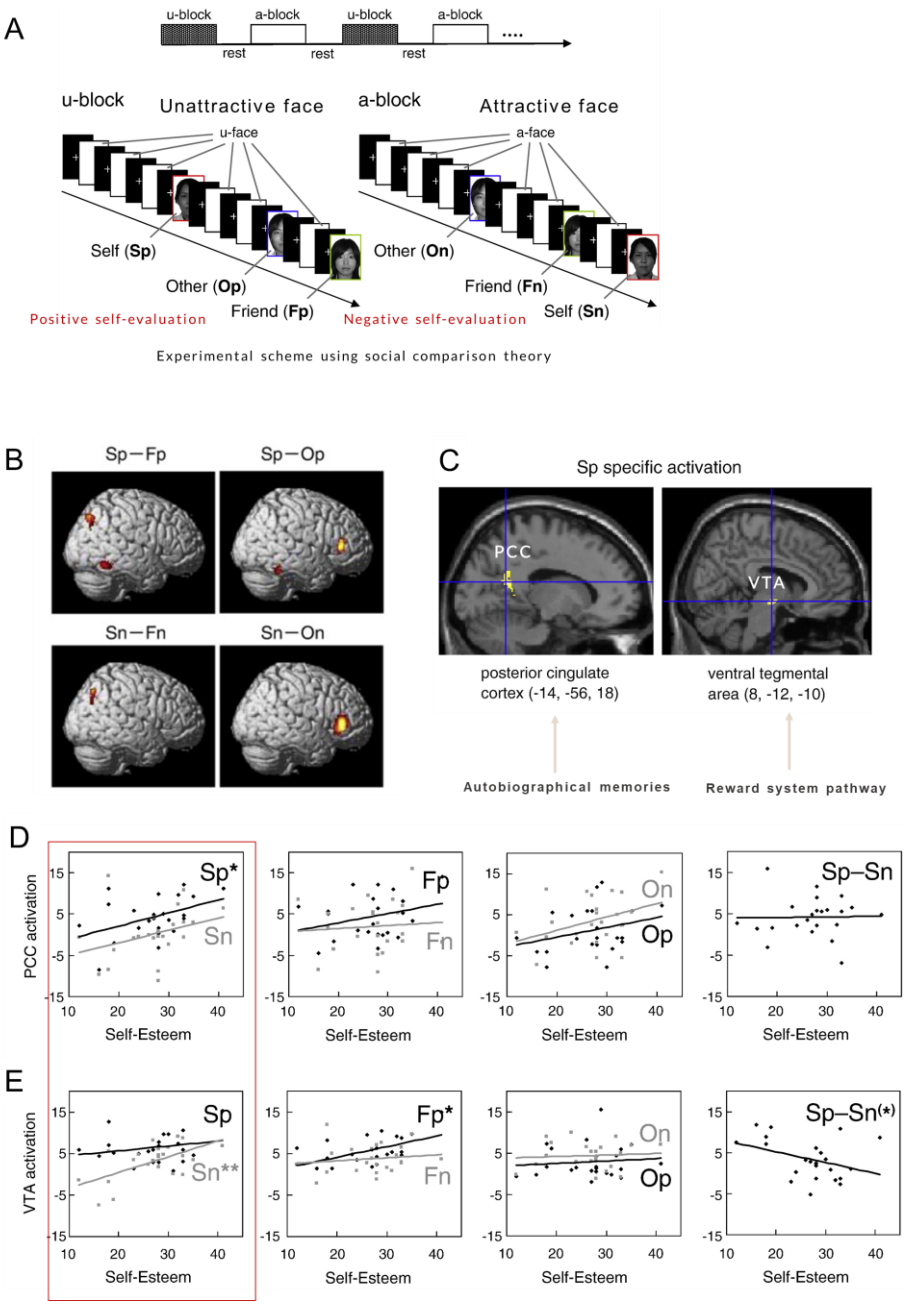


Fig 1.4 Brain activation during positive self-face evaluation

Modified from Oikawa et al (2008) [27]. (A) Experimental scheme based on the social comparison theory. (B) Self-face–specific brain activation pattern compared to a friend's face or another face. (C) Brain region with activation specific for positive self-face evaluation. (D, E) Regression lines between self-esteem and PCC or VTA activation. * P <0.05, ** P <0.01 (single regression analysis). Sp: self-positive evaluation, Op: others-positive evaluation, Fp: friend-positive evaluation.

Being overweight could also affect self-face perception and evaluation. The relationships between being overweight and psychosocial and emotional problems have been reported, including low self-esteem, body image concerns, eating disorders, and social marginalization [24, 83, 84]. In particular, overweight children are believed to be at high risk of developing low self-esteem. A previous study reported that weight negatively affects the overall self-perception of heavy girls [23].

Most females have a stronger tendency to perceive themselves as overweight than males do, even though they have the same measured BMI [85-87]. About 25.1% of females and 8% of males among normal-weight participants reported that they perceived themselves as being overweight. In addition, among females, low self-esteem is associated with misperceived overweight status [87]. These findings indicate that self-perception differs between males and females, and this difference could affect self-esteem. Interestingly, highly overweight girls had significantly lower physical self-esteem than moderately overweight girls, whereas boys showed opposite results. These data are interpreted as evidence for a significant discrepancy between cultural standards of attractiveness and perceived self physical appearance in highly overweight girls. However, highly overweight boys used to have opportunities to have physical dominance over others, so that they could shield their physical self-esteem [24]. A meta-analysis study revealed that males score higher than females in self-esteem measurements, but the difference is small [88].

In the brain, females and males showed differences during face processing [89, 90]. Electrophysiological methods show asymmetric patterns in men, whereas females exhibit symmetric face processing in N170 peak amplitude, measured in the 135–185 ms time window in the occipito/temporal region [89]. Whole-head magnetoencephalography (MEG) also confirmed larger

lateralized M170 amplitude in the right hemisphere in men than in women [90].

Interestingly, face-processing strategies differ between males and females through the asymmetric fusiform activation pattern. The right hemisphere is reportedly more related to holistic processing than to local processing [91]. Eye-tracking results [92] showed that females gaze at the eye-region more than males do. Males tend to spend more time to look at the central parts of faces, including the nose and mouth. Face-processing research [93] indicates that males gather information related to face using a global strategy, which shows central fixations, whereas females use a local strategy. This difference in face processing strategies has been interpreted as an explanation of the behaviors of males and females. For example, because holistic face processing is used to evaluate facial attractiveness [94, 95], males' brain response to females' faces has been interpreted as a reflection of females' interests. However, males also show asymmetric patterns during 150–180ms after the self-face onset; indicating that genetic difference rather than psychological gender difference may affect face processing.

To sum up, a study is needed that would reveal when and how odor stimuli modulate self-face perception processing by observation of the differences in responses according to sex, BMI, and self-esteem. The present study will be the first attempt to characterize the effects of odors on self-face processing using neuroimaging.

Ⅱ. Materials & Methods

2.1 Participants

A total of 39 healthy adults (20 females) were initially enrolled in this study. Nine participants had to be excluded from the analysis because of missing answers on questionnaires (7 participants), or because they did not undergo enough electroencephalography (EEG) trials (2 participants). Data from the remaining 30 participants (17 males, 13 females) were analyzed. The participants' mean age was 20.5 years (SD = 1.042).

For further analysis, information of body mass index (BMI) and Rosenberg self-esteem scale (RSES) were used. BMI was calculated using height and weight.

$$BMI = weight\ (kg)/(height\ (m))^2$$

The participants' mean BMI was 22.91 (SD = 2.82). Self-esteem level was measured using RSES [96]. Participants answered Korean-translated version (1974) of RSES [97]. The participants' mean RSES score was 26.63 (SD = 3.90) (Table 1). The participants had no neurological or psychiatric disorders and had normal or corrected-to-normal vision and olfactory ability. Olfaction was tested with a Sniffin' Sticks test kit (Burghardt, Wedel, Germany) before the EEG recording to exclude functional anosmia [98, 99].

This study was approved by the Institutional Review Board Ethics Committee of the Daegu Gyeongbuk Institute of Science and Technology (DGIST-181210-HR-024-02). All participants gave written consent before participating in the experiment. All experimental procedures were performed under all relevant guidelines and regulations.

Table 1 Participant's sex, BMI, self-esteem

Participant #	Sex	BMI	Self-esteem (RSES)
P1	Male	21.88	26
P2	Male	22.44	25
P3	Male	20.96	24
P4	Male	30.32	23
P5	Male	22.34	25
P6	Male	25.95	24
P7	Male	24.44	25
P8	Male	28.4	25
P9	Male	23.18	25
P10	Male	19.38	31
P11	Male	23.51	29
P12	Male	26.81	32
P13	Male	22.34	26
P14	Male	24.39	31
P15	Male	25.31	31
P16	Male	25.25	36
P17	Male	20.66	29
P18	Female	19.57	25
P19	Female	21.36	24
P20	Female	18.29	38
P21	Female	21.48	26
P22	Female	23.73	21
P23	Female	22.04	25
P24	Female	21.3	24
P25	Female	21.94	25
P26	Female	20.06	22
P27	Female	27.24	27
P28	Female	21.45	25
P29	Female	20.58	24
P30	Female	20.58	26

Table 2 Smell ability test using Sniffin' Sticks

Simplified protocols were used to test the threshold score and discrimination score. The odor threshold score range was 1–15 (1: the highest intensity, 15: the lowest intensity). The odor discrimination score was calculated as the percentage of correct answers. The odor identification score was calculated by counting the number of correct identification answers among 16 odors. Functional anosmia is defined by a threshold, discrimination, identification score of less than 16.5 [99]. In this study, only the participants who had a threshold score > 3, discrimination score > 50%, and identification score > 8 underwent EEG.

Participant #	Threshold score	Discrimination score	Identification score
P1	9	67%	12
P2	5	100%	12
P3	5	100%	10
P4	8	100%	13
P5	5	100%	12
P6	9	100%	15
P7	5	100%	12
P8	4	67%	13
P9	5	67%	10
P10	10	75%	13
P11	4	67%	10
P12	5	100%	13
P13	6	100%	12
P14	5	100%	15
P15	6	100%	14
P16	6	60%	10
P17	6	60%	14
P18	11	100%	11
P19	6	67%	13
P20	6	100%	12
P21	8	100%	10
P22	9	100%	13
P23	4	100%	15
P24	5	67%	13
P25	9	100%	13
P26	4	100%	12
P27	6	67%	11
P28	4	67%	14
P29	5	100%	15
P30	9	100%	12

2.2 Stimulus

2.2.1 Olfactory stimuli

Three odor conditions were tested in this study: lavender (L; a pleasant, herbal, floral odor), isovaleric acid (IVA; an unpleasant, sweaty, pungent, stinky odor), and clean air (control odor, solvent only). The solvent was mineral oil (CAS number: M5904, Sigma-Aldrich, LOT#MKBX0231V). Lavender oil (CAS number: 61718, Sigma-Aldrich, LOT#BCBM0576V) was used at a concentration of 0.05%. Isovaleric acid (CAS number: 503-74-2, Sigma-Aldrich, LOT#STBG4549V) was used at a concentration of 0.01%. Each solution (1 ml) was stored in a glass bottle, which was placed into a customized olfactometer (Figure 2.1). Each bottle was connected to a silicone tube that fit the olfactometer's channel (Figure 2.1 A). The odor was presented with air in a mask (flow speed: 5 m/s) (Figure 2.1 B) for one respiratory cycle (Figure 2.1 C). The participants' respiration was monitored using a respiration belt. The odor was sent through the olfactometer while the participant exhaled.

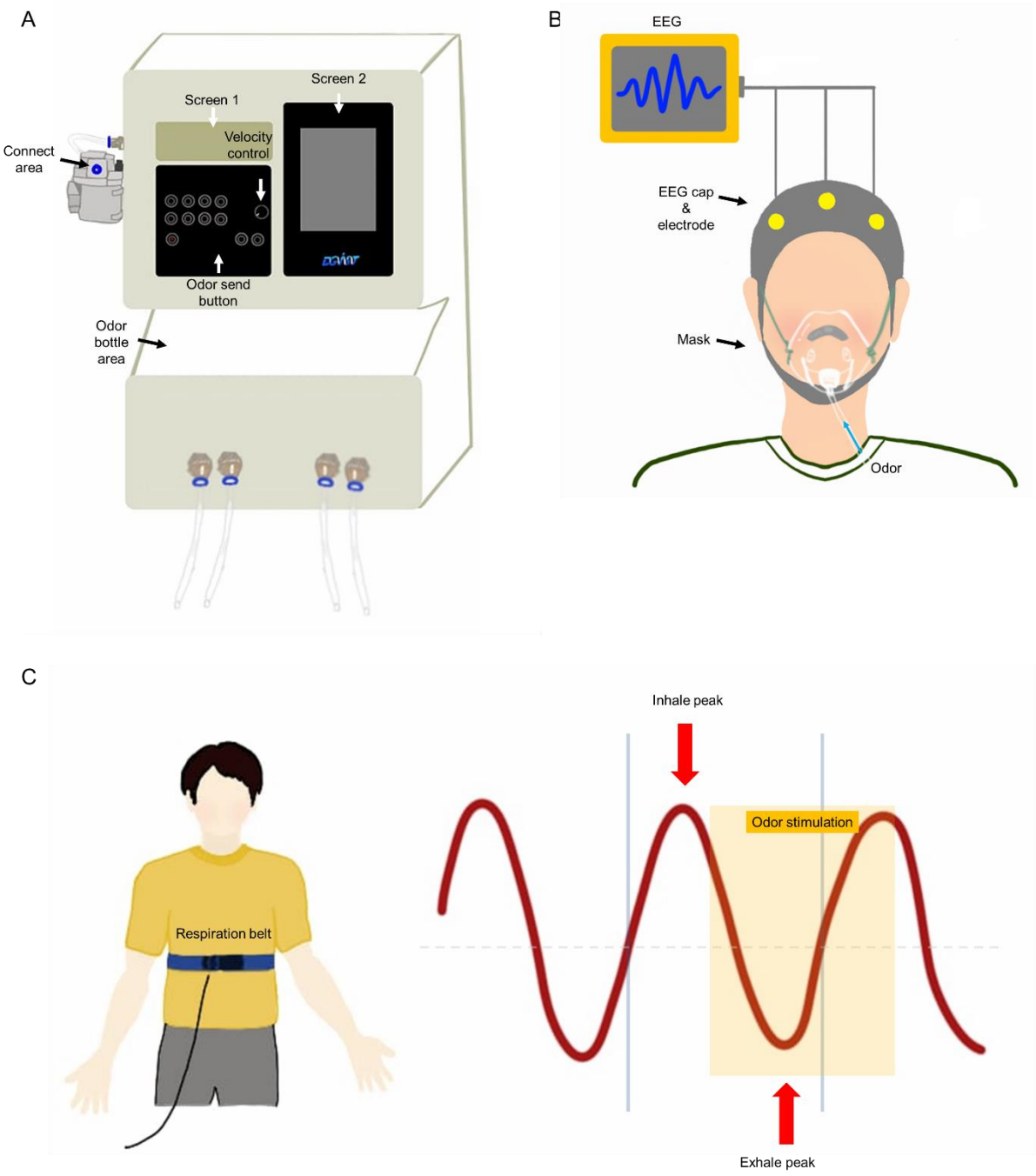


Figure 2.1 Experimental set up for odor stimulation.

Each odor condition was presented through a tube that was connected to an olfactometer and the mask of the participant. (A) Customized olfactometer. (B) EEG recording was set up with a mask.(C) Odor stimulation timing and respiration cycle.

2.2.2 Visual stimulus

Each participants' face (with a neutral facial expression) was photographed with a digital camera (SONY FDR-AXP35) in the same room. The participants consented to the use of their facial images to create visual stimuli for this study. The participants could not see the images. Each image was cropped into an oval shape to cover the face from the forehead to the chin. The brightness of each photo was increased by 30% in Microsoft PowerPoint, and all the photos were adjusted to the same size. Before EEG recording, participants were only told that the visual stimuli were produced using their own faces. They did not know whether their photos would be modified during the study.

2.3 Experimental scheme

The experimental design is illustrated in Figure 2.2. This experimental procedure was modified from Cook et al. (2015) [10]. I used a priming paradigm. As the prime, the participants inhaled air, lavender, or isovaleric acid; as the target, they saw the visual stimuli of their own faces. This paradigm has been used to reveal how olfactory stimuli affect visual processing [10, 17-19]. The participants were told about the experimental process and necessary precautions regarding EEG recordings before the start of the experiments. Each person participated in 3 sets of EEG recordings (Figure 2.2 A). They passively viewed visual stimuli after receiving an odor (air, lavender, or isovaleric acid). Each set of participants was presented with one of the three odor conditions, and 25 trials were done. For example, set 1 was exposed to lavender and then to the self-face visual stimuli. Set 2 was exposed to isovaleric acid and then to the self-face visual stimuli. Set 3 was given air as the no-odor condition and then the self-face visual stimuli. A post-test survey was conducted just after the end of the each set of EEG recordings. Additional EEG recording sets without surveys were done on the following two days in order to produce sufficient epochs for ERP analysis.

During EEG recording, participants sat in front of a 21-inch monitor screen. The screen displayed the following: a white cross on a black screen for fixation (baseline period) – black background (odor conditioning period) – self-face (face stimulus period) – black background (resting period); the images were shown as a Microsoft PowerPoint presentation (Figure 2.2 B). Before each set of EEG recordings, participants had time to stabilize their mood for about 1–2 min. The experimental sequence

was as follows: baseline period (10 s) – odor conditioning period (the olfactometer presented an odor for one respiratory cycle) – face stimulus period (0.5 s) – resting period (5 s) (Figure 2.2).

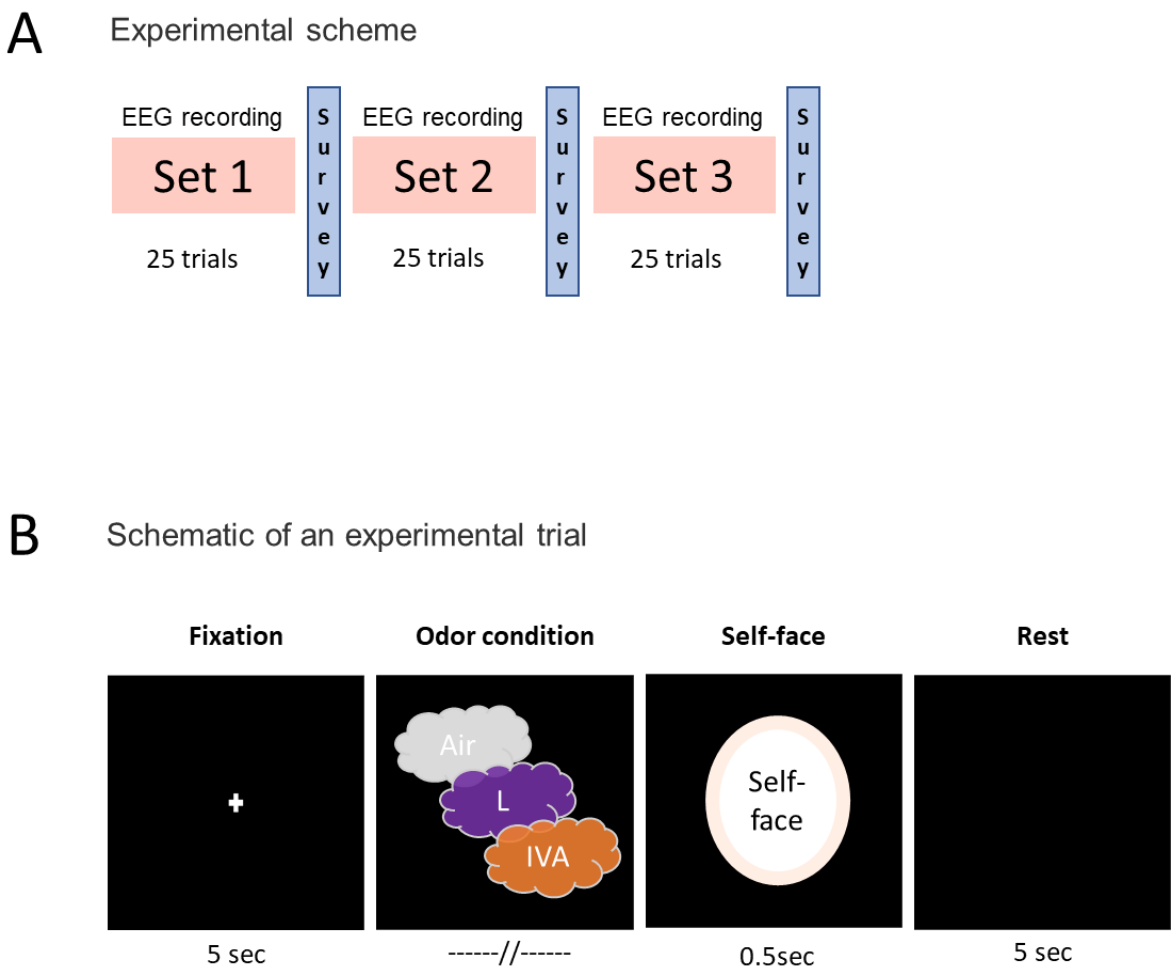


Figure 2.2 Experimental design.

A. Experimental scheme. Participants attended three sets of EEG recordings, each consisting of 25 trials. They then gave survey ratings for odor characteristics, self-face evaluation, and mood. B. The monitor screen presented during the EEG recording trials. Fixation cross (5 s) – odor presentation (during one respiratory cycle) – self-face visual stimulus (0.5 s) – black screen (5 s). Air: solvent (mineral oil) only (no odor condition), L: lavender, IVA: isovaleric acid.

2.4 Questionnaires

2.4.1 Mood ratings

After each EEG recording set, the participants conducted a post-test survey about their mood (1, relaxation–arousal; 2, pleasant–unpleasant) (Figure 2.3 A). They assessed elements of the experience using nine-point Likert scales.

2.4.2 Self-face evaluation ratings

After each EEG recording set, the participants conducted a post-test survey on self-face evaluation (Figure 2.3 B). They assessed elements of the experience using nine-point Likert scales. Before any ratings were taken, the participants were given detailed instructions on how to answer the survey questions. Participants were asked to evaluate the visual stimuli presented during the previous experimental set. They only knew that the visual stimuli were created using images of their faces. Thus, they evaluated the visual stimuli of self-face, not self-image. In this paradigm, the higher the number, the more the participant agreed with that question. There were six questions about self-face evaluation: preference, attractiveness, trustworthiness, dominance, maturity, and masculinity [100].

2.4.3 Odor characteristics ratings

The perceived odor characteristics were rated after each EEG recording set (Figure 2.3 C). There were eight questions about odor characteristics: intensity, preference, relaxation, familiarity, pungency, mood change (the degree to which presentation of the odor changed the participant's mood), positive mood change (the degree to which presentation of the odor positively changed the participant's mood), and attractiveness (how attractive the presented odor was).

2.4.4 Self-esteem questionnaires

The RSES [96] used in this study (Figure 2.4) contained five positively worded items and five negatively worded items. For calculating RSES scores, negatively worded items needed to reverse scoring. 4-point Likert scales were used. 1 = Strongly disagree, 2 = Disagree, 3 = Agree, 4 = Strongly disagree.

A

1. 실험 날짜: 년 월 일

2. 실험 참가자 이름: 이니셜:

설문지 (set 1)

■ 실험이 끝난 현재의 기분에 대해서 체크해주세요.

1) 편안한 정도

1	2	3	4	5	6	7	8	9
매우 긴장됨				보통				매우 편안함

2) 기분 좋은 정도

1	2	3	4	5	6	7	8	9
매우 불쾌함				보통				매우 좋음

Fig 2.3

B

■ 실험에 제시된 시각 자극에 대해서 체크해주세요.

1) 기분 좋은 정도

1	2	3	4	5	6	7	8	9
매우 나쁨				보통				매우 좋음

2) 매력도

1	2	3	4	5	6	7	8	9
매우 나쁨				보통				매우 매력적임

3) 신뢰성

1	2	3	4	5	6	7	8	9
신뢰성 없음				보통				매우 신뢰감

4) 지배성

1	2	3	4	5	6	7	8	9
지배적이지 않음				보통				매우 지배적인

5) 성숙성

1	2	3	4	5	6	7	8	9
매우 어린				보통				매우 성숙

6) 남성성

1	2	3	4	5	6	7	8	9
매우 여성적				보통				매우 남성적

Fig 2.3

C

■ 실험에 제시된 냄새에 대해서 체크해주세요.

1) 강도

1	2	3	4	5	6	7	8	9
냄새 없음				보통				매우 강함

2) 기분 좋은 정도

1	2	3	4	5	6	7	8	9
매우 불쾌함				보통				매우 좋음

3) 긴장 완화 효과

1	2	3	4	5	6	7	8	9
매우 긴장됨				보통				매우 편안함

4) 친숙성

1	2	3	4	5	6	7	8	9
매우 낯선				보통				매우 친숙한

5) 톡 쏘는 정도

1	2	3	4	5	6	7	8	9
매우 부드러운				보통				매우 톡쏘는

6) 이 냄새는 당신의 기분을 변화시킵니까?

1	2	3	4	5	6	7	8	9
전혀 아니다				보통				매우 그렇다

7) 이 냄새는 당신의 기분을 긍정적으로 변화시킵니까?

1	2	3	4	5	6	7	8	9
매우 부정				보통				매우 긍정

8) 이 냄새는 매력적입니까?

1	2	3	4	5	6	7	8	9
매력 없음				보통				매우 매력적

■ 냄새를 맡았을 때, 떠올랐던 것을 적어주세요. (냄새 묘사)

_____

Fig 2.3

Figure 2.3 Examples of questionnaires used in this study.

After an EEG recording set, a survey was conducted to evaluate mood, self-face visual stimuli, and odor stimuli. (A) Mood ratings. 1) Relaxation, 2) Pleasantness (B) Visual stimulus evaluation. 1) preference, 2) attractiveness, 3) trustworthiness, 4) dominance, 5) maturity, 6) masculinity, (C) Odor stimulus evaluation. 1) intensity, 2) pleasantness, 3) relaxation, 4) familiarity, 5) pungency, 6) mood change, 7) positive direction mood change, 8) attractiveness.

■ 다음은 자신에 대해 가지고 있던 일반적인 태도가 어떠한지 알아보기 위한 것입니다. 각 문장을 읽고 평소에 여러분이 자신에 대해 갖고 있던 생각과 일치되는 곳에 "O" 표시해 주십시오.

문 항	전혀 아니다	아니다	그렇다	매우 그렇다
1. 나는 내가 적어도 다른 사람만큼 가치가 있는 사람이라고 생각한다.	①	②	③	④
2. 나는 나에게 좋은 점이 많이 있다고 생각한다.	①	②	③	④
3. 나는 대체로 실패한 사람이라고 생각한다.	①	②	③	④
4. 나는 대부분의 다른 사람만큼 일을 잘 할 수 있다.	①	②	③	④
5. 나는 자랑할 만한 것이 별로 없는 것 같다.	①	②	③	④
6. 나는 내 자신에 대해 긍정적으로 생각하고 있다.	①	②	③	④
7. 나는 내 자신에 대해 대체로 만족한다.	①	②	③	④
8. 나는 내 자신을 좀 더 존중할 수 있으면 좋겠다.	①	②	③	④
9. 나는 내 자신이 정말로 쓸모 없는 사람이란 생각이 들 때가 있다.	①	②	③	④
10. 나는 가끔 내가 좋지 않은 사람이라고 생각할 때가 있다.	①	②	③	④

Figure 2.4 Rosenberg's self-esteem scale.

The Korean version of RSES was used in this study. Positively worded items: 1, 2, 4, 6, 7; negatively worded items: 3, 5, 8, 9, 10. Self-esteem level was measured using RSES [96]. Participants answered Korean-translated version (1974) of RSES [97].

2.5 EEG data analysis

2.5.1 Principles of EEG

2.5.1.1 EEG

Our brain is composed of neurons and neuroglia. All the neurons establish interneuronal connections through synapses. There are two modes of synaptic transmission: electrical and chemical. Electrical transmission is very rapid because voltage-dependent channels in the pre-synapse generate direct current. Electric synapses often interconnect entire populations of neurons to synchronize their responses. Most of the electric synapses can transmit both depolarizing and hyperpolarizing currents. In chemical synapses, the neuromodulators are released, and postsynaptic potentials could be excitatory or inhibitory, depending on the neurotransmitter. Excitatory neurotransmitters generate excitatory postsynaptic potential (ERSP) by triggering the entry of Na^+ ions into the cell. Inhibitory neurotransmitters generate inhibitory postsynaptic potential (IPSP) by allowing entry of Cl^- ions, and exit of K^+ ions. Triggered voltage changes can be measured as the summated ERSPs and IPSPs by using EEG on the scalp (Figure 2.5) [101, 102].

In 1924, Hans Berger first reported the electrical activity of the human brain [103]. He measured human brain activity by placing an electrode on the scalp and plotted the voltage changes using EEG [104].

2.5.1.2 Event-related potentials

EEG can measure neural responses associated with specific sensory, cognitive, and motor events. These responses can be extracted through averaging and are called 'event-related potentials' (ERP) because they are associated with specific events. The ERP components are usually labeled with their waveform polarity and position after events. For example, the ERP components are called P1, P2, N1, N2 (or P300), and N170 [104].

2.5.1.3 Current source density

Currents flow through the cell membranes during neural activity. When the membrane currents are inward, we called the inward current 'sink,' and when currents are outward, we called the outward

current ‘source.’ This sink/source balance causes field potentials. Through the ‘current source-density (CSD) method,’ it is possible to calculate the sink and source distributions in the extracellular space from the field potentials [105].

2.5.2 EEG recording

EEG and electrooculography were measured using an EEG amplifier and Actiview software (Active Two, Biosemi, Amsterdam, Netherlands) with 64 channels (sampling rate = 2048 Hz). The electrodes were placed on an EEG cap (64 ch, Biosemi), and a 10–20 international system was used (Figure 2.6). I used the common-mode-sensor (CMS) and driven-right-leg (DRL) electrodes as reference electrodes. During recording, electrode impedance was below 15 kΩ.

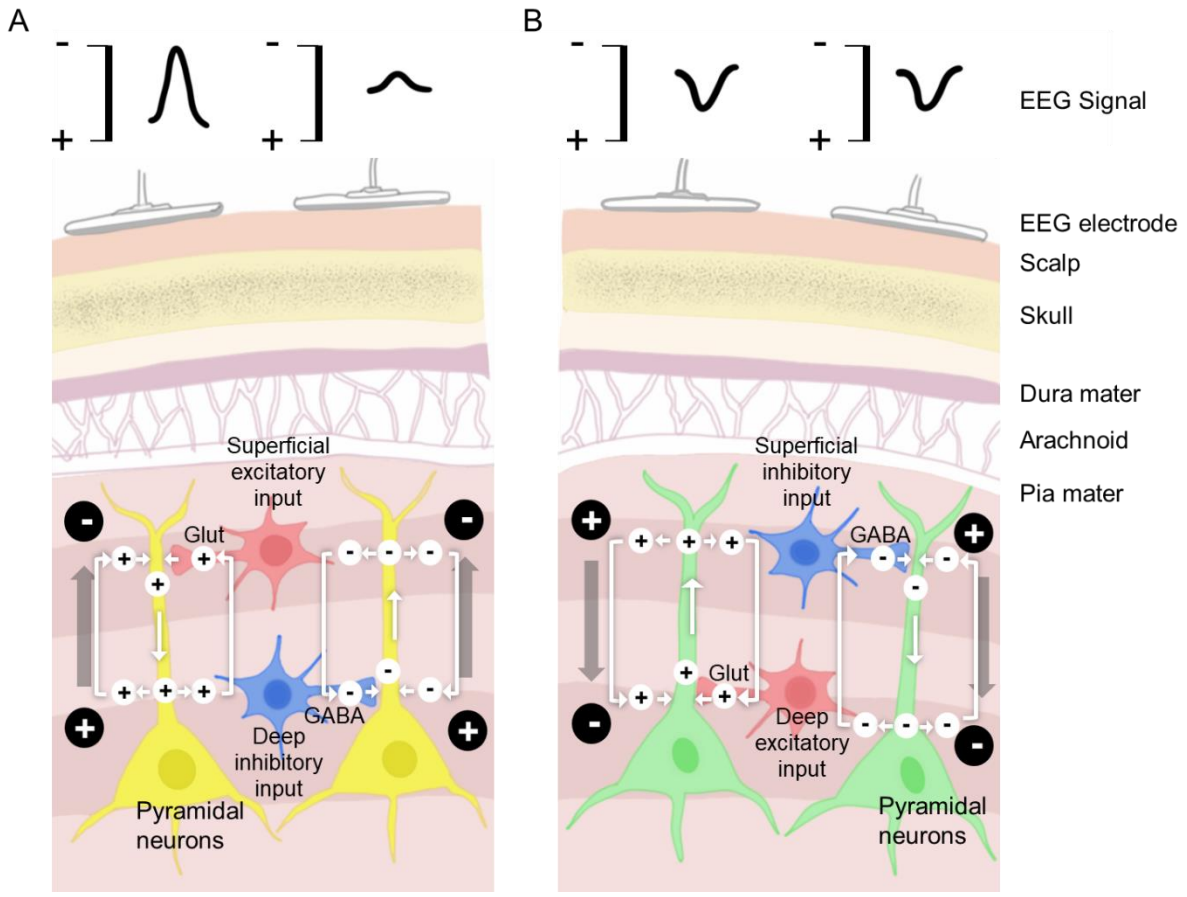
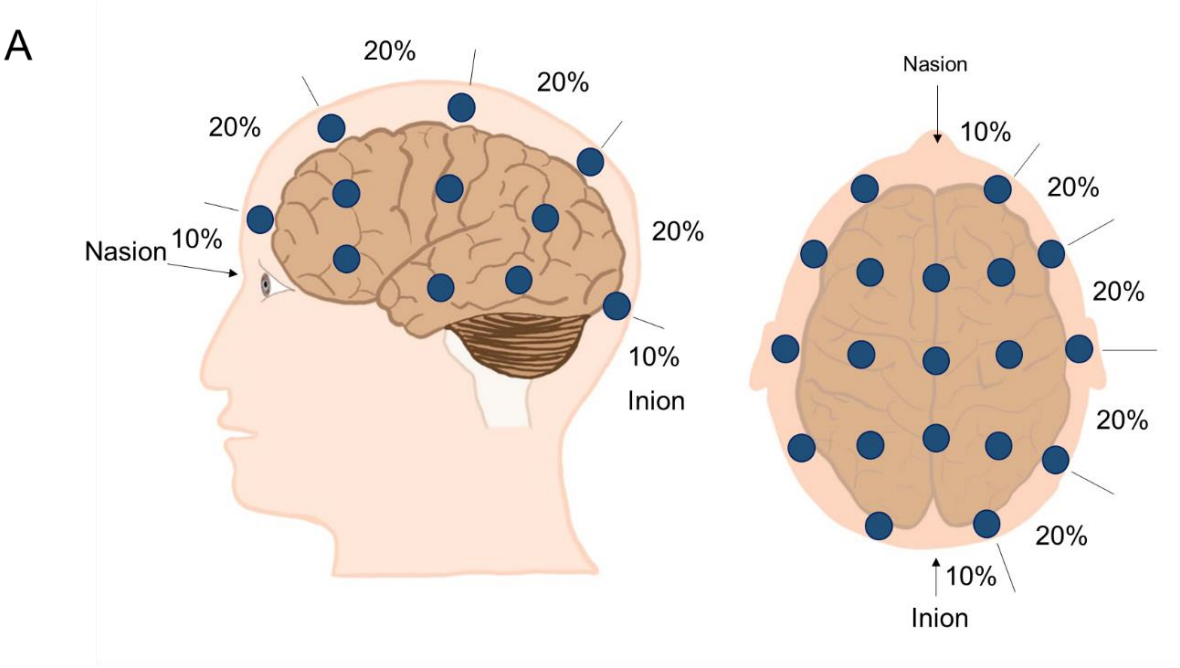


Figure 2.5 Source of the EEG signal.

The EEG electrodes measure the negative and positive deflections elicited from summated ERSPs and IPSPs. A. Negative peaks of the EEG signal. B. Positive peaks of the EEG signal. EEG: electroencephalography, ERSP: excitatory postsynaptic potentials, IPSP: inhibitory postsynaptic potentials, Glut: glutamate, GABA: gamma-aminobutyric acid (modified from M. Brienza and O. Mecarelli [102]).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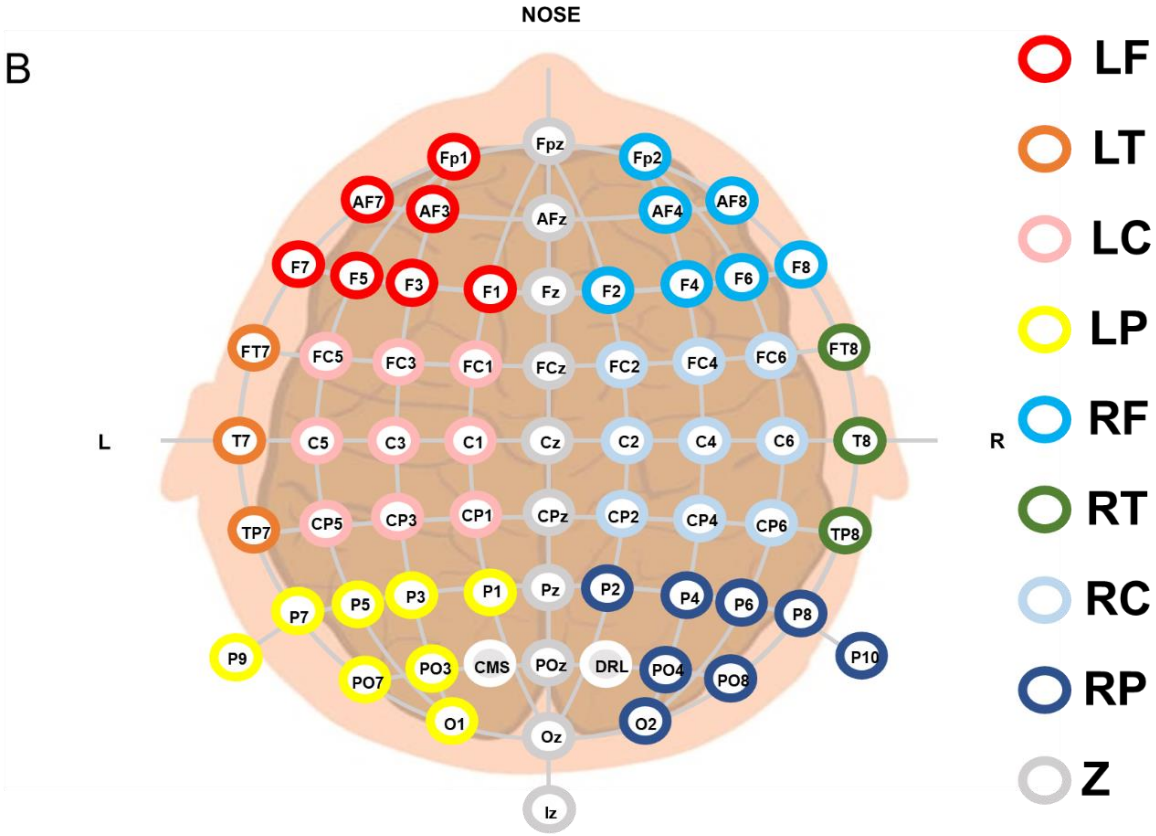
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P8
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PO3
CMS
POz
DRL
PO4
PO8
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Oz
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Iz
LF
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LC
LP
RF
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Z

Figure 2.6 EEG recording and electrode location.

Electrodes are placed on the scalp. (A) The 10–20 international system of EEG electrode placement. (B) An electrode array of 64 channels. Each color represents a region of interest. LF (left frontal): left hemisphere–frontal lobe region, LT (left temporal): left hemisphere–temporal lobe region, LC (left central): left hemisphere–parietal lobe region, LP (left posterior): left hemisphere–posterior lobe region, RF (right frontal): right hemisphere–frontal lobe region, RT (right temporal): right hemisphere–temporal lobe region, RC (right central): right hemisphere–parietal lobe region, RP (right posterior): right hemisphere–posterior lobe region).

2.5.3 ERP analysis

The EEG data were analyzed with Matlab R2015a (MathWorks, Natick, MA, USA) and EEGLAB toolbox (v13.5.4b) [106]. The ERPLAB toolbox (v7.0.0) [107] was used for ERP analysis (Figure 2.7). The sampling rate was reduced from 2048 Hz to 512 Hz. Averaging all channels was done for re-reference. Continuous EEG data were filtered between 1 Hz and 30 Hz before the extraction of epochs. Then, independent component analysis (ICA) was run. Stimulus-synchronized epochs were extracted from 200 ms pre-stimulus onset (self-face) to 800 ms post-stimulus onset. For baseline correction, the recordings from −200 ms to stimulus onset (0 ms) were used. ICA component features that showed horizontal or vertical eye movement noise and electromyogram (EMG) features without neural activity were manually rejected to remove artifacts [108, 109]. Contamination by blinks or other artifacts (exceeding ±100 μv) were rejected automatically using the moving window peak-to-peak function [no odor condition: 2014 epochs accepted (93.7%), 135 epochs rejected (6.3%); lavender condition: 2007 epochs accepted (94.7%), 112 epochs rejected (5.3%); isovaleric acid condition: 1874 epochs accepted (93%), 141 epochs rejected (7%)]. Afterward, the epochs of a single subject were averaged for each experimental condition (air, lavender, isovaleric acid). Then, all participants' ERPs were grand averaged (Figure 2.8).

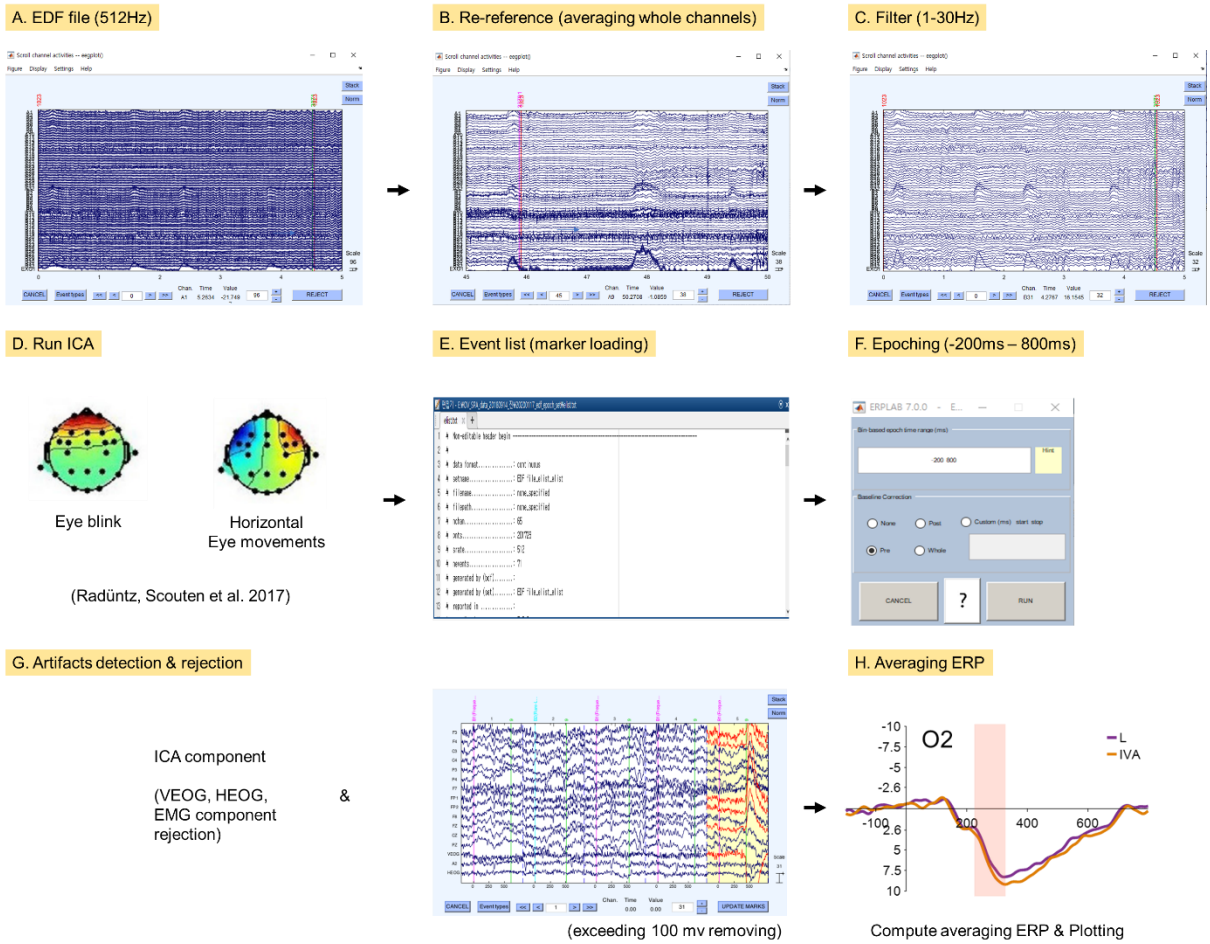

Figure 2.7 Data reduction using ERPLAB

(A) Loading the EDF file. (B) Averaging all 64 channels for re-reference. (C) Filtering (1–30 Hz). (D) Running ICA. (E) Event marker loading for epoching. (F) Epoching from 200 ms before stimulus (to 800 ms after stimulus. (G) Artifact detection and rejection from ICA components; rejecting eye blinks, horizontal eye movements, and EMG components (if the latter did not contain any ERP feature). (H) Obtaining ERP of each participant by averaging epochs, then obtaining grand average ERP by averaging participant's ERPs. L: lavender, IVA: isovaleric acid, O2: electrode name, VEOG: vertical electrooculography, HEOG: horizontal electrooculography.

Mean ERP amplitude was used to assess neural activity when looking at the self-face after odor presentation. The mean ERP amplitudes were measured during four selected time windows (Figure 2.8). These time ranges have been used in previous face processing research. The [a] 80–120 ms time window, or P1, has been suggested to be an index of fast cortical pathways [110] and is involved in emotional enhancement of visual processing [111-114]. The [b] 150–180 ms time window, or N170 or N1, is involved in the structural encoding of facial information [115-117]. Both [a] and [b] have been used to assess the early attentional processes of face processing [118]. The [c] 220–330 ms time window, also called P200, EPN (early posterior negativity), and N2 or N250, shows enhanced negativity during affective information processing [16, 119]. EPN has been interpreted as the first integration of specific emotional meaning in visual processing [120]. The [d] 400–600 ms time window, or LPP (late positive potential), is reported to modulation effects by pleasant and unpleasant stimuli [10, 121]. Both [c] and [d] were used because they represent later stages of electro-cortical affective stimulus processing [118].

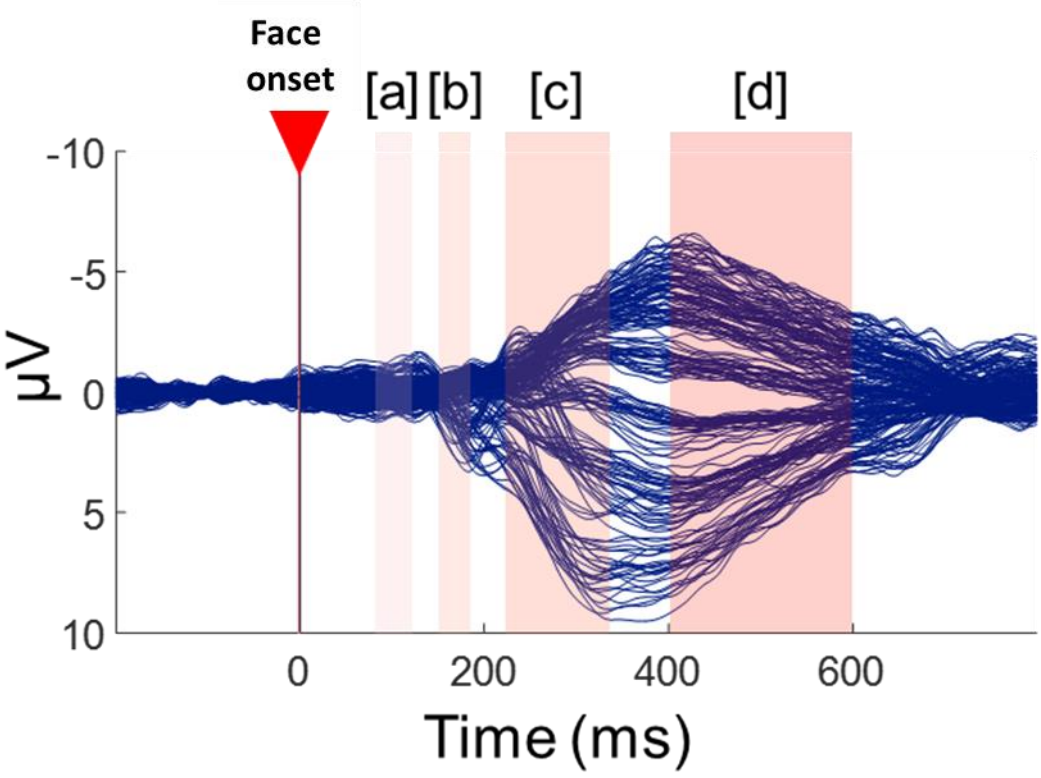

Figure 2.8 ERP analysis time windows.

Grand average ERPs from 64 electrodes. ERPs of the 30 participants from no odor conditions are presented. Self-face visual stimulus onset was set to 0 ms. [a] 80–120 ms (p1), [b] 150–180 ms (N170 or N1), [c] 220–330 ms (EPN, N2, N250, or P200), [d] 400–600 ms (LPP).

2.5.4 CSD analysis

To specify the source of neural activity, I also confirmed the CSD [122]. In previous studies, the CSD maps have been effectively used to explain differences in topographic neural activation patterns [123, 124]. These maps represent the magnitude of the transcranial current flow, which shows the source from the brain to the scalp and sink from the scalp to the brain [122, 123]. CSD was calculated using the ERPLAB toolbox in EEGLAB with averaged ERPs.

2.6 Statistical analysis

For statistical analysis, I used GraphPad Prism 5 software (GraphPad Software, Inc., La Jolla, CA, USA) and Matlab R2015a and R2020a were used for statistical analysis. Two-way repeated-measures ANOVA containing within-subject factors and Bonferroni post-tests were used for the analysis of odor characteristic ratings and self-face evaluation ratings (Chapter 4; n = 30). For comparison between groups (Chapters 3 and 5; sex, BMI, self-esteem group), I first checked Gaussian distribution by conducting the following normality tests: Kolmogorov–Smirnov test, D'Agostino and Pearson omnibus test, and Shapiro–Wilk test. Then, I chose the parametric or non-parametric statistics. For the parametric statistics, I used two-way ANOVA or two-way repeated-measures ANOVA and conducted the Bonferroni post-test. For the non-parametric statistics, I used the Kruskal–Wallis test and conducted Dunn's multiple comparison test to check the difference in rank-sum.

Ⅲ. Characterization of self-face perception and evaluation depending on sex, BMI, and self-esteem

3.1. Significance & Hypothesis

In this study, self-face processing was characterized using the mean amplitudes of four ERP components and six self-face evaluation items. Also, the potential influence of individual features sex, BMI, and self-esteem on self-face processing was considered. I hypothesized that 1) Males might evaluate their self-face more positively than females; 2) Participants with lower BMI might evaluate their self-face more positively than participants with higher BMI; 3) Participants with higher self-esteem might evaluate their self-face more positively than participants with lower self-esteem. I analyzed 30 participants and split them into groups for further analysis according to sex (males (n=17) vs. females (n=13)), BMI (low BMI (n=18) vs. high BMI (n=12)), and self-esteem (low RSES (n=17) vs. high RSES (n=13)). This study will help us understand how individual differences modify the neural processing and evaluation of the self.

3.2 Results

3.2.1 Self-face evaluation ratings

From a behavioral point of view, I checked how participants perceived their self-face by using 9-point scale ratings of six face evaluation items. On average, the participants rated self-face above the median score of 5 except for dominance and masculinity **(Fig 3.1)**. Self-face evaluation ratings of all participants showed that dominance was significantly lower than self-face preference, attractiveness, trustworthiness, and maturity. The average score of masculinity was close to 5.

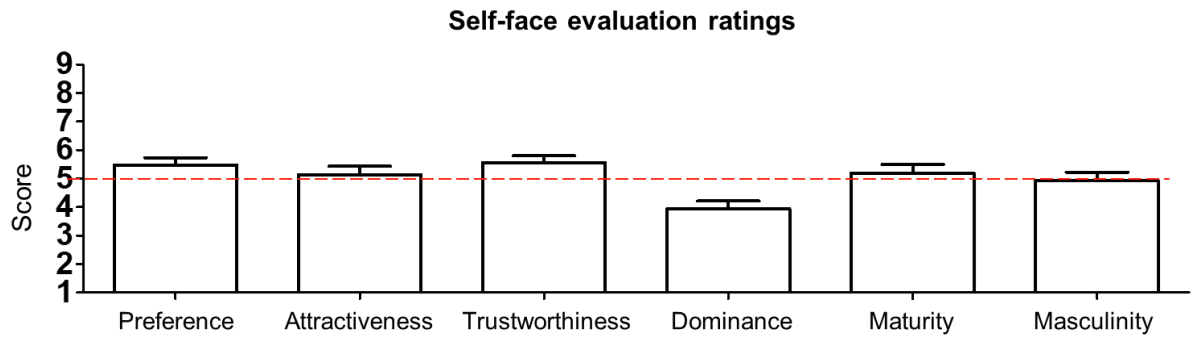

Figure 3.1 Self-face evaluation ratings of all participants in the no-odor condition

Participants (n=30) rated six face evaluation items on a scale from 1 to 9 when viewing their own faces. One-way ANOVA, *P*-value: 0.0006; Bonferroni multiple comparison test, **P*<0.05, ***P*<0.01, ****P*<0.001. Preference vs. dominance **, attractiveness vs. dominance *, trustworthiness vs. dominance ***, dominance vs. maturity *.

3.2.2 Neural processing of self-face

From a neurophysiological point of view, I examined how participants perceived their self-face by checking the mean ERP amplitude in four-time windows immediately after the participants saw their self-face (**Fig 2.8** and [a]–[d] in **Fig 3.2)**. Each time window is reported in previous studies: [a] P1, 80–120 ms [110-114]; [b] N170, 150–180 ms [115-117]; [c] EPN or N2, 220–330 ms [16, 119, 120]; [d] LPP, 400–600 ms [10, 121]. In this study, to observe not only the specific brain area corresponding to the ERP peak but also the entire brain area, I analyzed the mean ERP amplitude of the windows [a] – [d] **(Fig 3.2 A).**

The patterns of neural processing of self-face differed among the time windows; however, no hemispheric difference was observed **(Fig 3.2 B, C).** Overall, early time windows after self-face onset showed a smaller ERP range than late time windows. Window [a] showed positive mean ERP amplitude in the frontal region and negative in the posterior region. Window [b] showed broad negativity except in the left and right posterior regions. Windows [c] and [d] showed strong positivity in the LP and RP regions. Each time window showed significant differences among ROI; however, left and right hemispheres showed no significant difference under the no-odor condition.

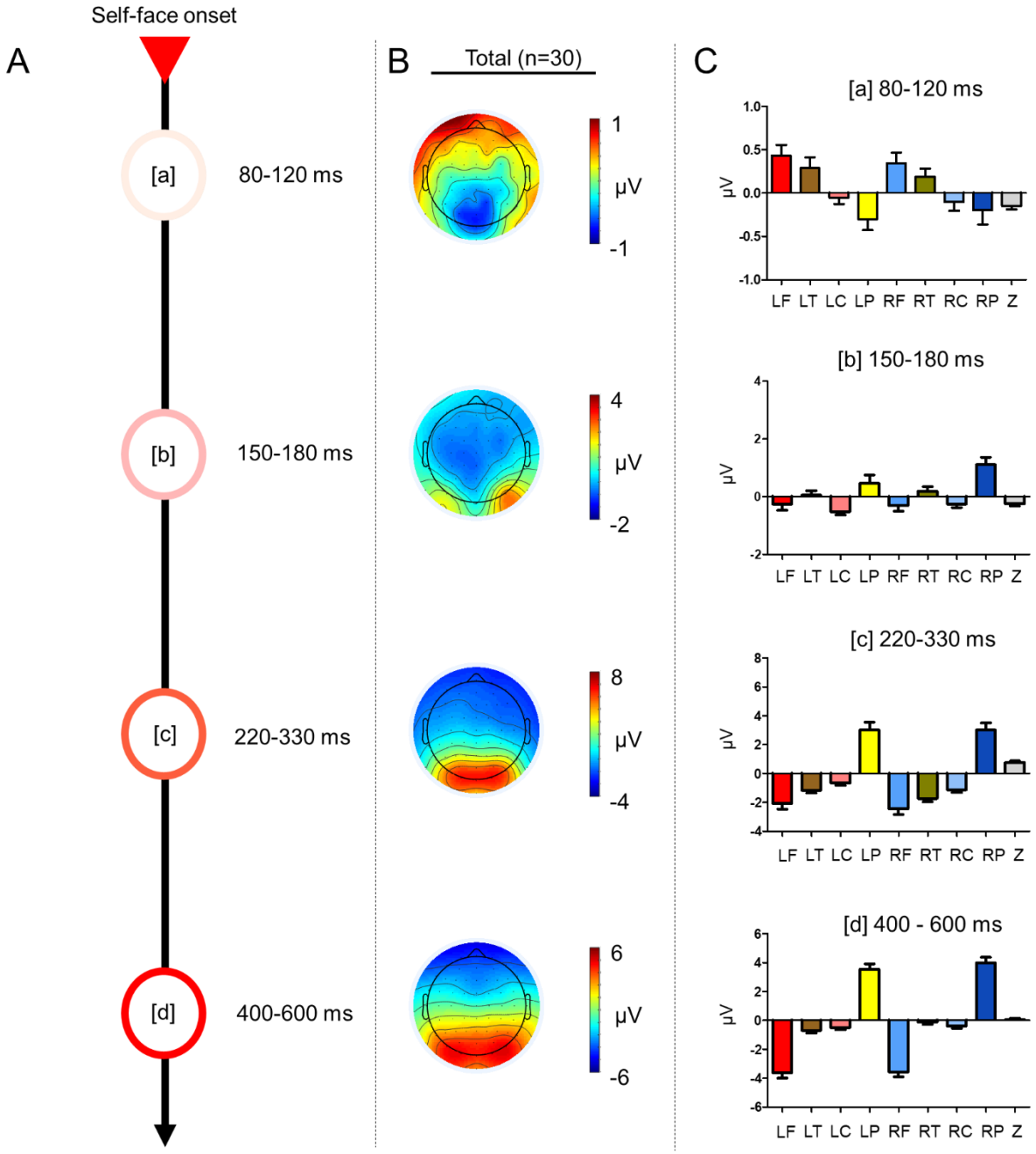

Figure 3.2 Self-face neural processing of all participants.

(A) Analyzed ERP time windows after self-face onset (B) Topographies of self-face neural processing. Average values of ERP mean amplitude per channel are shown (total number of participants: n=30). (C) Average ERP mean amplitude of ROIs. One-way ANOVA, [a] 80–120 ms: $P < 0.0001$, [b] 150–180 ms: $P < 0.001$, [c] 220–330 ms: $P < 0.0001$, [d] 400–600 ms: $P < 0.0001$.

3.2.3 Effects of sex, BMI, and self-esteem on self-face processing

To check whether self-face processing depends on the individual characteristics (sex, BMI, and self-esteem) I checked behavior ratings and neural processing of each group. All participants were divided into groups according to the following criteria. (1) sex: males (n=17), females (n=13); (2) BMI: low (BMI<23, n=18), high (BMI≥ 23, n=12), 23 is the criteria for overweight, (3) self-esteem: low (RSES ≤ 25, n=17), high (RSES > 25, n=13), 25 is median score of RSES.

To test the hypothesis that males may perceive self-face more positively than females, I compared self-face evaluation ratings and neural processing after self-face visual stimuli between male and female participants **(Fig 3.3).** In survey ratings, masculinity was significantly higher in males than in females (two-way ANOVA, row factor *P*-value: 0.0005; Bonferroni post-test: masculinity t=2.753, P <0.05) **(Fig 3.3 A)**, confirming that self-face evaluation survey results were well reflected the characteristics of the participants. Females showed slightly higher scores on preference, attractiveness, trustworthiness, and dominance than males, but the differences were not statistically significant. In ERP results, no significant differences were observed **(Fig 3.3 B,C).** However, in comparison with topography in males, females showed higher positivity in the posterior region and higher negativity in the frontal region at [b] 150–180 ms.

To test the hypothesis that a low-BMI person may perceive self-face more positively than a high-BMI person, I compared self-face evaluation ratings and neural processing after self-face visual stimuli between the low-BMI and high-BMI groups **(Fig 3.4)**. In survey ratings, the comparison showed no significant differences in post-test results, however, the ratings of preference, attractiveness, trustworthiness, and dominance for self-face were slightly higher in the low-BMI group than in the high-BMI group, whereas maturity and masculinity showed lower ratings **(Fig 3.4 A).** Interestingly, in ERP results, [c] 220–330 ms showed a significant difference between low BMI and high BMI in the left frontal (LF) and right frontal (RF) parts (Kruskal–Wallis test, Dunn's multiple comparison test (low BMI vs. high BMI, 9 conditions), P < 0.05) **(Fig 3.4 B, C).** This result showed that the low-BMI group had significantly larger negativity in the channels in the frontal region than high BMI group.

To test the hypothesis that a high self-esteem person may perceive self-face more positively than a low self-esteem person, I compared self-face evaluation ratings and neural processing after self-

face visual stimuli between the low-RSES and high-RSES groups **(Fig 3.5)**. In survey ratings, the comparison showed no significant differences in post-test results; however, the high-RSES group showed higher average ratings of maturity than the low-RSES group **(Fig 3.5 A)**. In ERP results, the topography showed asymmetric patterns in the posterior part at [a] 80–120 ms and [b] 150–180 ms, although no significant differences were observed **(Fig 3.5 B, C).**

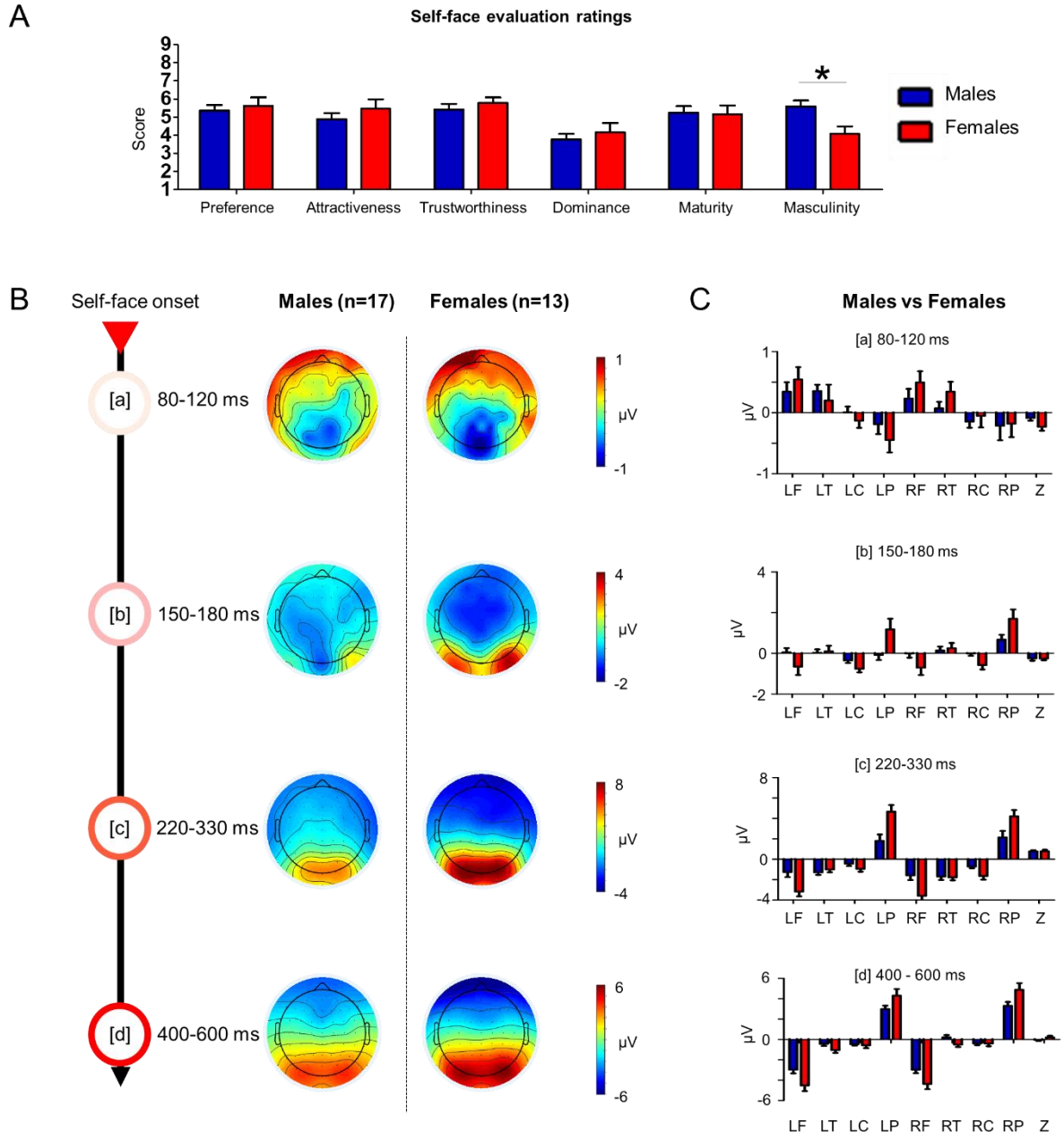

Figure 3.3 Self-face processing (sex).

(A) Self-face evaluation. Two-way ANOVA, row factor *P*-value: 0.0005, Bonferroni post-test: masculinity *t*=2.753, **P* <0.05. (B) Topographies of self-face neural processing. Average values of ERP mean amplitude per channel are shown. (C) Average ERP mean amplitude of ROI. Kruskal–Wallis test, Dunn's multiple comparison test (males vs. females, 9 conditions): ns.

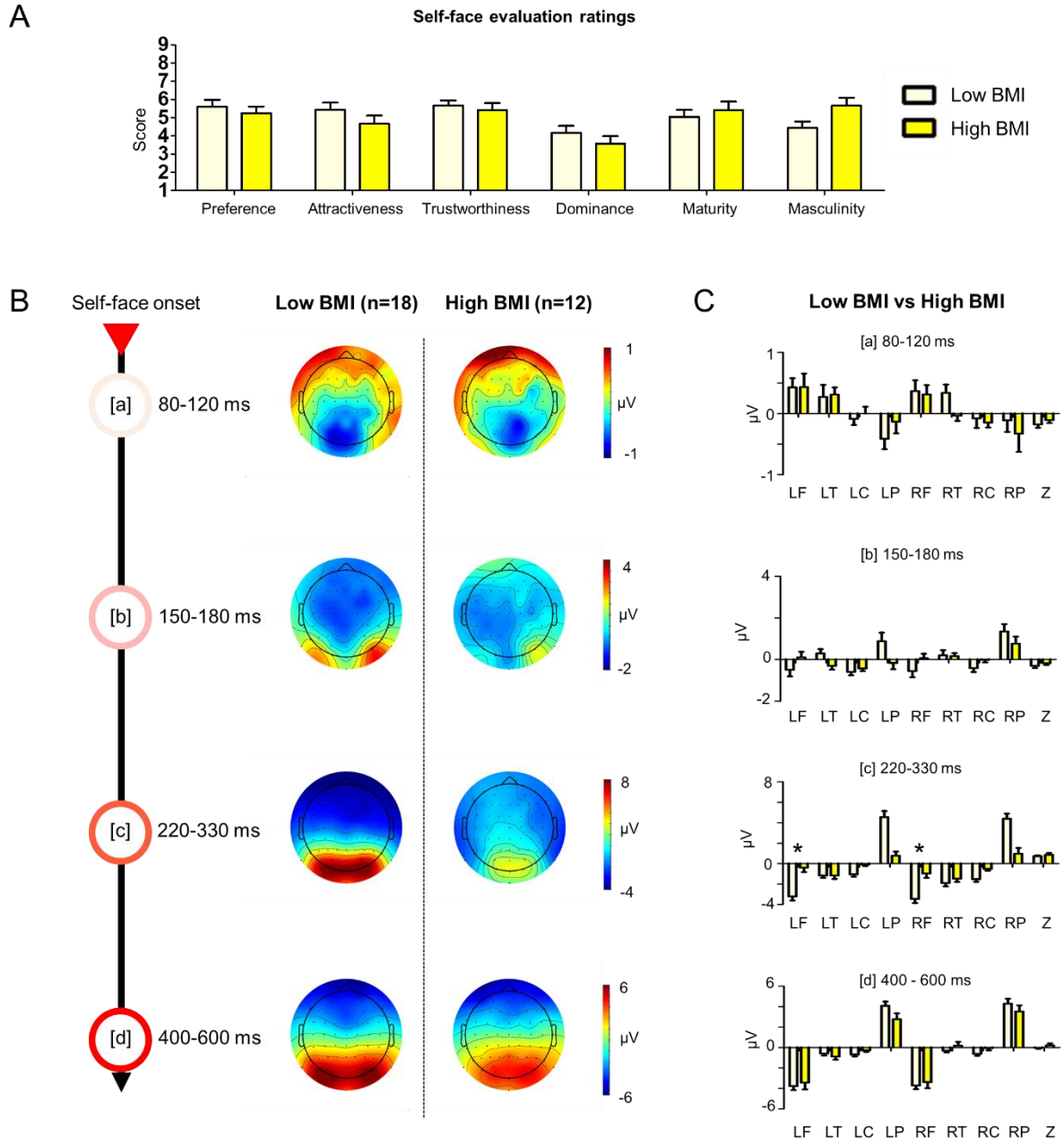

Figure 3.4 Self-face processing (BMI).

(A) Self-face evaluation. Two-way ANOVA, row factor *P*-value: 0.0005, Bonferroni post-test: ns. (B) Topographies of self-face neural processing. Average values of ERP mean amplitude per channel are shown. (C) Average ERP mean amplitude of ROI. Kruskal–Wallis test, Dunn's multiple comparison test (low BMI vs. high BMI, 9 conditions), *$P < 0.05$. [b] 150–180 ms, Two-way ANOVA, interaction *P*-value: 0.0165, row factor *P*-value < 0.0001, Bonferroni post-test: ns.

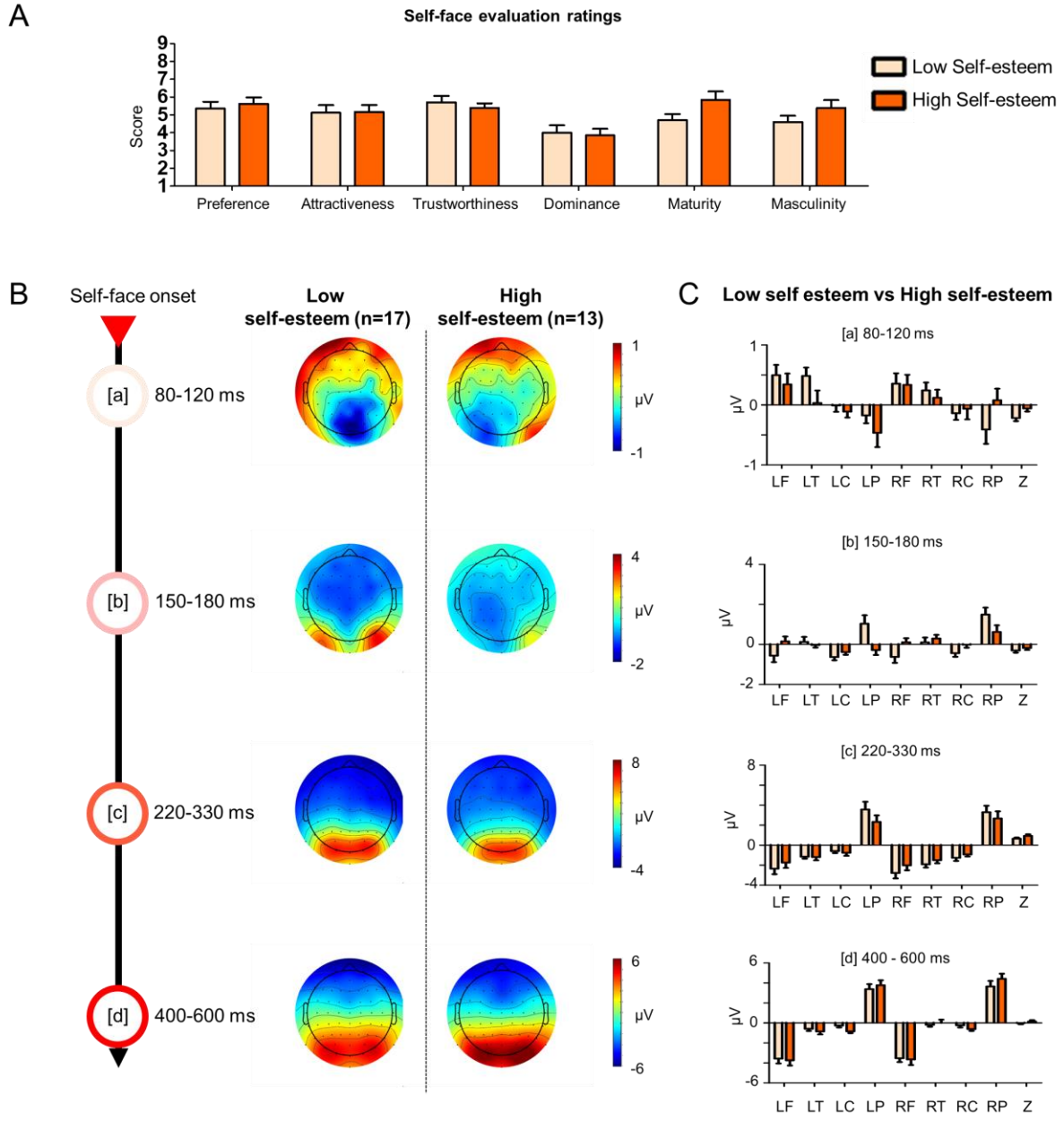

Figure 3.5 Self-face processing (self-esteem).

(A) Self-face evaluation. Kruskal–Wallis test, Dunn's multiple comparison test (low self-esteem vs. high self-esteem, 6 conditions), ns. (B) Topographies of self-face neural processing. Average value of ERP mean amplitude per channel are shown. (C) Average ERP mean amplitude of ROI. Kruskal–Wallis test, Dunn's multiple comparison test (low self-esteem vs. high self-esteem, 9 conditions), ns.

3.3. Discussion

In this chapter, I examined self-face perception processing differences according to three factors—sex, BMI, and self-esteem—in the no-odor condition.

During self-face processing, males' and females' topography showed significant differences within 150–180 ms, which is known as the face coding time window [115-117]. Previous studies revealed that the fusiform gyrus (FG) is activated differently in males and females [89]. The amplitude of the occipito/temporal N170 component of ERPs shows a more marked lateralization in males than in females. A standardized weighted low-resolution brain electromagnetic tomography (sLORETA) reconstruction revealed significant asymmetry patterns in BA 19, where the fusiform gyrus is located [90]. In addition, males show a right-lateralized M170 component, whereas females show a bilateral response to face stimuli as revealed using whole-head magnetoencephalography. In this study, I examined the sex differences during self-face perception processing.

During 220–330 ms, the high-BMI group showed significant differences from the low-BMI group in both LF and RF. The high-BMI group showed significantly less negativity in LF and RF than the low-BMI group. This is the first report to reveal an association between BMI and self-face perception using neuroimaging. This result is impressive because numerous neuroimaging studies have reported a PFC abnormality in obese or high-BMI participants [25, 26]. Even though only overweight participants, not obese patients, attended this study, the high-BMI group showed statistically significant differences in the frontal-region electrodes.

According to self-esteem, I observed asymmetric patterns in the posterior part in early windows of self-face perception processing. The high-RSES group showed a slightly higher maturity score than the low-RSES group. However, there were no statistically significant differences. An fMRI study [27] reported that self-esteem affects self-face evaluation in young females. Activation in the posterior cingulate cortex (PCC) and ventral tegmental area (VTA) regions positively correlate with RSES score during positive self-face evaluation, indicating that the PCC might affect positive self-face processing by retrieving participants' positive self-image from positive autobiographical memories, whereas the VTA might process the self-face as a social reward because VTA is the main region of the reward system. However, in this study, no significant differences between the RSES groups were

observed, probably because the experimental scheme in the previous study [14] used social comparison visual stimuli in young females only whereas I studied in both males and females and different experimental scheme. For further study, non-self-face visual stimuli are needed for social comparison experimental conditions to clarify the differences in self-face perception depending on self-esteem in the no-odor condition.

To sum up, I examined different mean ERP amplitude characteristics in the no-odor condition and checked self-face evaluation ratings. I will use the neural patterns established in chapter III as the baseline for further analysis in chapters IV and V.

IV. Effects of odor stimuli on self-face perception and evaluation

4.1 Significance & Hypothesis

This study aimed to reveal how odor changes our perception and evaluation of the self. I hypothesized that different hedonic evaluation of odors would differentially alter self-face perception and evaluation. Therefore, I tested whether and how olfactory conditioning affects self-face evaluation and its neural processing in the brain by using surveys and event-related potentials (ERP) in 30 participants (17 males, 13 females, 20.5 ± 1.042 years). They saw their self-face after inhalation of lavender (L) or isovaleric acid (IVA), which they recognized as a pleasant or an unpleasant odor. Then, I examined the timing of neural responses in the brain regions that are affected by odor conditions during self-face processing. This study will be helpful in understanding how odor priming modulates the cognitive and behavioral processes of the self in the social world.

4.2 Results

4.2.1 Odor characteristic ratings

To understand how participants perceived the presented odors, I conducted a post-test survey of odor characteristics and odor descriptions. The odor descriptions presented by the participants were visualized using the word cloud method **(Fig 4.1)**. Representative descriptions of L were perfume, herb, and fabric conditioner, whereas those of IVA were rotten, toilet, and ammonia.

Odor characteristic ratings showed that the presented odors (L and IVA) were perceived differently **(Fig 4.2)** in terms of preference, relaxation, familiarity, positive mood change, and attractiveness (repeated-measures two-way ANOVA with Bonferroni post-tests: preference, $t = 6.02$, $P < 0.001$; relaxation, $t = 5.19$, $P < 0.001$; familiarity, $t = 3.33$, $P < 0.01$; positive mood, $t = 5.12$, $P < 0.001$, attractiveness, $t = 5.57$, $P < 0.001$). On the other hand, odor intensity, pungency, and mood change were perceived similarly (odor intensity, $t = 1.35$, $P > 0.05$; pungency, $t = 1.09$, $P > 0.05$; mood change, $t = 0.58$, $P > 0.05$). Additionally, I confirmed that the odors were perceived more strongly, were more pungent, and brought about a greater mood change than did air **(Table 3)**. Overall, IVA was perceived as less pleasant than L and also scored lower on relaxation, familiarity, positive mood change, and attractiveness than L.

The odors also changed affective ratings after the experiment **(Fig 4.3)**. L increased and IVA decreased relaxation and mood in comparison with the air condition. Relaxation and mood ratings were significantly different according to presented odors (repeated-measures two-way ANOVA with Bonferroni post-tests).

Figure 4.1 Word clouding of presented odor description.

Odor descriptions by all participants (n=30) after the experiment. L, lavender. IVA, isovaleric acid.

Table 3 Difference of odor characteristics in three odor conditions

The table shows odor characteristics ratings in the three odor conditions. Participants (n=30) rated eight odor characteristics on a scale from 1 to 9 after each experimental set. One-way ANOVA, Bonferroni multiple comparison test, * $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$.

Odor characteristics	F	P	Odor condition		Difference	S.D	Significance	P
Intensity	34.343	0.000	Air	L	-2.13	0.36	***	0.00
			Air	IVA	-2.83	0.36	***	0.00
			L	**IVA**	**-0.70**	**0.36**	**ns**	**0.16**
Pleasantness	39.829	0.000	Air	L	-0.67	0.37	ns	0.22
			Air	IVA	2.47	0.37	***	0.00
			L	**IVA**	**3.13**	**0.37**	***	**0.00**
Relaxation	22.599	0.000	Air	L	-0.50	0.43	ns	0.74
			Air	IVA	2.20	0.43	***	0.00
			L	**IVA**	**2.70**	**0.43**	***	**0.00**
Familiarity	11.886	0.000	Air	L	-0.87	0.36	*	0.05
			Air	IVA	0.87	0.36	*	0.05
			L	**IVA**	**1.73**	**0.36**	***	**0.00**
Pungency level	7.580	0.001	Air	L	-1.23	0.47	*	0.03
			Air	IVA	-1.80	0.47	**	0.00
			L	**IVA**	**-0.57**	**0.47**	**ns**	**0.70**
Mood change	4.809	0.010	Air	L	-0.80	0.37	ns	0.10
			Air	IVA	-1.10	0.37	*	0.01
			L	**IVA**	**-0.30**	**0.37**	**ns**	**1.00**
Positively mood change	24.609	0.000	Air	L	-0.50	0.40	ns	0.66
			Air	IVA	2.17	0.40	***	0.00
			L	**IVA**	**2.67**	**0.40**	***	**0.00**
Attractiveness	26.530	0.000	Air	L	-0.43	0.43	ns	0.95
			Air	IVA	2.47	0.43	***	0.00
			L	**IVA**	**2.90**	**0.43**	***	**0.00**

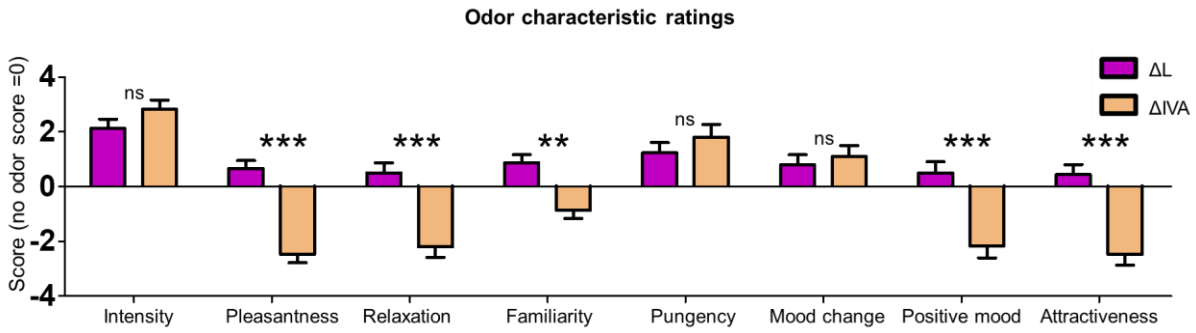

Figure 4.2 Characteristics of the presented odors.

Odor characteristic ratings. Participants (n = 30) rated eight odor characteristics after the experimental set. The *y*-axis score displays subtraction of the no-odor condition (air) from the odor condition (L or IVA). Repeated-measures two-way ANOVA with Bonferroni post-tests; ns: not significant, ** $P < 0.01$, *** $P < 0.001$).

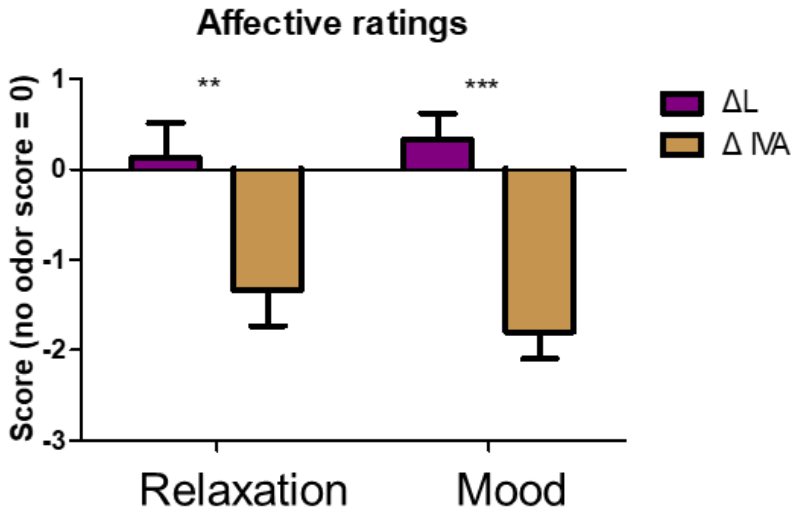

Figure 4.3 Affective ratings after odor priming experimental set compared to air condition.

Affective ratings depending on odor primes. (L: lavender, I: isovaleric acid). Repeated-measures two-way ANOVA with Bonferroni post-tests; ** $P < 0.01$, *** $P < 0.001$.

4.2.2 Self-face evaluation ratings after odor priming

Even though the participants saw the same self-face visual stimuli, surprisingly, they evaluated their own faces differently depending on the odor primes **(Fig 4.4)**. I presented different odor conditions for each set in a random order, and the participants answered the questions after trials in each set. I calculated changes in self-face evaluation rating scores for each participant by subtracting the scores in the no-odor condition from the scores in the odor condition.

In the no-odor condition, participants gave scores of about five, on average, except for dominance (mean ratings: preference = 5.47; attractiveness = 5.13; trustworthiness = 5.57; dominance = 3.93; maturity = 5.2; masculinity = 4.93). In the odor condition, three of the six items showed significant differences between odor primes. Self-face attractiveness showed a highly significant main effect between L and IVA (repeated-measures two-way ANOVA with Bonferroni post-tests: $t = 3.92$, $P < 0.001$). After smelling L, participants rated their faces as slightly more attractive than in the no-odor condition; however, after smelling IVA, they evaluated their faces as unattractive compared to the L or no-odor conditions. Preference and trustworthiness of their own faces were also significantly affected by the odor primes (preference, $t = 3.03$, $P < 0.05$; trustworthiness, $t = 3.47$, $P < 0.01$). Dominance, maturity, and masculinity ranked higher in both odor conditions than in the no-odor condition. However, the scores for those factors were similar between the two odor primes (dominance, $t = 0.22$, $P > 0.05$; maturity, $t = 1.23$, $P > 0.05$; masculinity, $t = 1.57$, $P > 0.05$).

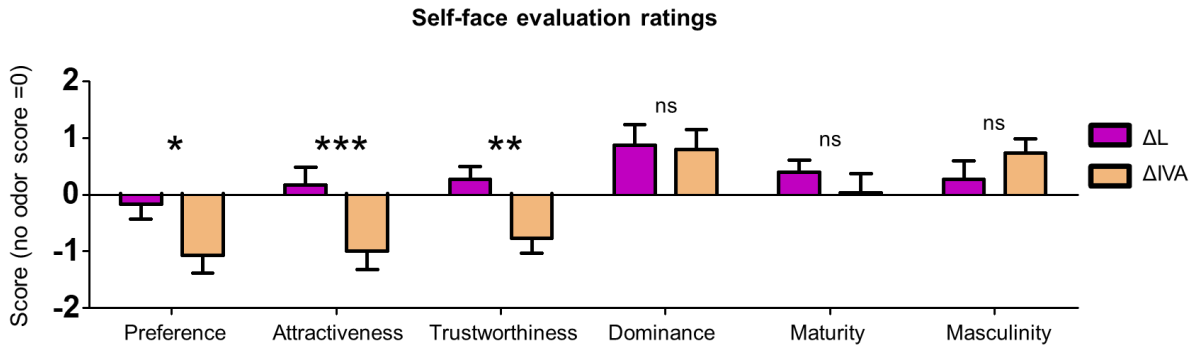

Figure 4.4 Self-face evaluation ratings with odor primes.

Participants (n = 30) rated their faces using six characteristics, ranging from 1 to 9 for each characteristic. The *y*-axis shows the subtraction of the no-odor condition (air) score from the odor condition (L or IVA) score. Repeated-measures two-way ANOVA with Bonferroni post-tests; ns: not significant, * $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$.

4.2.3 Neural processing of self-face after odor priming

To reveal how odor primes affected self-face evaluation ratings, I analyzed neural activity while participants viewed their own faces **(Fig 4.5)**. I recorded the self-face processing brain signals after each odor prime and subtracted the brain signals under the no-odor condition. Topographies after self-face onset represented changes in mean ERP amplitudes by L or IVA **(Fig 4.5 A).** Interestingly, compared to the no-odor condition, the odors modulated the mean ERP amplitude from each channel. L upregulated ERP positivity in the channel of the frontal region and enhanced ERP negative patterns in the channel of the posterior regions from the [a]–[c] time windows. On the other hand, IVA upregulated positivity patterns in the channel of the posterior region. A significant difference was observed between odors in the LF region at [c] 220–330 ms (repeated-measures two-way ANOVA, Bonferroni post-test: L vs. IVA $t = 2.889$, $P < 0.05$) **(Fig 4.5 B).**

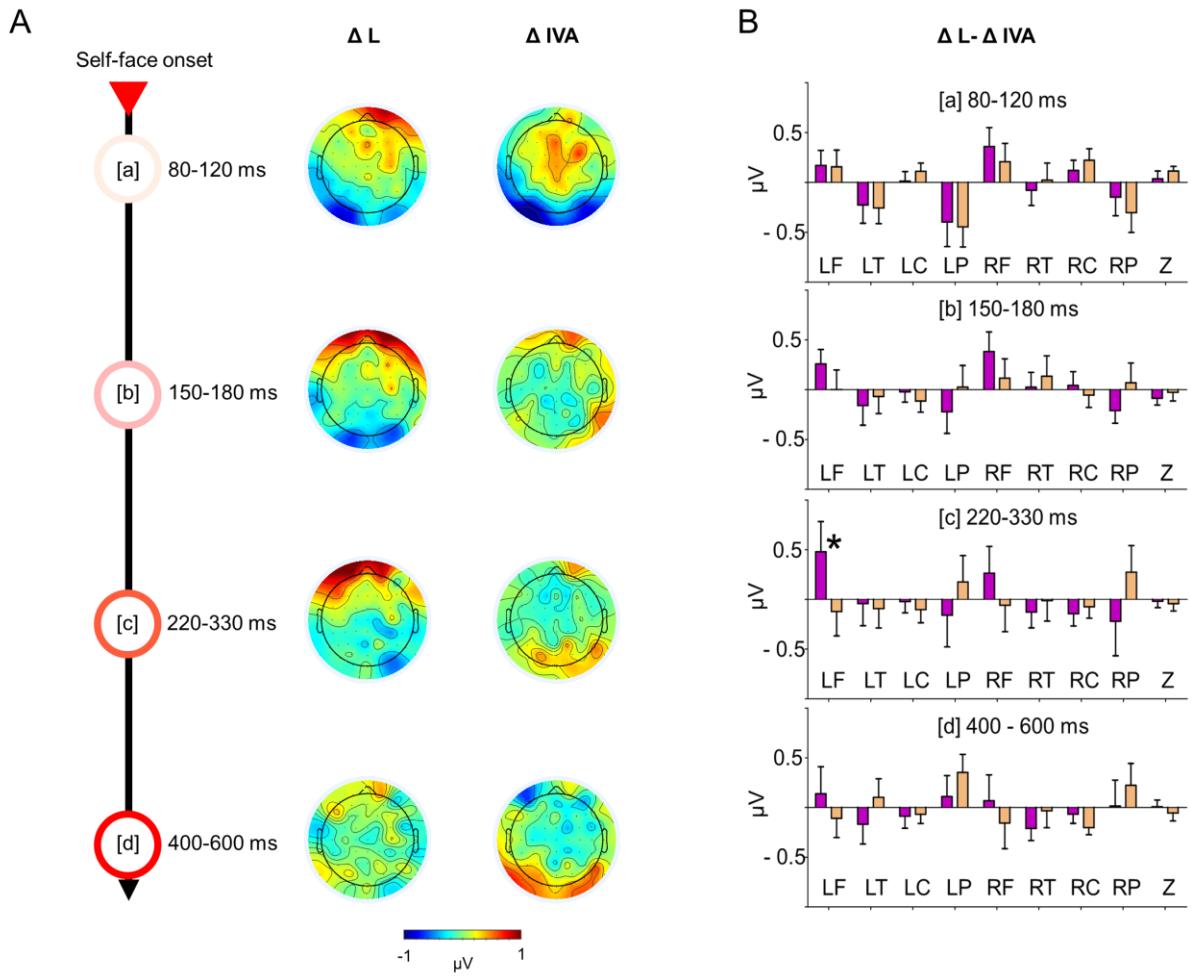

Figure 4.5 Neural processing of self-face with odor primes.

(A) Mean ERP amplitude topographies at each time window with odor primes. The ΔL column represents mean ERP amplitude changes from the no-odor condition to the lavender odor prime. The ΔI column represents mean ERP amplitude changes from the no-odor condition to the isovaleric acid odor prime. (B) Average mean ERP amplitude of ROI. Repeated-measures two-way ANOVA, Bonferroni post-test, [c] 220–330 ms LF: L vs. IVA $t = 2.889$, * $P < 0.05$.

Self-face processing with odor primes showed noticeable differences in the frontal lobe region compared to the no-odor condition **(Fig 4.6)**. In the case of L, the FP1 and AF7 channels showed strong positivity in the left frontal region, whereas IVA showed negativity **(Fig 4.6 A)**. To verify the source of neural activity, I additionally analyzed CSD. CSD showed hemispheric asymmetry between L and IVA in the frontal region **(Fig 4.6 B)**, with the patterns opposite between the two odors. CSD also showed positivity in the left FP1 and AF7, but negativity in the right FP2 and AF8 channels after presenting L. When IVA was presented, CSD showed negativity in the FP1 and AF7 channels and positivity in the FP2 channel. The mid-line channel Fz showed similar CSD patterns between L and IVA.

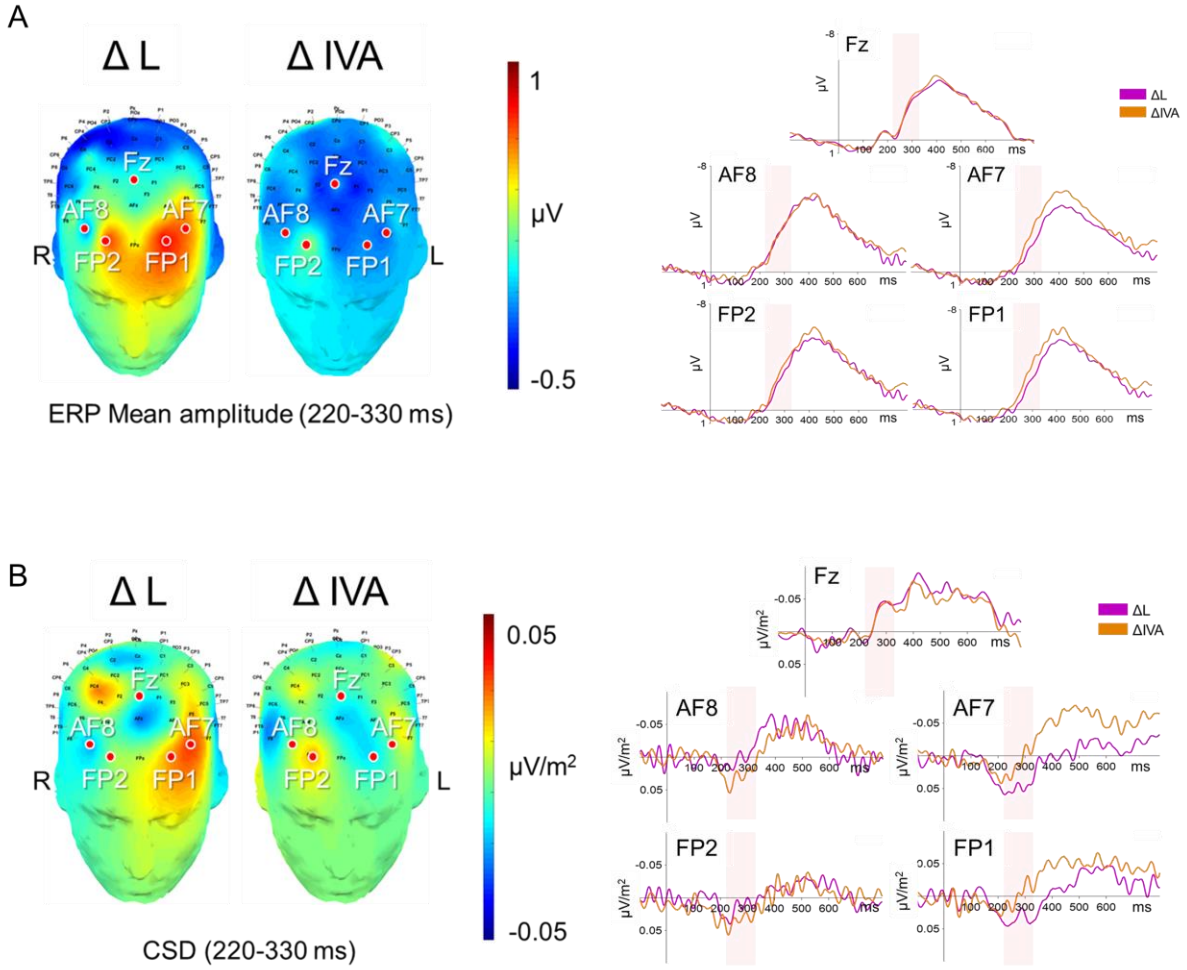

Figure 4.6 ERP and CSD with odor primes.

(A) Mean ERP amplitude over the frontal region. (B) CSD topography and plots over the frontal region. Each red dot represents an electrode.

4.2.4 Correlation between odor perception and self-face evaluation

To confirm which odor characteristics affect self-face processing, I analyzed the correlation between odor characteristics perception ratings and self-face evaluation after odor primes **(Tables 4 and 5).** Overall, the ratings of self-face preference and attractiveness were greatly influenced by how the presented odors were perceived. L showed a more significant correlation than IVA.

Table 4 Correlation between lavender odor ratings and self-face evaluation ratings.

Pearson's correlation (* $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$).

ΔL		Self-face evaluation					
		Preference	Attractiveness	Trustworthy	Dominance	Maturity	Masculinity
Odor characteristics	Intensity	0.50**	0.41*	0.31	-0.052	0.1	-0.35
	Preference	0.62***	0.48**	0.37*	-0.14	-0.019	-0.33
	Relaxation	0.56**	0.43*	0.35	-0.14	0.18	-0.27
	Familiarity	0.33	0.41*	0.31	-0.087	0.36*	-0.3
	Pungent	0.013	0.25	0.34	0.058	-0.07	0.1
	Mood change	0.35	0.22	-0.032	-0.38*	-0.038	-0.14
	Positive mood	0.57***	0.33	0.19	-0.2	0.013	-0.40*
	Attractiveness	0.51**	0.40*	0.26	-0.2	0.041	-0.46*

Table 5 Correlation between isovaleric acid odor ratings and self-face evaluation ratings.

Pearson's correlation (* $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$).

ΔIVA		Self-face evaluation					
		Preference	Attractiveness	Trustworthy	Dominance	Maturity	Masculinity
Odor characteristics	Intensity	-0.12	-0.011	0.23	-0.15	-0.071	-0.12
	Preference	**0.56****	0.43*	0.33	-0.28	0.15	-0.43*
	Relaxation	0.46*	0.42*	0.35	-0.26	0.22	-0.45*
	Familiarity	0.19	0.074	-0.03	-0.13	0.21	0.0011
	Pungent	-0.034	0.015	0.12	-0.18	-0.19	-0.046
	Mood change	0.13	0.26	0.093	-0.1	-0.027	-0.28
	Positive mood	**0.49****	0.38*	0.33	-0.16	0.16	-0.41*
	Attractiveness	0.43*	0.42*	0.3	-0.18	0.2	-0.44*

4.3 Discussion

Could olfactory perception change our self-face perception and evaluation? Previous studies have reported the effects of odors on the modulation of face perception and evaluation of others' faces [10, 125]. In this study, I first investigated odor prime effects on neural processing of self-face evaluation. I revealed that the modulating effect of odor primes was more pronounced in females than in males. I presented three different odor conditions: air, lavender, and isovaleric acid. Then, I analyzed the perceived self-face evaluation ratings and ERPs. The results showed that the participants perceived their own faces differently according to odor primes, even though they were always presented with the same neutral image of their own face.

This study indicates that odor affects self-face perception and evaluation, as evidenced by the post-survey and matching brain signals. The presented odor primes changed participants' ratings of their own faces. My tests showed significant differences between L and IVA in perceived self-face attractiveness, trustworthiness, and preference ratings **(Fig 4.4).** These behavioral differences were reflected in the brain activity while self-face processing occurred **(Fig 4.5 and 4.6).** L and IVA odor primes differently modulated ERP at the time window [c] 220–330 ms after self-face onset (called EPN or N2); there were significant differences in the frontal region of the left hemisphere between L and IVA. In this time range, L showed more positivity in the left frontal region, and more negativity was observed in the right posterior region compared to IVA.

Interestingly, previous studies reported similar ERP patterns when people saw an attractive face rather than an unattractive face [126, 127]. From 230–280 ms, they also observed positivity in the frontal region and negativity in the posterior region while participants viewed 32 faces with neutral expressions, which were rated as extremely attractive [126]. This indicates that, somehow, L made the participants' neural activity similar to that seen when viewing attractive faces. This result may explain why participants gave higher scores for self-face attractiveness, trustworthiness, and preference to their own faces when given L and lower scores when presented with IVA. The brain may accept our own faces as being more attractive when we smell L and less attractive when we smell IVA, even though our faces remain the same.

This study also showed an asymmetric pattern of brain activation while seeing one's own face.

This suggests that pleasant or unpleasant odor stimuli may affect brain activation while seeing one's own face. Previous studies have reported that the right hemisphere activity mediates negative emotions, while the left hemisphere is related to positive emotions [128, 129]. During face processing, it is possible that emotional stimuli could modulate responses in visual cortices by feedback from the amygdala and the orbitofrontal cortex [120]. Thus, different neural patterns between L and IVA indicate that odors may activate emotion-related circuits during self-face perception processing. However, further studies are needed to reveal specific activation patterns in brain regions during self-face perception after exposure to odor stimuli.

The results of this study indicate that the perceived odor affects self-face perception processing. Different odor valence evokes different ERP patterns and self-face evaluation ratings. An fMRI study revealed that pleasant odors (amyl acetate, banana-like smell, menthone odor, peppermint-like smell) activate the left hemisphere more than the right hemisphere, including the anterior frontal and temporal cortex regions [130]. Conversely, unpleasant odors (pyridine, fish-like smell) activate the right hemisphere more than the left hemisphere. This study's CSD result at 220–330 ms showed positivity from the left frontal regions after exposure to a pleasant odor stimulus, but positivity from the right frontal regions after exposure to an unpleasant odor stimulus **(Fig 4.6 B).** Even though only two odors were used in this study, the results suggest that differently perceived odor valence considerably affects self-face perception processing. However, further research is needed to determine whether olfactory chemical's characteristics or emotions induced by an odor alter self-face perception and evaluation.

From another point of view, the odor stimuli could modulate self-face evaluation circuits. During positive self-face evaluation, activation of the ventral tegmental area has been reported [27]. This is the main region of the dopamine reward system-related brain regions, and it affects the nucleus accumbens and prefrontal cortex [27]. During negative self-face evaluation, the right middle inferior frontal gyrus (mIFG) activity was reported when participants felt embarrassed by the self-face because of a gap between self-images and ideal self-images [70]. According to the ***concept of the looking-glass self*** [131], part of how we see ourselves comes from our perception of how others see us. In the case of the effects of odor stimuli on self-face perception processing, odors seem to evoke memories of how we evaluated others with pleasant or unpleasant odors. Therefore, pleasant odors may shift our perception

towards a positive self-image; thus, participants show positive self-evaluation neural patterns. On the other hand, unpleasant odors could evoke negative memories, thus they could lead to negative self-face evaluations.

This study provides evidence that the self-face is perceived and evaluated differently depending on odor stimuli. The results may give a general idea of why we feel more attractive after spraying perfume. The fragrant smell of perfume could make us see our own faces in a more positive light within just 400 ms. My findings may also provide a clue to enhancing self-esteem, which refers to the positive feelings about ourselves, by a simple approach using odors.

V. Effects of odor stimuli on self-face perception and evaluation depending on sex, BMI, and self-esteem

5.1 Significance & Hypothesis

In chapter IV, I measured changes in self-face processing by odor priming. To verify the differences depending on sex, BMI, and self-esteem, I separated participants into groups and analyzed mean ERP amplitudes and survey ratings after odor priming. The groups were the same as in chapter III (sex: males (n=17) vs. females (n=13), BMI: low (n=18) vs. high (n=12), self-esteem: low RSES (n=17) vs. high RSES (n=13)). I checked the modulation effects of odors (L or IVA) relative to the baseline, depending on the personal features. I hypothesized that participants might differently respond to the self-face after presenting odor stimuli depending on sex, BMI, and self-esteem. To test this hypothesis, I first analyzed self-face evaluation ratings to determine the behavioral differences. Second, I observed the characteristics of mean ERP amplitudes in each selected time windows, from [a] to [d]. This study will help to understand why people differently respond to the same stimuli.

5.2 Results

5.2.1. Sex difference

I analyzed odor characteristic ratings to verify the sex difference in odor perception **(Fig 5.1)**. Interestingly, although most items showed similar patterns, females showed a more obvious difference between L and IVA in the odor-evoked positive mood and odor attractiveness ratings than males.

To check whether the effects of odor prime on self-face processing differ between sexes differences or not, I examined self-face evaluation ratings and neural processing separately in males and females **(Figs 5.2 and 5.3)**. Interestingly, males showed no significant differences in self-face evaluation ratings according to odor primes, whereas females showed significant changes in self-face preference and attractiveness upon presentation of L or IVA (repeated-measures two-way ANOVA with Bonferroni post-tests: females, preference, $t = 3.29$, $P < 0.01$; attractiveness, $t = 3.59$, $P < 0.01$).

This difference was also seen in the mean ERP amplitude, which measures brain signals when participants look at their faces **(Fig 5.3)**. In female topographies, self-face processing with L showed increased ERP patterns in the frontal region and decreased ERP patterns in the posterior region from early time windows ([a] and [b]). The difference between L and IVA showed significant changes at [a] 80–120 ms and [b] 150–180ms **(Fig 5.3 A)**. Compared to the no-odor condition, odor presentation did not resulted in significant changes in the [a] and [b] time ranges in males; however, females showed a large change when presented with L from the early stage ([a] and [b]) of face processing in the right hemisphere. IVA also produced noticeably different patterns at [b]. Females showed a statistically significant difference between L and I in the channels of the right central ROI at [a] and right posterior ROI at [b] **(Fig 5.3 B)**.

To verify the source of ERP difference at [b] 150–180 ms, CSD analysis was conducted **(Fig 5.3 C)**. Males showed negativity in the posterior region with the exception of the left posterior region, whereas in females' PO8 electrode, CSD showed strong negativity throughout the posterior region when presented with L, and strong positivity when presented with IVA.

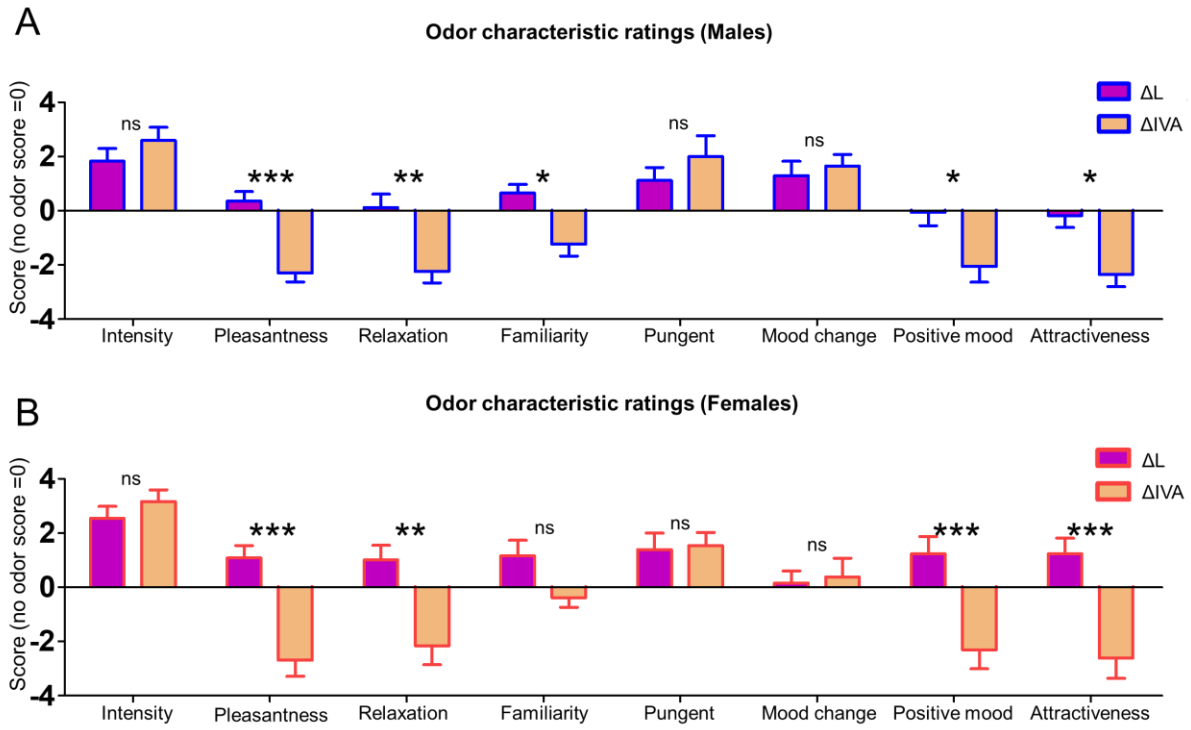

Figure 5.1 Characteristics of the presented odors in males and females.

Odor characteristic ratings depending on sex (L: lavender, I: isovaleric acid). Repeated-measures two-way ANOVA with Bonferroni post-tests; ns: not significant, * $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$.

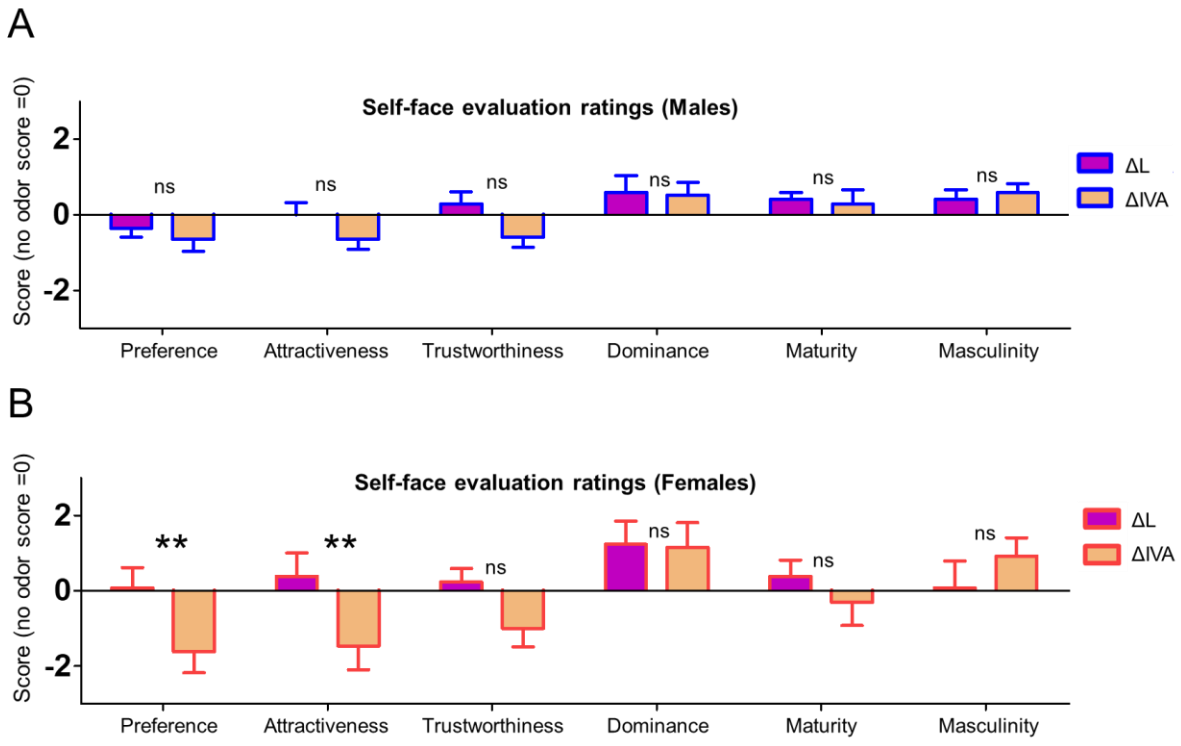

Figure 5.2 Self-face evaluation ratings with odor primes (males vs. females).

Participants rated six items regarding face evaluation, with scores ranging from 1 to 9, after inhaling either L or IVA. The *y*-axis score is a subtraction of the no-odor condition (air) score from the odor condition (L or IVA) score. Repeated-measures two-way ANOVA with Bonferroni post-tests; ns: not significant, ** $P < 0.01$. (A) Self-face evaluation ratings in male participants (n=17). (B) Self-face evaluation ratings in female participants (n=13).

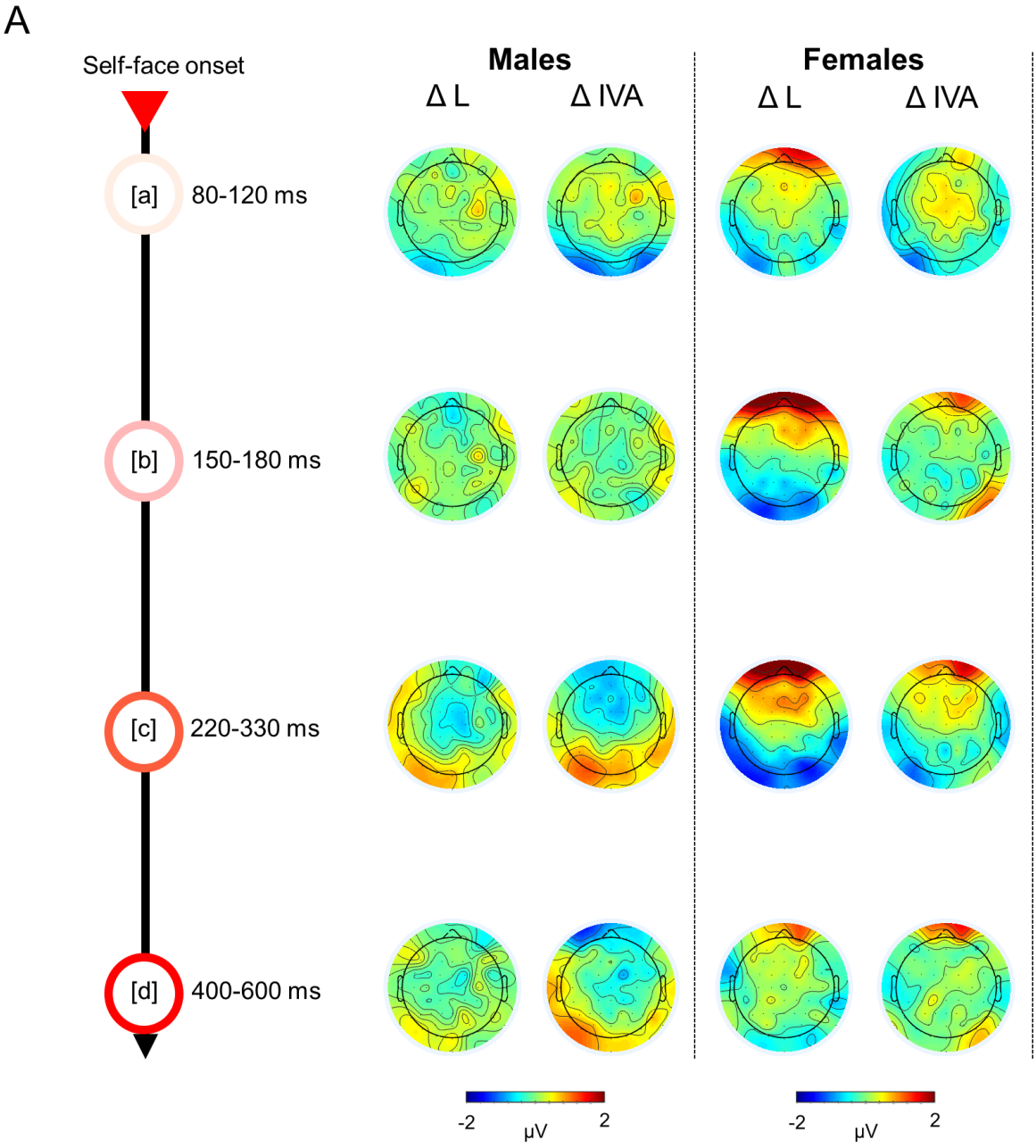
A
Self-face onset
Males
Females
Δ L
Δ IVA
Δ L
Δ IVA
[a]
80-120 ms
[b]
150-180 ms
[c]
220-330 ms
[d]
400-600 ms
-2
μV
2
-2
μV
2

Fig 5.3

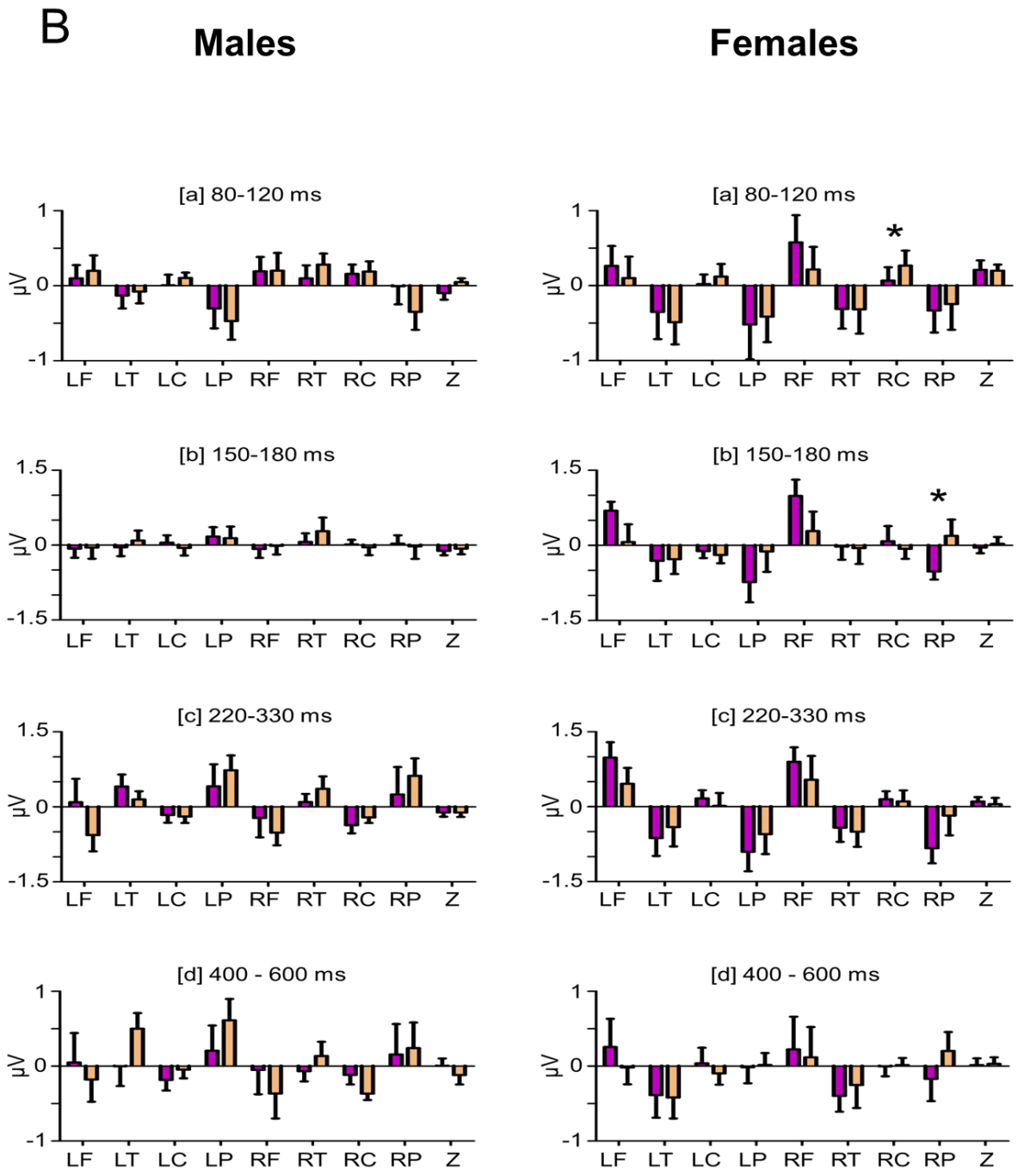
B
Males
Females
[a] 80-120 ms
[b] 150-180 ms
[c] 220-330 ms
[d] 400 - 600 ms
μV
LF LT LC LP RF RT RC RP Z
*

Fig 5.3

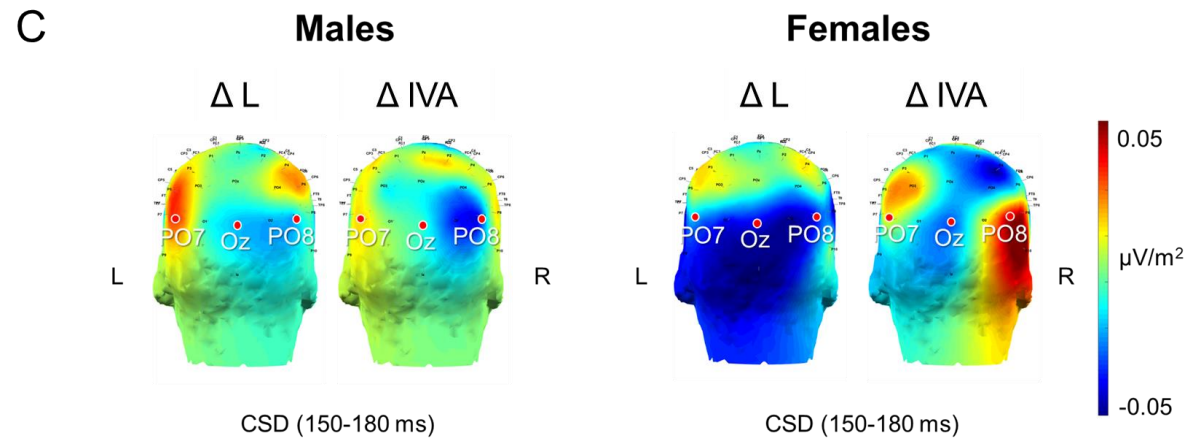

Figure 5.3 Sex difference in self-face neural activity with odor primes.

(A) Topographies of mean ERP amplitude with odor primes depending on the sex. Each topography represents the normalized mean ERP amplitude of males and females. ΔL: L – no-odor condition, ΔIVA: IVA – no-odor condition. (B) Bar graphs of ROI ERP mean amplitude in males and females. Purple, lavender; brown, isovaleric acid. Repeated-measures two-way ANOVA with Bonferroni post-tests; * $P <$ 0.05). (C) 3D topographies of the CSD in males and females at 150–180 ms from self-face onset. The posterior regions are represented.

5.2.2.BMI

To check whether odor prime effects on self-face processing are modulated by BMI or not, I examined self-face evaluation ratings and neural processing separately in low-BMI and high-BMI participants **(Figs 5.4 and 5.5)**.

In survey ratings, the low-BMI group showed significant differences in preference, attractiveness, and trustworthiness between L and IVA (repeated-measures two-way ANOVA with Bonferroni post-tests) **(Fig 5.4 A)**. However, the high-BMI group showed no significant differences between the odor primes **(Fig 5.4 B)**. Interestingly, in the high-BMI group, topography showed similar patterns regardless of the context of the odor stimuli **(Fig 5.5 A)**. When L or IVA was presented to the high-BMI group, the topography was similar to that when IVA was presented in chapter IV. The low-BMI group showed similar results to those in chapter 4 with odor primes. In particular, it showed positivity in the frontal regions and negativity in the posterior regions induced by L at [c] **(Fig 5.5 B)**.

Figure 5.4 Self-face evaluation ratings with odor primes (low BMI vs. high BMI).

Participants rated six items regarding face evaluation, with scores ranging from 1 to 9, after inhaling either L or IVA. The *y*-axis score is a subtraction of the no-odor condition (air) score from the odor condition (L or IVA) score. Repeated-measures two-way ANOVA with Bonferroni post-tests: ns: not significant, ** $P < 0.01$, *** $P < 0.001$. (A) Self-face evaluation ratings in low-BMI participants (n=18). (B) Self-face evaluation ratings in high-BMI participants (n=12).

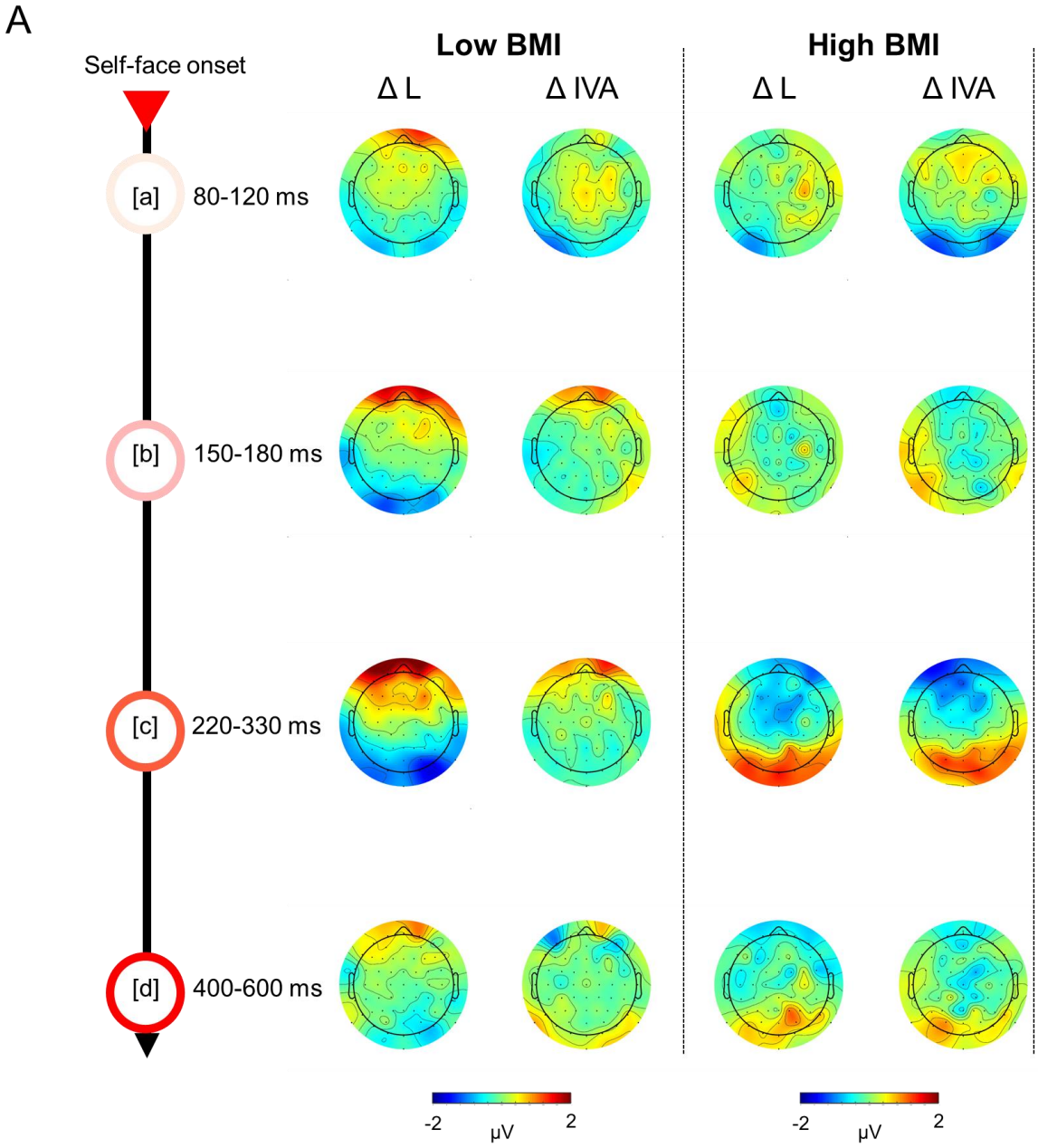
A
Low BMI
High BMI
Δ L
Δ IVA
Δ L
Δ IVA
Self-face onset
[a]
80-120 ms
[b]
150-180 ms
[c]
220-330 ms
[d]
400-600 ms
-2
μV
2
-2
μV
2

Fig 5.5

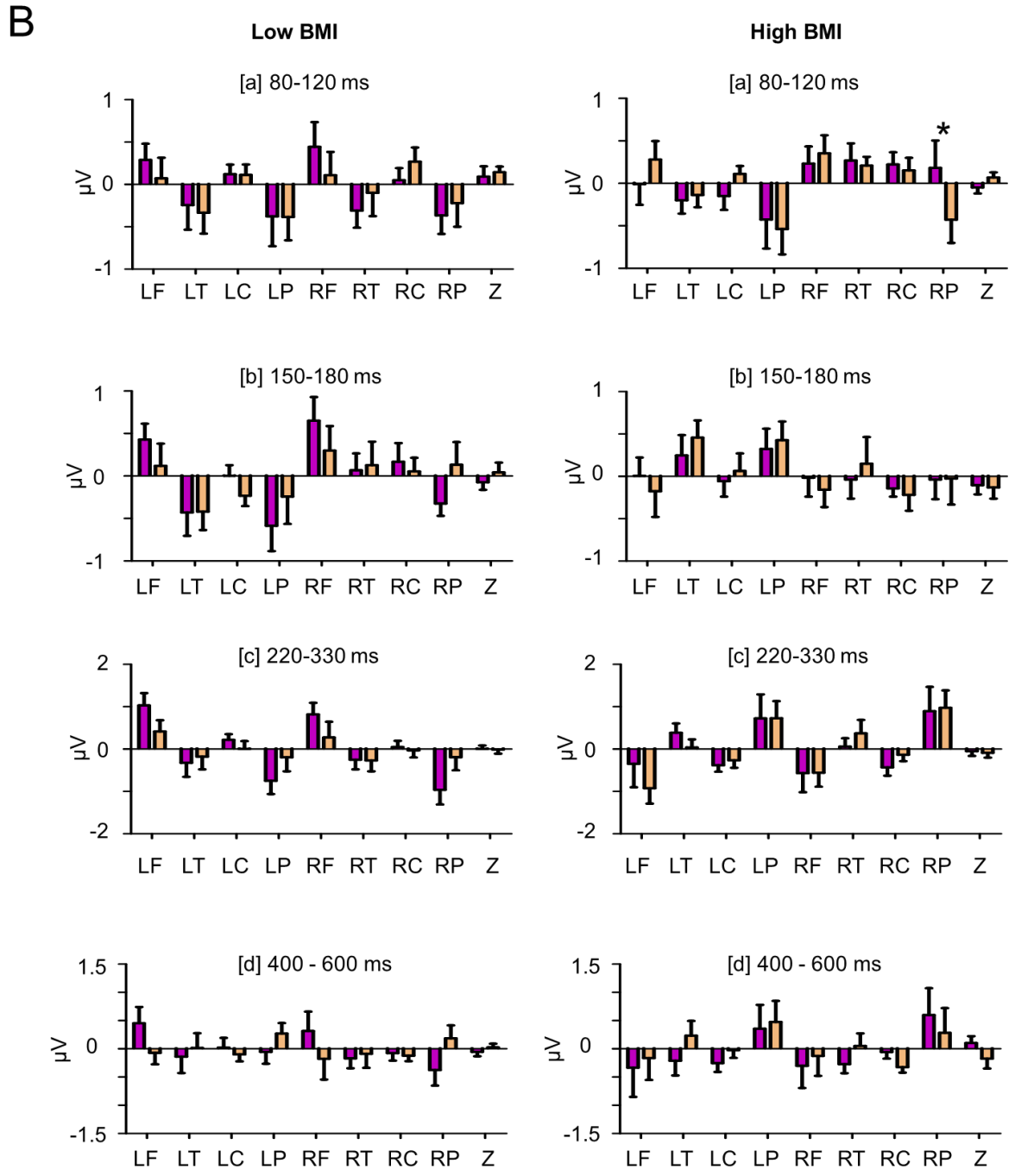

Figure 5.5 Self-face neural activity with odor primes depending on BMI.

(A) Topographies of mean ERP amplitude with odor primes. Each topography represents the normalized mean ERP amplitude of the low-BMI or high-BMI group. ΔL: L – no odor condition, ΔIVA: IVA – no odor condition. (B) Bar graphs of ROI ERP mean amplitude. Purple, L; brown, IVA. Repeated-measures two-way ANOVA with Bonferroni post-tests; * $P < 0.05$.

5.2.3 Self-esteem

To check whether odor prime effects on self-face processing are modulated by self-esteem or not, I examined self-face evaluation ratings and neural processing separately in the low-RSES and high-RSES groups **(Figs 5.6 and 5.7).**

In survey ratings, only the low-RSES group showed statistically significant changes by odor primes in self-face evaluation ratings on preference, attractiveness, and trustworthiness **(Fig 5.6)**. The high-RSES group showed no significant difference between L and IVA in self-face evaluation.

Surprisingly, in the high-RSES group, the topography also showed similar patterns regardless of the odor stimuli **(Fig 5.7 A)**. However, unlike the high-BMI group, high RSES group showed opposite patterns. The high-RSES group topography at [c] 220–330 ms with L and IVA was similar to that with L in chapter 4. The topography patterns with both L and IVA showed positivity in the frontal region and negativity in the posterior region at [c]. In contrast, the low-RSES group showed similar results those in chapter 4 with odor primes **(Fig 5.7 B).** It showed a significant difference between L and IVA in LF ROI at [c].

Figure 5.6 Self-face evaluation ratings with odor primes depending on the self-esteem level (low RSES vs. high RSES).

Participants rated six items regarding face evaluation, with scores ranging from 1 to 9, after inhaling either L or IVA. The *y*-axis score is a subtraction of the no-odor condition (air) score from the odor condition (L or IVA) score. Repeated-measures two-way ANOVA with Bonferroni post-tests; ns: not significant, ** $P < 0.01$, *** $P < 0.001$). (A) Self-face evaluation ratings of low-RSES participants (n=17). (B) Self-face evaluation ratings of high-RSES participants (n=13).

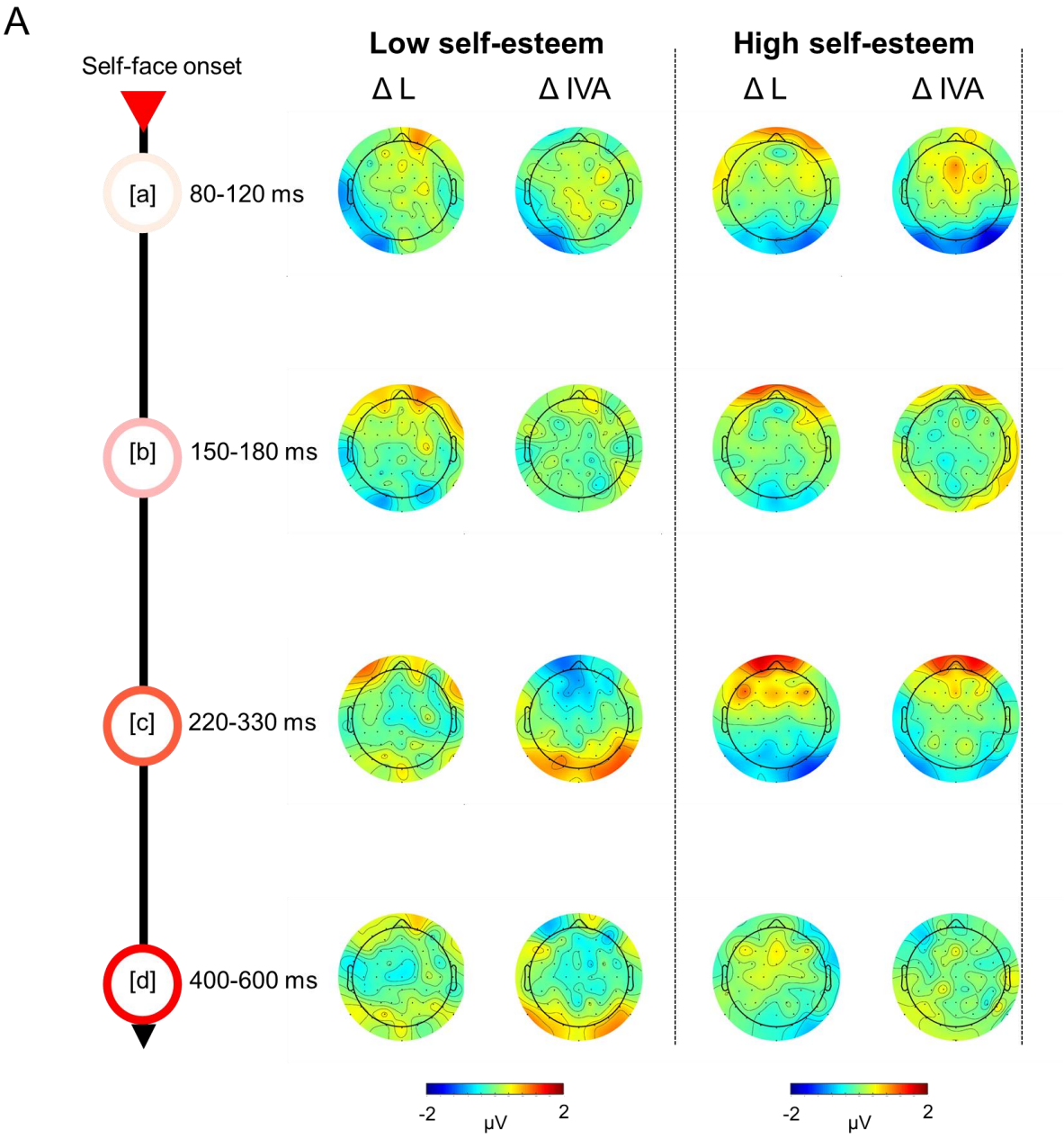
A
Low self-esteem
High self-esteem
Δ L
Δ IVA
Δ L
Δ IVA
Self-face onset
[a] 80-120 ms
[b] 150-180 ms
[c] 220-330 ms
[d] 400-600 ms
-2
μV
2
-2
μV
2

Fig 5.7

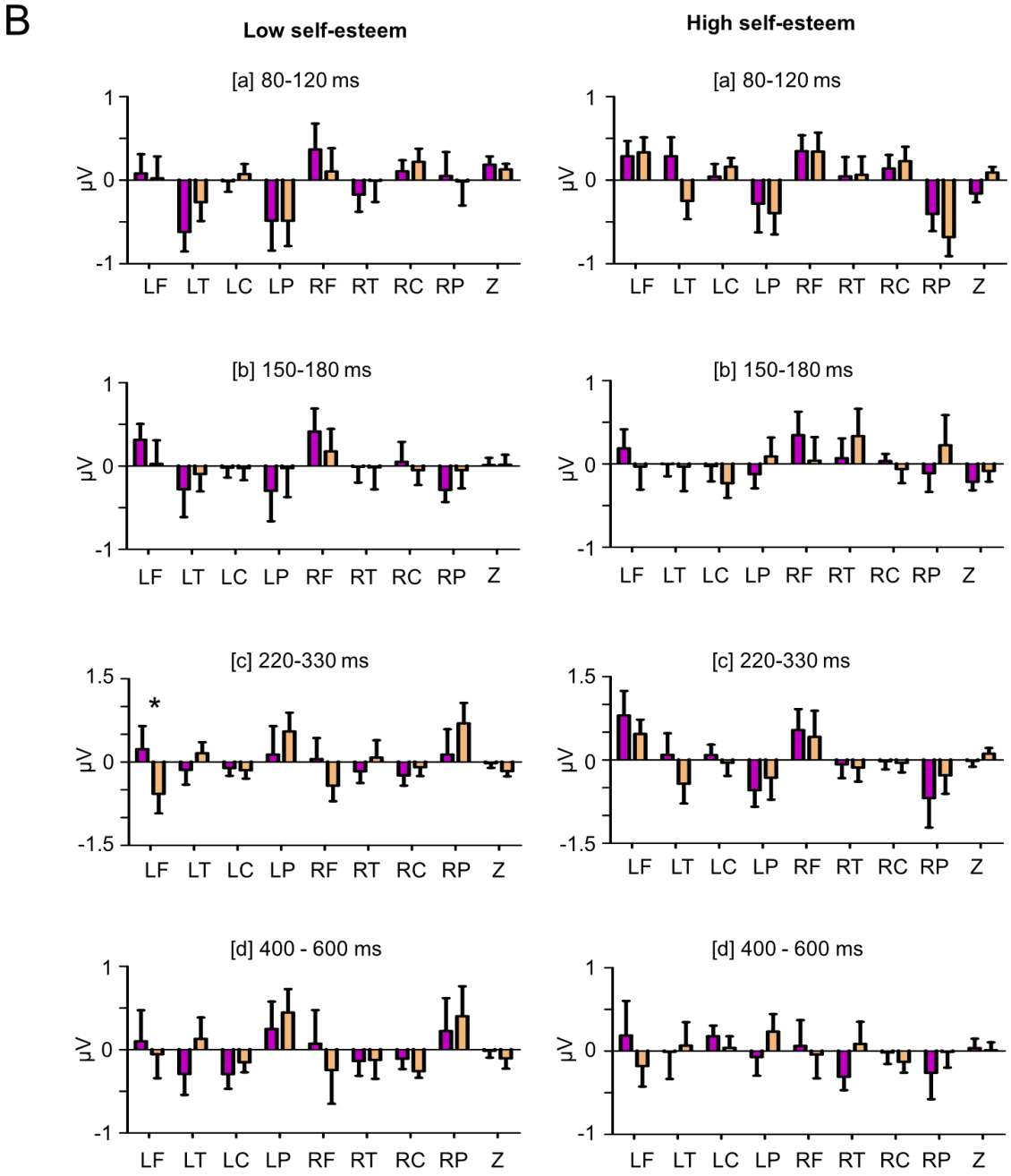

Figure 5.7 Self-face neural activity with odor primes depending on RSES.

(A) Topographies of mean ERP amplitude. Each topography represents the normalized mean ERP amplitude of the low-RSES group or high-RSES group. ΔL: L – no odor condition, ΔIVA: IVA – no odor condition. (B) Bar graphs of ROI mean ERP amplitude. Purple, lavender; brown, isovaleric acid. Repeated-measures two-way ANOVA with Bonferroni post-tests; * $P < 0.05$.

5.2.4 BMI & Self-esteem

The results described above revealed that the high-BMI group showed IVA-like neural modulation patterns with both odors, whereas the high-self-esteem group showed L-like neural modulation patterns with both odors. Thus, these groups showed opposite patterns. Therefore, I additionally analyzed the neural patterns in four subgroups: A, high BMI and high RSES; B, low BMI and high RSES; C, high BMI and low RSES; and D, low BMI and low RSES **(Fig 5.8)**. During time window [c] 220–330 ms, noticeable intergroup differences were observed. Especially in group C, the neural patterns observed during [c] remained until [d] 400–600 ms **(Fig 5.8 C)**. The patterns at [c] were similar to the high-BMI group patterns; however, these patterns showed more strong negativity in the frontal region and positivity in the posterior region **(Fig 5.9 D)**. On the other hand, in the group B, they showed more powerful positivity in the frontal region and negativity in the posterior region than in the high-RSES group **(Figs 5.8 B and 5.9 A)**. In participants with high RSES, even though they had a high BMI, strong neural patterns were removed **(Fig 5.9 B)**. Group D showed odor-dependent changes **(Fig 5.9 C)**.

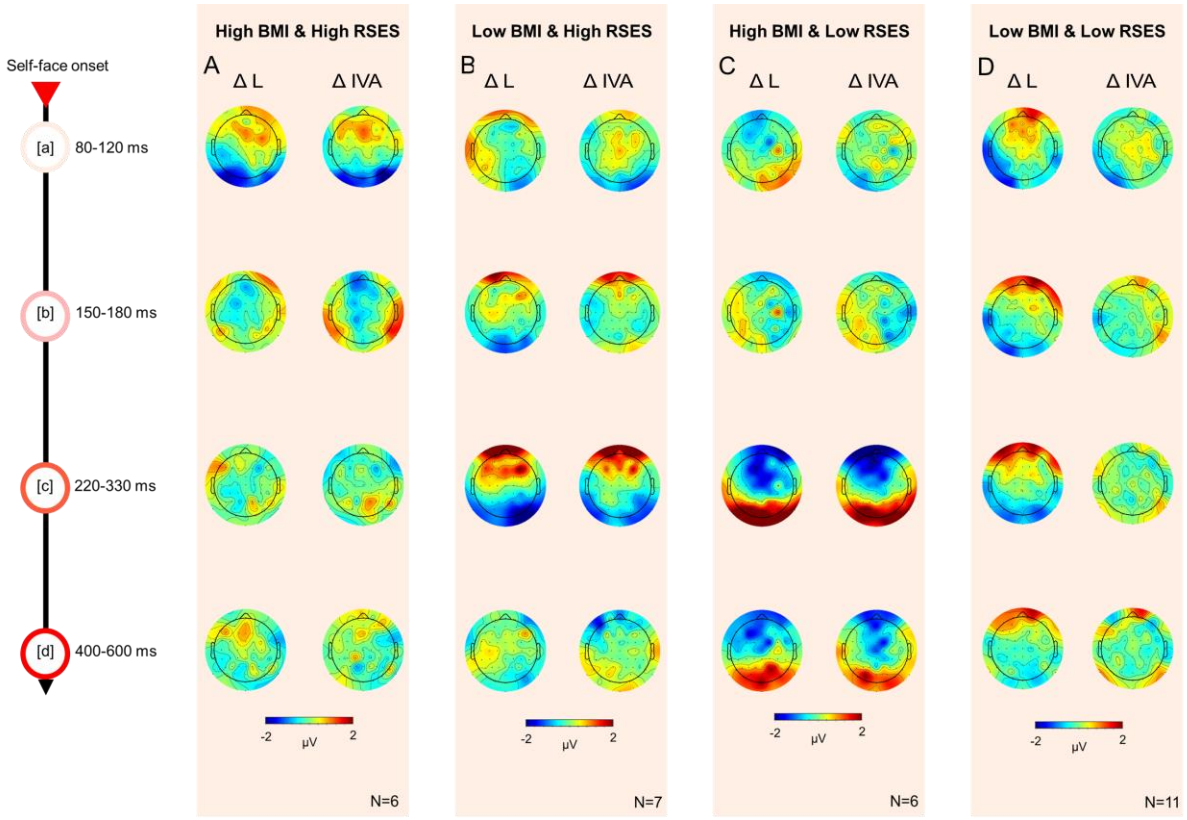

Figure 5.8 Topographies of BMI and self-esteem subgroups during self-face processing with odor primes

(A) Participants with high BMI and high RSES scores, (B) Participants with low BMI and high RSES scores, (C) Participants with high BMI and low RSES scores, (D) Participants with low BMI and low RSES scores. Each topography represents the normalized mean ERP amplitude, ΔL: L – no-odor condition, ΔIVA: IVA – no-odor condition.

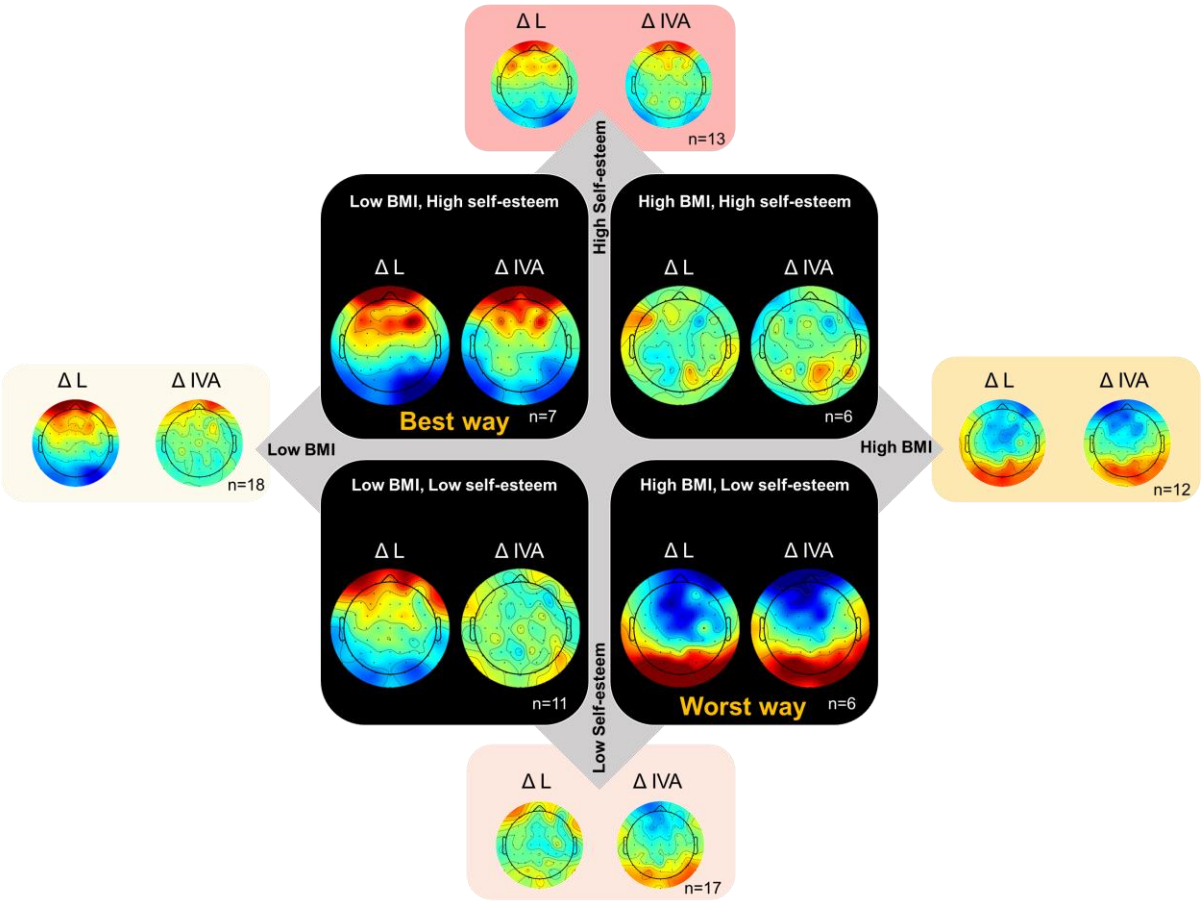

Figure 5.9 Neural activity features in the220–330 ms time window depending on BMI and self-esteem

Each group showed specific patterns. ΔL: L – no-odor condition, ΔIVA: IVA – no-odor condition.

5.3 Discussion

This study provides evidence that the self-face is perceived and evaluated differently depending on odor and individual differences (sex, BMI, and self-esteem).

The modulatory effects of odor were observed during self-face processing in the female's brain. With the pleasant odor (lavender) females showed intense negativity of N170 in the posterior region. On the other hand, with the unpleasant odor (isovaleric acid), they showed positivity in the right posterior region. A previous study reported that N170 showed more significant negativity in the context of a pleasant odor compared with an unpleasant odor while viewing faces [132]. My results agree with this previous study. However, the effects of self-face were observed only in females.

I found that females were more responsive to external stimuli during self-face processing compared to males. Previous studies revealed that females have a tendency to describe themselves in terms of connectedness to others, while males have a tendency to describe themselves in terms of separateness from others [20-22]. An ERP study revealed that males have significant attentional enhancement over the parietal area (during 420–620 ms) during self-face processing compared to females [133]. ERPs over the central electrodes were enlarged in females when they saw a familiar face compared to a stranger's face (during 430–530 ms). This indicates that females may be affected by social information from various external stimuli more quickly than are males.

The results indicated that odor effects are caused not only by the emotional changes due to odor valence but also by the self-view difference. Participants might have different views on 'how others evaluate me in the presence L or IVA' depending on sex, BMI, and self-esteem. If emotional changes were caused only by the pleasantness of the odor, participants would show similar neural pattern changes. However, I found distinct patterns depending on the above factors. Females showed a sensitive response to odor primes. In the high-BMI group, both L and IVA primes modulated neural activity toward unattractiveness. On the other hand, in the high self-esteem group, both L and IVA primes attractively modulated neural activity. According to these results, when we evaluate our self-face after odor priming, most of us may evaluate ourselves as we have evaluated others who had this smell. However, these results also suggest that external stimuli could be interpreted differently according to each person's various personal features and could result in different behaviors. Through

these neural activity patterns, I hope we could understand more about the various aspects of social relationships in human society.

VI Conclusion

My research reveals how odor stimuli modulate our self-face perception and evaluation from the baseline depending on differences in sex, BMI, and self-esteem.

First, I examined the characteristics of self-face processing in the no-odor condition. I found distinct patterns of mean ERP amplitudes and survey ratings between groups (sex, BMI, and self-esteem). I used the characteristics confirmed by surveys and ERP as a baseline to understand the change in neural patterns in odor conditions. In particular, I confirmed the male and female brain asymmetry in the posterior region [68, 70] and abnormal activity of the frontal region in the high-BMI participants [25, 26].

Second, I provide evidence that the self-face is perceived and evaluated differently depending on odor stimuli. This finding may give a general idea of why we feel more attractive after spraying perfume. The fragrant smell of perfume could make us see our faces in a more positive light within just 400 ms. When participants saw the self-face after smelling lavender, the ERP patterns at 220–330 ms were similar to those in a previous study [126] that reported positivity in the frontal region and negativity at posterior electrodes when seeing attractive faces of others at 230–280 ms. These data indicate that the brain may accept our faces as being more attractive when we see them with a pleasant odor, even though our faces remain the same. My findings may also give a clue to enhancing self-esteem, which refers to the positive feelings about ourselves, by a simple approach using odors.

Lastly, I found that the modulatory effects of odors on self-face processing could depend on the individual differences. I obtained impressive results that the high-BMI and high self-esteem participants showed little changes in both self-face evaluation and ERPs between the two odor primes. In both L and IVA conditions, high-BMI neural patterns were similar to self-face neural processing in the IVA condition, whereas high-self-esteem neural patterns were similar to self-face neural processing in the L condition. Fortunately, participants with high BMI and high self-esteem showed weaker neural patterns than those with high BMI and low self-esteem. In addition, females responded to the odor stimulus more sensitively than males. From the early processing time, females but not males showed well-marked changes by odor stimuli. These results indicate that accumulated feelings toward the self or sensitivity to the presented external stimuli may produce different self-face perceptions and

evaluations.

In this study, I used EEG for measuring the neural activity, and the analysis methods were limited to mean ERP amplitudes and CSD. Therefore, I could not confirm the neural activity during self-face processing from the deep brain. Further investigation is needed to reveal where odor priming modulates the exact brain area during self-face processing using a high spatial resolution method such as fMRI. Nevertheless, I could answer the question of 'where' and 'when' odors modulate self-face perception and evaluation. The results showed different neural patterns and time windows for L and IVA. In this study, instead of peak amplitudes, I used ERP mean amplitudes to observe the characteristic patterns at broad electrode sites within selected time windows. Peak amplitude is highly sensitive to noise, whereas mean amplitude could filter out noises at high and intermediate frequencies from the analysis procedure. When measuring peak amplitudes at multiple electrodes, each site's time points are too diverse [134]. Thus, the mean ERP amplitude analysis was suitable for achieving the study goal and finding the differences in neural patterns among groups.

To sum up, this study gives us insights into how we enhance positive feelings to the self. Pleasant odors may give us a more positive self-face evaluation through modulation of neural processing at 220–330 ms from viewing self-face. Pleasant odor enhances mean ERP amplitude positivity in the left frontal region and negativity in the right posterior region than unpleasant odors. However, we need to remember that these responses to odors differ depending on our personal features. We may need to lose weight to respond more positively to external stimuli or increase our self-esteem to feel optimistic about all of the stimuli associated with the self. I hope this study could provide a scientific basis for understanding and loving ourselves more, and people could make happier social relationships using pleasant odors.

Reference

1. Young A W, Brédart S (2004) Self-recognition in everyday life. Cognitive Neuropsychiatry **9**(3): 183-197.
2. Tsakiris M (2008) Looking for myself: current multisensory input alters self-face recognition. PloS one **3**(12).
3. Alaoui-Ismaïli O, Robin O, Rada H, Dittmar A, Vernet-Maury E (1997) Basic emotions evoked by odorants: comparison between autonomic responses and self-evaluation. Physiology & behavior **62**(4): 713-720.
4. De Araujo I E, Rolls E T, Velazco M I, Margot C, Cayeux I (2005) Cognitive modulation of olfactory processing. Neuron **46**(4): 671-679.
5. Warrenburg S (2005) Effects of fragrance on emotions: moods and physiology. Chemical Senses **30**(suppl_1): i248-i249.
6. Field T, Diego M, Hernandez-Reif M, Cisneros W, Feijo L, Vera Y, Gil K, Grina D, Claire He Q (2005) Lavender fragrance cleansing gel effects on relaxation. International Journal of Neuroscience **115**(2): 207-222.
7. Lorig T S, Schwartz G E (1988) Brain and odor: I. Alteration of human EEG by odor administration. Psychobiology **16**(3): 281-284.
8. Moon S A, Bae J, Kim K, Cho S Y, Kwon G, Lee R, Ko S H, Lim S, Moon C (2020) EEG Revealed That Fragrances Positively Affect Menopausal Symptoms in Mid-life Women. Experimental neurobiology **29**(5): 389.
9. Syrjänen E, Liuzza M T, Fischer H, Olofsson J K (2017) Do valenced odors and trait body odor disgust affect evaluation of emotion in dynamic faces? Perception **46**(12): 1412-1426.
10. Cook S, Fallon N, Wright H, Thomas A, Giesbrecht T, Field M, Stancak A (2015) Pleasant and unpleasant odors influence hedonic evaluations of human faces: An event-related potential study. Frontiers in human neuroscience **9**: 661.
11. Cook S, Kokmotou K, Soto V, Fallon N, Tyson-Carr J, Thomas A, Giesbrecht T, Field M, Stancak A (2017) Pleasant and unpleasant odour-face combinations influence face and

odour perception: an event-related potential study. Behavioural brain research **333**: 304-313.

12. Homan P, Ely B A, Yuan M, Brosch T, Ng J, Trope Y, Schiller D (2017) Aversive smell associations shape social judgment. Neurobiology of learning and memory **144**: 86-95.
13. Li W, Moallem I, Paller K A, Gottfried J A (2007) Subliminal smells can guide social preferences. Psychological science **18**(12): 1044-1049.
14. Lõhmus M, Sundström L F, Björklund M. *Dress for success: Human facial expressions are important signals of emotions*. in *Annales Zoologici Fennici*. 2009. BioOne.
15. Cohen M X (2011) It's about time. Frontiers in human neuroscience **5**(2).
16. Schupp H T, Øhman A, Junghöfer M, Weike A I, Stockburger J, Hamm A O (2004) The facilitated processing of threatening faces: an ERP analysis. Emotion **4**(2): 189.
17. Grigor J, Van Toller S, Behan J, Richardson A (1999) The effect of odour priming on long latency visual evoked potentials of matching and mismatching objects. Chemical Senses **24**(2): 137-144.
18. Bensafi M, Pierson A, Rouby C, Farget V, Bertrand B, Vigouroux M, Jouvent R, Holley A (2002) Modulation of visual event-related potentials by emotional olfactory stimuli. Neurophysiologie Clinique/Clinical Neurophysiology **32**(6): 335-342.
19. Castle P, Van Toller S, Milligan G (2000) The effect of odour priming on cortical EEG and visual ERP responses. International Journal of Psychophysiology **36**(2): 123-131.
20. Cross S E, Madson L (1997) Models of the self: self-construals and gender. Psychological bulletin **122**(1): 5.
21. Guimond S, Branscombe N R, Brunot S, Buunk A P, Chatard A, Désert M, Garcia D M, Haque S, Martinot D, Yzerbyt V (2007) Culture, gender, and the self: Variations and impact of social comparison processes. Journal of personality and social psychology **92**(6): 1118.
22. Lyons N P (1983) Two perspectives: On self, relationships, and morality. Harvard Educational Review **53**(2): 125-145.
23. O'dea J A (2006) Self-concept, self-esteem and body weight in adolescent females: a three-year longitudinal study. Journal of health psychology **11**(4): 599-611.

24. Israel A C, Ivanova M Y (2002) Global and dimensional self-esteem in preadolescent and early adolescent children who are overweight: Age and gender differences. International Journal of Eating Disorders **31**(4): 424-429.

25. Yokum S, Ng J, Stice E (2012) Relation of regional gray and white matter volumes to current BMI and future increases in BMI: a prospective MRI study. International journal of obesity **36**(5): 656-664.

26. Pannacciulli N, Del Parigi A, Chen K, Le D S N, Reiman E M, Tataranni P A (2006) Brain abnormalities in human obesity: a voxel-based morphometric study. Neuroimage **31**(4): 1419-1425.

27. Oikawa H, Sugiura M, Sekiguchi A, Tsukiura T, Miyauchi C M, Hashimoto T, Takano-Yamamoto T, Kawashima R (2012) Self-face evaluation and self-esteem in young females: an fMRI study using contrast effect. Neuroimage **59**(4): 3668-3676.

28. Tedxbeaconstreet, *What makes a good life? Lessons from the longest study on happiness*. 2015.

29. August K J, Rook K S, *Social Relationships*, in *Encyclopedia of Behavioral Medicine*, Gellman Marc D.Turner J. Rick, Editors. 2013, Springer New York: New York, NY. p. 1838-1842.

30. House J S, Landis K R, Umberson D (1988) Social relationships and health. Science **241**(4865): 540-545.

31. Cohen S (2004) Social relationships and health. American psychologist **59**(8): 676.

32. Uchino B N (2006) Social support and health: a review of physiological processes potentially underlying links to disease outcomes. Journal of behavioral medicine **29**(4): 377-387.

33. Jhangiani R, Tarry H, Stangor C, *3. The self*, in *Principles of social psychology-1st international edition*. 2014. p. pp104-161.

34. Gallup G G (1970) Chimpanzees: self-recognition. Science **167**(3914): 86-87.

35. Boysen S, Himes G (1999) Current issues and emerging theories in animal cognition. Annual review of psychology **50**(1): 683-705.

36. Reiss D, Marino L (2001) Mirror self-recognition in the bottlenose dolphin: A case of cognitive convergence. Proceedings of the National Academy of Sciences **98**(10): 5937-5942.

37. Plotnik J M, De Waal F B, Reiss D (2006) Self-recognition in an Asian elephant. Proceedings of the National Academy of Sciences **103**(45): 17053-17057.

38. Prior H, Schwarz A, Güntürkün O (2008) Mirror-induced behavior in the magpie (Pica pica): evidence of self-recognition. PLoS biology **6**(8): e202.

39. Asendorpf J B, Warkentin V, Baudonniere P-M (1996) Self-awareness and other-awareness. II: Mirror self-recognition, social contingency awareness, and synchronic imitation. Developmental Psychology **32**(2): 313.

40. Harter S, *Chapter 3:The development of self-representations*, in *Handbook of child psychology: Social, emotional, and personality development*. 1998. p. pp 553-617.

41. Doherty M, *Chapter 1: Introduction to theory of mind*, in *Theory of mind: How children understand others' thoughts and feelings*. 2008, Psychology Press. p. pp1-3.

42. Duval S, Wicklund R A (1972) A theory of objective self awareness.

43. Leary M R, Tangney J P, *3. Self-awareness*, in *Handbook of self and identity*. 2011, Guilford Press. p. pp50-65.

44. Fejfar M C, Hoyle R H (2000) Effect of private self-awareness on negative affect and self-referent attribution: A quantitative review. Personality and Social Psychology Review **4**(2): 132-142.

45. Storms M D (1973) Videotape and the attribution process: Reversing actors' and observers' points of view. Journal of personality and social psychology **27**(2): 165.

46. Duval T S, Duval V H, Mulilis J-P (1992) Effects of self-focus, discrepancy between self and standard, and outcome expectancy favorability on the tendency to match self to standard or to withdraw. Journal of Personality and Social Psychology **62**(2): 340.

47. Higgins E T (1987) Self-discrepancy: A theory relating self and affect. Psychological Review **94 (3)**: 319-340.

48. Tobin S J, Vanman E J, Verreynne M, Saeri A K (2015) Threats to belonging on Facebook : Lurking and ostracism. Social Influence **10**(1): 31-42.

49. Gonzales A L, Hancock J T (2011) Mirror, mirror on my Facebook wall: Effects of exposure to Facebook on self-esteem. Cyberpsychology, behavior, and social networking **14**(1-2): 79-83.

50. Yin R K (1969) Looking at upside-down faces. Journal of experimental psychology **81**(1): 141.

51. O'toole A J, Deffenbacher K A, Valentin D, Mckee K, Huff D, Abdi H (1998) The perception of face gender: The role of stimulus structure in recognition and classification. Memory & Cognition **26**(1): 146-160.

52. Rhodes M G, Anastasi J S (2012) The own-age bias in face recognition: a meta-analytic and theoretical review. Psychological bulletin **138**(1): 146.

53. O'toole A J, Deffenbacher K A, Valentin D, Abdi H (1994) Structural aspects of face recognition and the other-race effect. Memory & Cognition **22**(2): 208-224.

54. Jones A L, Kramer R S, Ward R (2012) Signals of personality and health: The contributions of facial shape, skin texture, and viewing angle. Journal of Experimental Psychology: Human Perception and Performance **38**(6): 1353.

55. Grammer K, Thornhill R (1994) Human (Homo sapiens) facial attractiveness and sexual selection: the role of symmetry and averageness. Journal of comparative psychology **108**(3): 233.

56. Ekman P, Friesen W V, O'sullivan M, Chan A, Diacoyanni-Tarlatzis I, Heider K, Krause R, Lecompte W A, Pitcairn T, Ricci-Bitti P E (1987) Universals and cultural differences in the judgments of facial expressions of emotion. Journal of personality and social psychology **53**(4): 712.

57. Willis J, Todorov A (2006) First impressions: Making up your mind after a 100-ms exposure to a face. Psychological science **17**(7): 592-598.

58. Rule N O, Ambady N (2008) Brief exposures: Male sexual orientation is accurately perceived at 50 ms. Journal of Experimental Social Psychology **44**(4): 1100-1105.

59. Perrett D I, Lee K J, Penton-Voak I, Rowland D, Yoshikawa S, Burt D M, Henzi S, Castles D L, Akamatsu S (1998) Effects of sexual dimorphism on facial attractiveness. Nature **394**(6696): 884-887.

60. Rhodes G (2006) The evolutionary psychology of facial beauty. Annu. Rev. Psychol. **57**: 199-226.

61. Sutherland C A, Oldmeadow J A, Santos I M, Towler J, Burt D M, Young A W (2013) Social inferences from faces: Ambient images generate a three-dimensional model. Cognition **127**(1): 105-118.

62. Jack R E, Schyns P G (2015) The human face as a dynamic tool for social communication. Current Biology **25**(14): R621-R634.

63. Platek S M, Loughead J W, Gur R C, Busch S, Ruparel K, Phend N, Panyavin I S, Langleben D D (2006) Neural substrates for functionally discriminating self-face from personally familiar faces. Human brain mapping **27**(2): 91-98.

64. Northoff G, Heinzel A, De Greck M, Bermpohl F, Dobrowolny H, Panksepp J (2006) Self-referential processing in our brain—a meta-analysis of imaging studies on the self. Neuroimage **31**(1): 440-457.

65. Keyes H, Brady N, Reilly R B, Foxe J J (2010) My face or yours? Event-related potential correlates of self-face processing. Brain and cognition **72**(2): 244-254.

66. Sel A, Harding R, Tsakiris M (2016) Electrophysiological correlates of self-specific prediction errors in the human brain. Neuroimage **125**: 13-24.

67. Gillihan S J, Farah M J (2005) Is self special? A critical review of evidence from experimental psychology and cognitive neuroscience. Psychological bulletin **131**(1): 76.

68. Uddin L Q, Kaplan J T, Molnar-Szakacs I, Zaidel E, Iacoboni M (2005) Self-face recognition activates a frontoparietal "mirror" network in the right hemisphere: an event-related fMRI study. Neuroimage **25**(3): 926-935.

69. Raichle M E, Macleod A M, Snyder A Z, Powers W J, Gusnard D A, Shulman G L (2001) A default mode of brain function. Proceedings of the National Academy of Sciences **98**(2): 676-682.

70. Morita T, Itakura S, Saito D N, Nakashita S, Harada T, Kochiyama T, Sadato N (2008) The role of the right prefrontal cortex in self-evaluation of the face: a functional magnetic resonance imaging study. Journal of Cognitive Neuroscience **20**(2): 342-355.

71. Gottfried J A (2010) Central mechanisms of odour object perception. Nature Reviews Neuroscience **11**(9): 628-641.

72. Carmichael S T, Clugnet M C, Price J L (1994) Central olfactory connections in the macaque monkey. Journal of Comparative Neurology **346**(3): 403-434.

73. Zald D H (2003) The human amygdala and the emotional evaluation of sensory stimuli. Brain Research Reviews **41**(1): 88-123.

74. Winston J S, O'doherty J, Kilner J M, Perrett D I, Dolan R J (2007) Brain systems for assessing facial attractiveness. Neuropsychologia **45**(1): 195-206.

75. O'doherty J, Winston J, Critchley H, Perrett D, Burt D M, Dolan R J (2003) Beauty in a smile: the role of medial orbitofrontal cortex in facial attractiveness. Neuropsychologia **41**(2): 147-155.

76. Saive A-L, Royet J-P, Plailly J (2014) A review on the neural bases of episodic odor memory: from laboratory-based to autobiographical approaches. Frontiers in Behavioral Neuroscience **8**: 240.

77. Pahl S, Eiser J R (2005) Valence, comparison focus and self-positivity biases: Does it matter whether people judge positive or negative traits? Experimental psychology **52**(4): 303-310.

78. Perloff L S, Fetzer B K (1986) Self–other judgments and perceived vulnerability to victimization. Journal of Personality and social Psychology **50**(3): 502.

79. Alicke M D (1985) Global self-evaluation as determined by the desirability and controllability of trait adjectives. Journal of personality and social psychology **49**(6): 1621.

80. Epley N, Whitchurch E (2008) Mirror, mirror on the wall: Enhancement in self-recognition. Personality and Social Psychology Bulletin **34**(9): 1159-1170.

81. Debruine L M (2005) Trustworthy but not lust-worthy: Context-specific effects of facial resemblance. Proceedings of the Royal Society B: Biological Sciences **272**(1566): 919-922.

82. Tao R, Zhang S, Li Q, Geng H (2012) Modulation of self-esteem in self-and other-evaluations primed by subliminal and supraliminal faces. PloS one **7**(10): e47103.

83. Strauss R S, Pollack H A (2003) Social marginalization of overweight children. Archives of pediatrics & adolescent medicine **157**(8): 746-752.

84. Mendelson B K, White D R (1985) Development of self-body-esteem in overweight youngsters. Developmental Psychology **21**(1): 90.

85. Kilpatrick M, Ohannessian C, Bartholomew J B (1999) Adolescent weight management and perceptions: an analysis of the National Longitudinal Study of Adolescent Health. Journal of School Health **69**(4): 148-152.

86. Pritchard M E, King S L, Czajka-Narins D M (1997) Adolescent body mass indices and self-perception. Adolescence **32**(128): 863.

87. Perrin E M, Boone-Heinonen J, Field A E, Coyne-Beasley T, Gordon-Larsen P (2010) Perception of overweight and self-esteem during adolescence. International Journal of Eating Disorders **43**(5): 447-454.

88. Kling K C, Hyde J S, Showers C J, Buswell B N (1999) Gender differences in self-esteem: a meta-analysis. Psychological bulletin **125**(4): 470.

89. Proverbio A M, Riva F, Martin E, Zani A (2010) Face coding is bilateral in the female brain. PloS one **5**(6): e11242.

90. Tiedt H O, Weber J E, Pauls A, Beier K M, Lueschow A (2013) Sex-differences of face coding: evidence from larger right hemispheric M170 in men and dipole source modelling. PloS one **8**(7): e69107.

91. Fink G R, Halligan P W, Marshall J C, Frith C D, Frackowiak R, Dolan R J (1996) Where in the brain does visual attention select the forest and the trees? Nature **382**(6592): 626-628.

92. Sæther L, Van Belle W, Laeng B, Brennen T, Úvervoll M (2009) Anchoring gaze when categorizing faces' sex: evidence from eye-tracking data. Vision research **49**(23): 2870-2880.

93. Miellet S, Caldara R, Schyns P G (2011) Local Jekyll and global Hyde: the dual identity of face identification. Psychological science **22**(12): 1518-1526.

94. Abbas Z-A, Duchaine B (2008) The role of holistic processing in judgments of facial attractiveness. Perception **37**(8): 1187-1196.

95. Todorov A, Loehr V, Oosterhof N N (2010) The obligatory nature of holistic processing of faces in social judgments. Perception **39**(4): 514-532.

96. Rosenberg M, *Society and the adolescent self-image*. 1965: Princeton university press.

97. Jeon B-J (1974) Self-esteem: A test of its measurability. Yonsei Nonchong **11**(1): 107-130.

98. Rumeau C, Nguyen D, Jankowski R (2016) How to assess olfactory performance with the Sniffin'Sticks test®. European annals of otorhinolaryngology, head and neck diseases **133**(3): 203-206.

99. Kobal G, Klimek L, Wolfensberger M, Gudziol H, Temmel A, Owen C, Seeber H, Pauli E, Hummel T (2000) Multicenter investigation of 1,036 subjects using a standardized method for the assessment of olfactory function combining tests of odor identification, odor discrimination, and olfactory thresholds. European Archives of Oto-rhino-laryngology **257**(4): 205-211.

100. Bertelson P, Vroomenti J, Gelderti B D. *Auditory-visual interaction in voice localization and in bimodal speech recognition: The effects of desynchronization*. in *Audio-Visual Speech Processing: Computational & Cognitive Science Approaches*. 1997.

101. Kandel E R, Schwartz J H, Jessell T M, Biochemistry D O, Jessell M B T, Siegelbaum S, Hudspeth A, *Overview of synaptic transmission*, in *Principles of neural science*. 2000, McGraw-hill New York. p. 177-187.

102. Brienza M, Mecarelli O, *Neurophysiological Basis of EEG*, in *Clinical Electroencephalography*. 2019, Springer. p. 9-21.

103. Berger H (1929) Über das elektroenkephalogramm des menschen. Archiv für psychiatrie und nervenkrankheiten **87**(1): 527-570.

104. Luck S J, *An introduction to Event-Related Potentials and their neural origins*, in *An introduction to the event-related potential technique*. 2014, MIT press. p. 3-49.

105. Mitzdorf U (1985) Current source-density method and application in cat cerebral cortex: investigation of evoked potentials and EEG phenomena. Physiological reviews **65**(1): 38-45.

106. Delorme A, Makeig S (2004) EEGLAB: an open source toolbox for analysis of single-trial EEG dynamics including independent component analysis. Journal of neuroscience methods **134**(1): 9-21.

107. Lopez-Calderon J, Luck S J (2014) ERPLAB: an open-source toolbox for the analysis of event-related potentials. Frontiers in human neuroscience **8**: 213.

108. Radüntz T, Scouten J, Hochmuth O, Meffert B (2017) Automated EEG artifact elimination by applying machine learning algorithms to ICA-based features. Journal of neural engineering **14**(4): 046004.

109. Li R, Principe J C. *Blinking artifact removal in cognitive EEG data using ICA*. in *2006 International Conference of the IEEE Engineering in Medicine and Biology Society*. 2006. IEEE.

110. Pessoa L, Adolphs R (2010) Emotion processing and the amygdala: from a'low road'to'many roads' of evaluating biological significance. Nature reviews neuroscience **11**(11): 773-782.

111. Eimer M, Holmes A (2002) An ERP study on the time course of emotional face processing. Neuroreport **13**(4): 427-431.

112. Smith E, Weinberg A, Moran T, Hajcak G (2013) Electrocortical responses to NIMSTIM facial expressions of emotion. International Journal of Psychophysiology **88**(1): 17-25.

113. Halgren E, Raij T, Marinkovic K, Jousmäki V, Hari R (2000) Cognitive response profile of the human fusiform face area as determined by MEG. Cerebral cortex **10**(1): 69-81.

114. Pizzagalli D, Regard M, Lehmann D (1999) Rapid emotional face processing in the human right and left brain hemispheres: an ERP study. Neuroreport **10**(13): 2691-2698.

115. Bentin S, Allison T, Puce A, Perez E, Mccarthy G (1996) Electrophysiological studies of face perception in humans. Journal of cognitive neuroscience **8**(6): 551-565.

116. Eger E, Jedynak A, Iwaki T, Skrandies W (2003) Rapid extraction of emotional expression: evidence from evoked potential fields during brief presentation of face stimuli. Neuropsychologia **41**(7): 808-817.

117. Japee S, Crocker L, Carver F, Pessoa L, Ungerleider L G (2009) Individual differences in valence modulation of face-selective m170 response. Emotion **9**(1): 59.

118. Wieser M J, Gerdes A B, Büngel I, Schwarz K A, Mühlberger A, Pauli P (2014) Not so harmless anymore: How context impacts the perception and electrocortical processing of neutral faces. NeuroImage **92**: 74-82.

119. Krolak-Salmon P, Hénaff M-A, Vighetto A, Bertrand O, Mauguière F (2004) Early amygdala reaction to fear spreading in occipital, temporal, and frontal cortex: a depth electrode ERP study in human. Neuron **42**(4): 665-676.

120. Adolphs R (2002) Neural systems for recognizing emotion. Current opinion in neurobiology **12**(2): 169-177.

121. Cacioppo J T, Crites Jr S L, Berntson G G, Gh Coles M (1993) If attitudes affect how stimuli are processed, should they not affect the event-related brain potential? Psychological science **4**(2): 108-112.

122. Perrin F, Pernier J, Bertnard O, Giard M-H, Echallier J (1987) Mapping of scalp potentials by surface spline interpolation. Electroencephalography and clinical neurophysiology **66**(1): 75-81.

123. Kamarajan C, Pandey A K, Chorlian D B, Porjesz B (2015) The use of current source density as electrophysiological correlates in neuropsychiatric disorders: A review of human studies. International Journal of Psychophysiology **97**(3): 310-322.

124. Kayser J, Tenke C E, Kroppmann C J, Alschuler D M, Fekri S, Gil R, Jarskog L F, Harkavy-Friedman J M, Bruder G E (2012) A neurophysiological deficit in early visual processing in schizophrenia patients with auditory hallucinations. Psychophysiology **49**(9): 1168-1178.

125. Todrank J, Byrnes D, Wrzesniewski A, Rozin P (1995) Odors can change preferences for people in photographs: A cross-modal evaluative conditioning study with olfactory USs and visual CSs. Learning and motivation **26**(2): 116-140.

126. Werheid K, Schacht A, Sommer W (2007) Facial attractiveness modulates early and late event-related brain potentials. Biological psychology **76**(1-2): 100-108.

127. Wiese H, Altmann C S, Schweinberger S R (2014) Effects of attractiveness on face memory separated from distinctiveness: Evidence from event-related brain potentials. Neuropsychologia **56**: 26-36.

128. Tucker D M (1981) Lateral brain function, emotion, and conceptualization. Psychological bulletin **89**(1): 19.

129. Lane R D, Reiman E M, Bradley M M, Lang P J, Ahern G L, Davidson R J, Schwartz G E (1997) Neuroanatomical correlates of pleasant and unpleasant emotion. Neuropsychologia **35**(11): 1437-1444.

130. Henkin R I, Lewy L M (2001) Lateralization of brain activation to imagination and smell of odors using functional magnetic resonance imaging (fMRI): left hemispheric

localization of pleasant and right hemispheric localization of unpleasant odors. Journal of computer assisted tomography **25**(4): 493-514.

131. Cooley C H, *chapter 5: The social self -- 1. The meaning of "I"*, in *Human nature and the social order*. 1992, Transaction Publishers. p. pp184-186.

132. Syrjänen E, Wiens S, Fischer H, Zakrzewska M, Wartel A, Larsson M, Olofsson J K (2018) Background odors modulate N170 ERP component and perception of emotional facial stimuli. Frontiers in psychology **9**: 1000.

133. Wang J, Kitayama S, Han S (2011) Sex difference in the processing of task-relevant and task-irrelevant social information: an event-related potential study of familiar face recognition. Brain research **1408**: 41-51.

134. Clayson P E, Baldwin S A, Larson M J (2013) How does noise affect amplitude and latency measurement of event-related potentials (ERPs)? A methodological critique and simulation study. Psychophysiology **50**(2): 174-186.

요 약 문

냄새 자극이 성별, BMI 및 자존감에 따른 자기 얼굴 인식에 미치는 영향: 사건 유발 전위 연구

본 논문은 긍정적 냄새 자극인 라벤더 (lavender) 또는 부정적 냄새 자극인 아이소발레릭에시드 (isovaleric acid) 제시 이후, 자기 얼굴을 보았을 때의 뇌신호 및 자기 얼굴 평가 변화에 대한 연구이다. 또한, 자기 얼굴에 대한 연구이기 때문에 성별, 체질량 지수(Body Mass Index; BMI), 자존감에 따른 뇌신호적 특징을 비교 분석하였다.

본 연구의 연구 방법으로는 뇌파 (Electtroencephalogram; EEG) 측정 후 사건 유발 전위 (Event-Related Potential; ERP) 분석을 진행하였으며, 자기 얼굴에 대해 (1) 얼마나 기분좋게 느껴지는지, (2) 얼마나 매력적으로 느껴지는지, (3) 얼마나 신뢰성 있게 느껴지는지, (4) 얼마나 지배적인 얼굴로 느껴지는지, (5) 얼마나 성숙하게 느껴지는지, (6) 얼마나 남성적인 얼굴로 느껴지는지 정도를 평가한 설문지를 분석하였다.

본 연구 결과, 챕터 3 에서는 성별, 체질량 지수, 자존감에 따른 자기 얼굴 지각 및 평가에 대한 차이점을 발견할 수 있었으며, 추후 분석에서의 기준선 (baseline) 으로 사용하였다. 챕터 4 에서는 라벤더와 아이소발레릭에시드 제시에 따라 기준점 대비 자기 얼굴 지각 및 평가가 어떻게 달라지는지 확인하였다. 자기 얼굴 시각 자극 제시 후 220-330 ms 시간대에 좌측 전두엽이 냄새 자극에 따라 유의하게 변화하였으며, 설문지를 통해서도 라벤더와 아이소발레릭 에시드의 제시에 따라 유의하게 자기 얼굴 평가가 달라지는 것을 밝혔다. 챕터 5 에서는 성별, 체질량지수, 자존감에 따라 냄새 자극에 반응하여 변화하는 뇌신호 및 설문 평가가 달라짐을 알 수 있었다. 여자들은 남성에 비해 냄새 자극에 더 빠르게 반응하여 뇌신호 변화를 보였으며, 냄새에 따라 자신의 얼굴에 대해 (1) 기분 좋게 느껴지는 정도와 (2) 얼마나 매력적으로 느껴지는지 항목 점수가 유의한 차이를 보였다. 반면, 남자들은 냄새에 따른 뇌파 신호 및 행동 변화가 크지 않았다. 체질량 지수에 따른 그룹 및 로젠버그 자존감점수에 따른 그룹에서는 체질량 지수가 낮은 그룹, 자존감이 낮은 그룹에서 냄새에 따른 뇌파 신호변화가 확인되었으며,

체질량체질량 지수가 높은 그룹과 자존감이 높은 그룹에서는 냄새 간의 차이가 보이지 않았다. 흥미롭게도 라벤더 및 아이소발레릭에시드 냄새 모두에 대해, 체질량 지수가 높은 그룹은 자신의 얼굴을 볼 때 아이소발레릭에시드&자기얼굴 조건과 비슷한 뇌신호를 보였으며, 반대로 자존감이 높은 그룹은 라벤더&자기얼굴 조건과 비슷한 뇌신호를 보였다. 이러한 경향은 체질량지수가 높지만 자존감이 높은 사람들에게서는 약하게 나타났다.

본 연구는 냄새 자극이 제시되었을 때 성별, 체질량 지수, 자존감에 따른 자기 얼굴 지각 및 평가 과정을 뇌신호를 통하여 살펴봄으로써, 개인의 특성에 따라 외부 자극에 어떻게 반응하며, 이것이 자기 평가에 어떠한 영향을 줄 수 있는가에 대한 과학적 근거를 제시하였다. 이 연구는 사회 속에서의 자기 자신에 대한 이해도를 높이는 데에 도움을 줄 뿐만 아니라, 향의 효과에 대한 과학적 근거 제시 및 뇌신호를 통한 산업적 응용에 도움이 될 것이다. 본 연구가 사람들이 기분 좋은 냄새로 더 행복한 사회적 관계를 만들어 나가며, 우리 자신을 더 잘 이해하고 사랑할 수 있는 과학적 토대가 되기를 기대한다.

핵심어: 자기 얼굴, 냄새, 뇌신호, 성별, 체질량지수, 자존감