Modulation of colour and odour perception, and cross-modal correspondences for women in the menstrual cycle and menopause

Thesis by

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Chapter 1

General Introduction

1.1 Female hormone changes during the menstrual cycle and menopause

Female hormones (e.g., estrogen and progesterone) are fundamental for modulation of women's physiological and psychological conditions. Women typically have had the menstrual cycle since the puberty period and undergo menopause at around 50 years old. In the menstrual cycle, one regular cycle is typically consists of approximately 28 days, and ovulation occurs at about 14 days prior to the first day of the next menstruation (Makhanova & Miller, 2013). However, this cycle can vary in an irregular manner because of various factors in individuals' health, mental and environmental conditions, such as smoking, alcohol consumption, dietary habits and stress (Kaplan & Manuck, 2004; Rowland et al., 2002; Yamamoto, Okazaki, Sakamoto, & Funatsu, 2009). Some women are also diagnosed with premenstrual syndrome (PMS) or premenstrual dysphoric disorder (PMDD), and they experience various physical symptoms such as headache, abdominal pain and weight gain, and psychological changes such as development of depression and irritability (Biggs & Demuth, 2011; Jukic et al., 2008).

Menopause occurs in accordance with gradual reduction of secretion of estrogen and progesterone at the age around 47 to 51 years, and it is normally diagnosed after a condition of amenorrhoea has continued for 12 months (McKinlay, 1996; Nelson, 2008). At midlife, at around 45 to 55 years of age, women experience various changes in their social and family circumstances, such as being required to take a more professional role, changes in sexual functioning and relationships, and/or new roles of caring for aged parents, ill partners or grandchildren (Dennerstein, Lehert, Burger, & Guthrie, 2005; Gyllstrom, Schreiner, & Harlow, 2007). During the menopausal transition, women may also have various health and mental symptoms, including hot flashes, night sweats, vaginal dryness, sleep disturbance and depression (Dennerstein, 1996; Judd, Hickey, &

Bryant, 2012; Soares, 2008; Vivian-Taylor & Hickey, 2014). These symptoms are not independent but interrelated, and in particular, depression is known to co-occur with other symptoms such as sleep disruption and hot flashes (Soares, 2008). Importantly, apart from the physiological features of menopause, the attitudes of women in menopause towards aging, sextual and family relationships are variously dependent on the social and cultural contexts surrounding them (Manderson, 2005).

1.2 Perception, cognition and behaviour according to the menstrual cycle and menopause

Many studies have shown that hormonal changes during the menstrual cycle and menopause could modulate perception, cognition and behaviour of women, although the methods and results showed some variation. For instance, during the menstrual cycle, some women showed better performance in visual sensitivity such as processing of asymmetries and space and the Stroop effect in the luteal phase (Bibawi, Cherry, & Hellige, 1995; McCourt, Mark, Radonovich, Willison, & Freeman, 1997), while other women showed better performance in the menstrual phase (Hampson, 1990; Hatta & Nagaya, 2009; Phillips & Silverman, 1997). Women can also detect and remember facial expressions better in the follicular phase than in the luteal phase (Derntl, Windischberger, et al., 2008; Derntl, Kryspin-Exner, Fernbach, Moser, & Habel, 2008). Moreover, near ovulation, women are more likely to choose men with a masculine face (Gangestad, Simpson, Cousins, Garver-Apgar, & Christensen, 2004; Johnston, Hagel, Franklin, & Fink, 2001; Penton-Voak et al., 1999). Regarding behaviour, some studies reported that women have different behaviours particularly near ovulation, when they join social gatherings to see people more frequently, wear sexier clothes, use and choose more cosmetics and products related to enhancing their attractiveness, in order to attract men, and possibly compete against other women (Durante, Griskevicius, Hill, Perilloux, & Li, 2011; Durante, Li, & Haselton, 2008; Grammer, Renninger, & Fischer, 2004; Guéguen, 2012; Haselton & Miller, 2006).

Perceptual and cognitive functioning of women in menopause can vary through the menopausal transition, and some women experience functional declines. Regarding visual perception, for example, women in menopause showed delayed reaction times in stimulus-response tasks such as a driving simulation task, flicker fusion task and spatial orientation task (Halbreich et al., 1995; Zilberman et al., 2015). Regarding cognitive functioning, many studies suggested that women's verbal fluency had been declined during the menopausal transition (Berent-Spillson et al., 2012; Laughlin, Kritz-Silverstein, & Barrett-Connor, 2010). Menopausal women also have difficulties in memory, such as remembering words, numbers and names of people, while women who had hormonal therapy showed better performance in verbal memory (Sullivan Mitchell & Fugate Woods, 2001; Wroolie et al., 2011). On the other hand, there are some studies that revealed no significant differences in memory according to hormonal changes (Henderson & Popat, 2011; Kocoska-Maras et al., 2011). It is also known that women in peri- and post-menopause have changes in facial preference, with these women preferring more feminine-like or less masculine faces of men (Jones, Vukovic, Little, Roberts, & DeBruine, 2011; Little et al., 2010). These findings suggest possible variation in perception and cognition due to menopause in women.

1.3 Perception, cognition and behaviour related to colour

Many of the published studies about colour perception, cognition and social behaviour of women during the menstrual cycle focused on cognitive and behavioural examinations rather than perception. Only a few studies revealed that women discriminated and perceived colours better in the ovulation phase than in any other phases, and showed that the use of hormonal contraceptives may negatively affect sensitivity of colour perception (Barris, Dawson, & Theiss, 1980; Da Silva, Anfe, Matos, & Vieira, 2015; Diamond, Diamond, & Mast, 1972; Giuffrè, Di Rosa, & Fiorino, 2006). Regarding colour perception in women during the menstrual cycle, an association between female hormones and the function of the short-wavelength cones has been mentioned. The sensitivity of the short-wavelength cones to light at the peak near 450 nm is fundamentally associated with perception of bluish colours (Baylor, 1995). In the luteal phase during the menstrual cycle, the sensitivity to short-wavelength light may be decreased (Akar, Yucel, Akar, Taskin, & Ozer, 2005; Apaydin, Akar, Akar, Zorlu, & Ozer, 2004), although the results seemed to vary according to the individuals (Eisner, Burke, & Toomey, 2004). The presence of estrogen receptors in the retina is known, but their function has not been clarified (Munaut et al., 2001; Ogueta, Schwartz, Yamashita, & Farber, 1999; Wickham et al., 2000).

Regarding cognitive and behavioural variations during the menstrual cycle, women are more likely to have specific colour preferences and choices according to the cycle. Many studies suggest that women prefer warm colours such as red and pink and choose clothes with these colours in the luteal phase or near ovulation phase (Beall & Tracy, 2013; Elliot, Greitemeyer, & Pazda, 2013; Elliot & Pazda, 2012; Kim & Tokura, 1997). These colour preference and choices could be related to women's reproductive strategy. The ovulation phase during the menstrual cycle is the peak period of reproductive fertility, and it is particularly important then women to attract men for mating (Makhanova & Miller, 2013; Wilcox, Weinberg, & Baird, 1995). Thus, women manipulate colours, such as red and pink, for attraction of men as one of the reproductive strategies, and men can also be more attracted by women of reproductive age with a red background or shirt compared with women with a white background and shirt (Pazda, Elliot, & Greitemeyer, 2012; Schwarz & Singer, 2013).

Compared with the evidence about colour perception and cognition of women in the menstrual cycle, such perception and cognition in menopausal women have not been well studied and have remained unclear. However, recent studies revealed that hormonal changes in menopause also affect dysfunction of the short-wavelength sensitivity, and that this sensitivity declines according to the menstrual cycle. For example, healthy peri- and post-menopausal women named the stimulus colour of 440 nm as lavender, from three possible colour choices, either blue, lavender or white (Eisner & Toomey, 2008). In the same experiments, middle-aged women who used tamoxifen to modulate the estrogen receptor answered the stimulus colour as white at a higher rate than women who used tamoxifen for a short term (Eisner, Austin, & Samples, 2004; Eisner & Incognito, 2006). Peri- or post-menopausal women who consumed food rich in phyto-estrogen performed better in tests of visual sensitivity to short-wavelength light than women who did not consume it (Eisner & Demirel, 2011). Hormonal changes in menopause could be related to colour perception, particularly to perception of bluish colours processed by the short-wavelength cones.

1.4 Odour perception

Association between odour perception and the menstrual cycle has been studied for a long time, and some studies revealed cyclic variations in odour perception, while other studies showed no clear relationship. For example, women had lower sensitivity of odour perception near the time of ovulation than during the menstrual phase, but the opposite results were also reported, showing higher sensitivity in the ovulation phase (Doty, Snyder, Huggins, & Lowry, 1981; Navarrete-Palacios, Hudson, Reyes-Guerrero, & Guevara-Guzmán, 2003; Nováková, Havlíček, & Roberts, 2014; Pause, Sojka, Krauel, Fehm-Wolfsdorf, & Ferstl, 1996). In addition, modulation of odour sensitivity seemed to depend on the type of odour and women's fertility status. In the ovulation phase, women who had a regular menstrual cycle and fertility were more sensitive to androstenone, androsterone and musk than women using oral contraceptives (Renfro & Hoffmann, 2013). Lundström et al. (2006) also used two types of odour: rose (phenyl-ethyl alcohol), defined as an environmental odour, and androstadienone, found in the sweat, urine and semen of men and defined as a social odour, in order to compare women's sensitivities, and the results revealed that women using oral contraceptives or in a non-fertile phase tended to be more sensitive to the environmental odour than to the social odour, while women in the fertile phase showed the opposite results. Although the results have shown some variations, overall, they indicate that the menstrual cycle could be related to olfactory perception, and it may play a role in women's reproductive strategy.

Menopausal women who are aged are more likely to experience olfactory dysfunction. Many studies showed that aged people had dysfunction of olfactory sensing, and reported that these olfactory deficits might be associated with other diseases and disorders such as Alzheimer's disease and Parkinson's disease (Koskinen, Vento, Malmberg, & Tuorila, 2004; Kovács, 2004; Murphy et al., 2002). Olfactory function could also be associated with hormonal changes during menopause, and these changes might affect nasal airflow and odour detection thresholds (Pouliot, Bourgeat, Barkat, Rouby, & Bensafi, 2008). Menopausal women, after they had had hormone replacement therapy for a certain period, showed improvement of their odour detection threshold (Caruso et al., 2004; Doty et al., 2015). Thus, hormonal changes during menopause may influence women's olfactory perception.

1.5 Cross-modal correspondence between colour and odour

Humans often use more than two different types of sensory modality simultaneously, relating two different types of information, such as taste and smell. These cross-modal or multimodal correspondences, often known as synaesthesia, have been studied, and many studies focused on visual and auditory correspondence (e.g., Baron-Cohen, Harrison, Goldstein, & Wyke, 1993; Baron-Cohen, Burt, Smith-Laittan, Harrison, & Bolton, 1996; Hubbard, Arman, Ramachandran, & Boynton, 2005; Maurer, Pathman, & Mondloch, 2006; Nunn et al., 2002; Ramachandran & Hubbard, 2001). Synaesthesia had been thought to be a specific phenomenon affecting only 1-2% of the population (Maurer et al., 2006). However, some studies showed that cross-modal correspondences were common phenomena regardless of age differences, such as the example of bouba/kiki in sound-shape correspondences (Maurer et al., 2006; Ramachandran & Hubbard, 2001).

Except for visual and auditory correspondence, the results of studies about correspondences of other types of sensory modality have not been clear. However, some studies revealed colour-odour cross-modal correspondence, that is, humans are known to relate specific colours to specific odours, and these associations were reported to depend on the intensity of the odour (e.g., stronger odours are often associated with darker colours) (Gilbert, Martin, & Kemp, 1996; Kemp & Gilbert, 1997; Zellner & Kautz, 1990; Zellner & Whitten, 1999). Another recent study showed a model of associations between colours and odours based on systematic data for many types of odours, such as spices, herbs and aromatic oils, in order to understand how humans fundamentally relate colours with odours (Miura & Saito, 2012a, 2012b; Saito, 2016). However, as in the case of the bouba/kiki phenomenon, whether these cross-modal correspondences between colour and odour are commonly found for different groups such as groups based on age, sex and culture, or not has remained unknown.

1.6 Scope of this thesis

A variety of evidence has shown various modulations of perception, cognition and behaviour for women according to hormonal changes both in the menstrual cycle and menopause. However, the results can vary depending on differences of research methods, and possibly depending on individual differences. Many studies have strongly focused on particular research topics; for example, there have been many studies of colour preference of women in the menstrual cycle, while colour perception in the menstrual cycle has remained unclear. Similarly, colour perception of menopausal women needs to be examined by various methods, including psychological experiments examining behaviour. Regarding cross-modal correspondences, some studies showed fundamental associations between colour and odour. On the other hand, whether these cross-modal correspondences can be commonly examined for different groups such as age or sex groups has not been studied. As shown in previous studies, women could have hormonal modulations of colour and odour perception and cognition. Thus, these perceptual and cognitive modulations could influence cross-modal correspondences.

In the present studies, the author examined how perception and cognition of, and cross-modal correspondence between, colour and odour could vary according to hormonal changes both in the menstrual cycle and menopause. Women fundamentally have various physical and mental symptoms, and deficit in perception and cognition according to female hormone changes, and some women suffer from these disorders greatly in their social lives. Therefore, it will be necessary to understand variation of perceptual and cognitive functioning, and physical and mental conditions according to female hormones and consider how women get along with these changes through their lives. Moreover, colour and odour are often used for therapy, so understanding of perception and cognition regarding colour and odour, and these cross-modal correspondence for women in the menstrual cycle and menopause may provide one of the effective methods to reduce influences of female hormone related disorders.

Based on the available evidence about women in the menstrual cycle and menopause, the author hypothesised that female hormones could modulate women's colour and odour perception and cognition, and cross-modal correspondence could also differ according to hormonal changes in the menstrual cycle and menopause. The author predicted that when hormonal levels were low, women's performance would decline.

In order to understand the influence of the menstrual cycle and menopause, the author performed the same experiments in both groups of women: the menstrual group and menopause group. The experiments included administering several tasks: a colour perception task using face and scrambled face stimuli, an evaluation of colour and odour impression task, a matching/nonmatching task in which participants chose suitable or unsuitable colours for odours, and an odour identification task. In Chapter 2, the author reports an experiment examining colour perception of women in the menstrual cycle. Chapter 3 is a report of the same experiment examining women in menopause. In these two chapters, the author discusses how hormonal changes, the menstrual cycle and menopause, could influence women's colour perception. Chapter 4 focuses on the experiments employing a series of tasks: evaluation of colour and odour impressions task, matching/nonmatching task and odour identification task performed by women during the menstrual cycle, and Chapter 5 includes a report of the same experiments in Chapter 4, with tasks performed by women in menopause. These two chapters look at cognitive features of colour and odour, and the impressions of women regarding colours and odours, and discuss about cross-modal correspondences between colour and odour. An odour identification task is also reported. Finally, in Chapter 6, the author summarises the above studies in Chapters 2 to 5, and discuss perceptual and cognitive features, and cross-modal correspondences between colour and odour according to the menstrual cycle and menopause.

All studies in this thesis were conducted in accordance with the Guidelines for Research in Human Participants, issued by the Human Research Ethics Committee of the Primate Research Institute, Kyoto University. The experimental protocol was approved by the Committee (Permit No.2017-05). The author obtained a signed consent from all participants before the experiments were started.

Chapter 2

Modulation of Visual Perception during the Menstrual Cycle: Comparison between the Menstrual and Ovulation Phases

Abstract

Women have changes in visual perception and cognition according to changes of female hormones during the menstrual cycle. There are many studies about these perceptual and cognitive changes, including colour perception changes, but various results have remained inconsistent. Here the author experimentally investigated visual perception of women in the menstrual compared to the ovulation phases by having the women perform colour judgment tasks. In the tasks, participants answered the colours (either red, yellow or blue) of three types of face stimuli (happy, neutral or sad) and corresponding scrambled face stimuli by pressing buttons, and we recorded participants' reaction times. The author also examined whether emotional facial expressions interfered with colour judgment reactions. The results showed that women reacted to the stimuli significantly more slowly near ovulation than during the menstrual phase. The scrambled face stimuli task particularly showed interaction effects, and participants showed no differences in reaction time only for happy scrambled shape and red between the phases. Thus, participants might give stronger attentions to faces with colours in the menstrual phase than in the ovulation phase, and attentions to scrambled face shapes might become weaker in the menstrual phase.

Keywords: visual perception, colour, emotional facial expression, menstrual cycle

2.1 Introduction

Female hormones, perception and cognition

Women often experience various changes in perception, cognition and behaviour caused by changes in female hormone levels during the menstrual cycle. This cycle typically occupies about 28 days cycle, and ovulation occurs at about 14 days prior to the beginning of the next menstruation, although the length of one regular cycle depends on the individuals and her health conditions (Makhanova & Miller, 2013). Regarding evolutionary aspects, women near the time of ovulation have higher reproductive fertility, and they show changes in social behaviour, such as more frequent attendance at social meetings, use of cosmetics and choices of products to enhance their appearance to attract men (Durante et al., 2011; Guéguen, 2012; Haselton & Miller, 2006). Regarding perceptual and cognitive functioning, women show various differences of performance of visual processing of asymmetries, visual-spatial tasks and the Stroop task at different times during the menstrual cycle. Some studies revealed better performance in these tasks in the luteal phase (Bibawi et al., 1995; McCourt et al., 1997), while other studies showed better performance in the menstrual phase (Hampson, 1990; Hatta & Nagaya, 2009). In addition, women were reported to have lower sensitivity of olfactory perception near the time of ovulation (Navarrete-Palacios et al., 2003), but some studies found higher sensitivity in the ovulation phase or no clear differences during the course of the menstrual cycle (Nováková et al., 2014; Pause et al., 1996). These findings suggest that there is a relationship between the menstrual cycle and perceptual and cognitive functions, and that the sensitivities of various different functions show different tendencies during the cycle. However, there does not seem to be a consistent pattern among the sensitivities reported thus far.

Colour perception and cognition

Perception and cognition, particularly of colours, may also change during the menstrual cycle. For example, women using hormonal contraceptives have lower ability of colour perception (Da Silva et al., 2015), and at ovulation, women perform better in a colour discrimination task (Giuffrè et al., 2006). In addition, visual perception of the short-wavelength (bluish colours) could be affected by hormonal changes, and the sensitivity for perceiving these colours seems to decline in the luteal phase (Akar et al., 2005; Apaydin et al., 2004). Regarding cognitive and social behavioural aspects such as colour preference, a number of studies revealed that women prefer warmer colours, especially red or pink, in the ovulatory phase at the peak fertility, and wear clothes with these colours, and this might be part of women's strategy to enhance their reproduction by making themselves look more attractive to men (Beall & Tracy, 2013; Elliot, Greitemeyer, et al., 2013; Elliot & Pazda, 2012). These findings suggest that hormonal changes during the menstrual cycle affect colour perception, and women also have specific preferences and social behaviour regarding colours that may be related to fertility.

Emotional facial expressions

Regarding facial preference and perception of emotional facial expressions, women can be influenced according to female hormone changes. At the time of ovulation, women are likely to prefer masculine faces of men (Gangestad et al., 2004; Penton-Voak et al., 1999). Regarding emotional facial expressions, women are able to detect and remember facial expressions better in the follicular phase than the luteal phase (Derntl, Windischberger, et al., 2008; Derntl, Kryspin-Exner, et al., 2008), but women have difficulties in perceiving or remembering expressions such as disgust, sadness and fear in the follicular phase (Conway et al., 2007; Gasbarri et al., 2008). However, some studies showed different results, in which women showed no difference in preference for masculine faces of men during ovulation (Harris, 2011), and they showed a delayed response when answering emotional facial expressions in a working memory task during the follicular phase (Gasbarri et al., 2008). During the menstrual cycle, female hormones could affect facial preference and perception of emotional facial expressions, but these influences still seem to be controversial.

Here the author experimentally examined whether colour perception is influenced by hormonal changes during the menstrual cycle by testing women's performance in the colour judgment task with stimuli including emotional facial expressions. The author predicted that task performance of participants would decline when they were in the menstrual phase with lower hormonal levels compared to when they were in the ovulation phase with higher levels. Moreover, colours are often associated with specific emotional facial expressions (e.g., a happy face with yellow or a sad face with blue) (F. Takahashi & Kawabata, 2018; Thorstenson, Elliot, Pazda, Perrett, & Xiao, 2018), so the author hypothesised that when judging colours, participants' responses could be affected by facial expressions, particularly when these colours and facial expressions were incongruent, and that the responses could also be differ between the menstrual phase and ovulation phase.

2.2 Materials and methods

Ethics

The author carried out all experiments in accordance with the Guidelines for Research in Human Participants, issued by the Human Research Ethics Committee of Primate

Research Institute, Kyoto University, and the experimental protocol was approved by the Committee (Permit No.2017-05). Before the experiments, the author obtained a signed consent form from all participants.

Participants

Twenty-six female university undergraduate and postgraduate students (mean with standard deviation of ages: 21.62 +/- 1.499 yrs, range 20-24 yrs) participated in the experiments, and they had regular menstrual cycles and recorded each starting date of menstruation (mean with standard deviation of menstrual cycle: 29.73 +/- 2.82 days) without taking contraceptive or hormonal medicine. After receiving consent for the participation, the author asked all participants about their menstrual cycle history for the past several months. Based on these records, the author calculated the next starting date of a menstrual period, and the approximate date of ovulation, which is about 14 days before the next starting date of a menstrual period. Each participant joined the experiments twice, namely, on a date within 4 days from the beginning of a menstrual period, and on a date within 3 days from the estimated date for ovulation. According to participants' menstrual cycle, some participants participated in the first experiment at the beginning of a menstrual period and the second experiment during the ovulation period, and others participated in the opposite order. After the experiments, particularly at the time of ovulation, the author asked all participants to inform us of the next start date of the menstrual period in order to confirm the estimated ovulation date. Fifteen out of 26 participants participated in experiments earlier or later than the first 4 days from the start of the menstrual period, or more than 3 days earlier or later than the calculated time of ovulation, so the author excluded the data of these participants from the analysis. The remaining 11 participants participated in the experiments twice: on dates within the first 4 days from the start of the menstrual period and on the calculated ovulation dates without a shift of more than 3 days from the estimated ovulation time, and the author carried out the analysis using the data of these 11 participants (age: 22.00 +/- 1.67 yrs, range: 20-24 yrs, menstrual cycle: 30.55 days +/- 2.50 days). All participants were Japanese, and they had no cognitive disorder tested by the Raven Coloured Progressive Matrices or colour blindness tested by the Ishihara Color Vision Test.

Stimuli

The author used simple cartoon depictions of faces as social stimuli and scrambled faces as non-social stimuli. These face stimuli had three types of emotional expressions: happy, neutral or sad, and each type of face was scrambled to produce the three types of scrambled face stimuli, respectively (Figure 2-1). Each stimulus was shown with either one of three colours: red, yellow or blue. All stimuli were converted to a size fitted in 250 x 250 pixels.

Apparatus

The author used a table computer with a custom-made program written with OpenSesame software ver. 3.1.6 (Mathôt, 2010-2016) in Microsoft Surface Pro 2 for all tasks in the experiments, and a USB keypad that was connected to the tablet. Participants pressed one of the buttons on the keypad to indicate their judgement of the colours of face or scrambled face stimuli, and their response times were recorded on the keypad during the tasks.

Procedure

In the experiments, participants sat in front of the Surface screen (the resolution: 1920 x 1080 pixels) and the keypad on a desk. In a single trial, first, a fixation dot with 8 pixels radius appeared at the centre of the screen on a grey background. After 0.5-1.5 seconds, the fixation dot disappeared, and one of either a happy, neutral or sad stimulus appeared at the centre of the screen. Then participants judged the colour (either red, yellow or blue) of the stimulus by pressing one of the three buttons of the keypad, which corresponded with the colour, using their right hand. The positions of buttons were counterbalanced for each participant. After participants responded, the next trial was automatically started. The experiment included an initial practice, and then the main phases. The main phases had 81 trials in total. During the main phases, three types of stimuli, happy, neutral and sad, appeared randomly in any one of three colours, red, yellow or blue, 9 times for each (3 stimulus types x 3 colours x 9 times). All participants were required to perform both face stimuli and scrambled face stimuli tasks, and a total trial consisted of 162 trials (81 trials x 2 tasks). The author recorded all the reaction times of the keypad presses during the experiments.

Analysis

The participants' reaction times were analysed by analysis of repeated measurements based on linear mixed models in SPSS ver. 25. The author set the repeated conditions of participants (menstrual phase or ovulation phase), the stimulus type (happy, neutral or sad) and the colour (red, yellow or blue) with their interaction effect terms (condition x stimulus type x colour) as the fixed main effect terms, and participant ID was a random effect term. When the author observed a significant interaction effect, as a post-hoc comparison, the author computed the 95% confidence intervals of the estimated marginal means between two comparison levels for each level of the other condition, and examined whether the two levels differed significantly.

2.3 Results

The author tested women's performance in the colour judgement task with stimuli including emotional facial expressions, and conducted an analysis of repeated measurements based on linear mixed models. As a result, the author found a statistically significant difference in reaction time in the face stimuli task between participants in the menstrual phase and ovulation phase ($F_{1,\ 1647.062}$ = 11.768, P = 0.001, partial η^2 = 0.062 Table 2-1, Figure 2-2). Participants tended to respond to the stimuli faster in the menstrual phase than in the ovulation phase. However, no interaction effects were found between conditions, stimuli types and colours. A similar pattern appeared in the scrambled face stimuli task, namely, participants responded to stimuli faster in the menstrual phase than the ovulation phase, and a statistically significant difference in reaction time was found between the menstrual phase and ovulation phase ($F_{1,\ 1637.106}$ = 14.351, P = 0.000, partial η^2 = 0.063 Table 2-2, Figure 2-3). However, in the scrambled face stimuli task, the author also found interaction effects between conditions of participants and stimuli types ($F_{2,\ 1637.097}$ = 4.505, P = 0.011, partial η^2 = 0.038), and between conditions and colours ($F_{2,\ 1637.056}$ = 3.400, P = 0.034, partial η^2 = 0.031).

Comparing reaction times among colours, in the face stimuli task it was found that participants in both the menstrual phase and ovulation phase tended to respond to blue more slowly than to red and yellow, although there were no statistically significant differences in reaction times to different colours. In the scrambled face stimuli task, for the happy scrambled shape the reaction times were similar between the menstrual phase and ovulation phase, while for the other two shapes (neutral and sad scrambled) the reaction times were faster in the menstrual phase than in the ovulation phase. Moreover, reaction times to red in the scrambled face stimuli task showed no differences between conditions, while those to yellow and blue were slower in the ovulation phase than in the menstrual phase.

2.4 Discussion

The results showed clear differences in reaction times between the menstrual phase and ovulation phase. Participants responded to stimuli more quickly when they were in the menstrual cycle than when they were near the ovulation period, in both face stimuli and scrambled face stimuli tasks. These results disagreed with the author’s prediction that performance would be better during ovulation than during menstruation. Moreover, in disagreement with the author’s hypothesis, in the face stimuli task, participants did not show significant differences in reaction time according to the types of stimuli with different facial expressions (happy, neutral or sad) or colours (red, yellow or blue) between the menstrual phase and ovulation phase. However, in the scrambled face stimuli task, the results were different from those in the face stimuli task. The reaction times to happy scrambled face stimuli and to red colour did not show differences between the menstrual and ovulation phases, while the reaction times to other stimuli types and colours were faster in the menstrual phase than the ovulation phase. These differences of the results between the face and scrambled face stimuli tasks might suggest that participants in the menstrual phase had more attention to colours with emotional facial expressions, but less attention to colours with meaningless scrambled shapes. Participants should have focused on both colours and stimuli types, but the proportion of their attention might vary according to the menstrual cycle condition and stimuli types depending on whether the stimuli were either meaningful or meaningless information.

Visual perception

Many previous studies showed changes in visual perception during the menstrual cycle, although these changes varied according to the different tasks performed in the studies. The author's findings here revealed that women had faster reaction times for colour judgment in the menstrual phase than the ovulation phase. In some other studies, women in the menstrual phase, whose levels of female hormones were relatively low, had better performance in processing of spatially related stimuli such as asymmetries and blocks (Hampson, 1990; Hausmann, Becker, Gather, & Güntürkün, 2002; Hausmann & Güntürkün, 2000; Phillips & Silverman, 1997). A higher level of the female hormone estrogen might be related to a decline in performance of visual-spatial tasks (Hausmann, Slabbekoorn, Van Goozen, Cohen-Kettenis, & Gunturkun, 2000), and performance in the Stroop task also seemed to vary according to the levels of estrogen (Hatta & Nagaya, 2009). Thus, participants in the experiments might also have had the same tendencies, in which their reaction times in visual tasks were faster in the menstrual phase than in the ovulation phase, and visual perception might be related to changes of estrogen level during the menstrual cycle.

Colour perception

Visual sensitivity, particularly colour sensitivity, in women during the menstrual cycle also seems to be related to changes of female hormone levels (Barris et al., 1980; Eisner et al., 2004), and such a relationship was also found for colour discrimination (Giuffrè et al., 2006). Several studies revealed that hormonal changes could be related to perception of short-wavelength light, with a decline of bluish colour sensitivity in the luteal phase, several days before the beginning of menstruation, when the estrogen level was decreased (Akar et al., 2005; Apaydin et al., 2004). The same phenomena were also reported in different conditions, such as menopausal transition, use of contraceptives, and consumption of estrogen-rich food, according to the level of estrogen (Eisner & Demirel, 2011; Eisner & Incognito, 2006; Eisner & Toomey, 2008). Thus, female hormones, particularly decreases of the level of estrogen, might affect bluish colour perception, and sensitivity to blue could decline according to decreases of the estrogen level, although individual differences may possibly influence these sensitivities. In the experiments, at menstruation there are the lowest levels of estrogen and progesterone, and at ovulation there is a gradual decline of estrogen level. Thus, participants' reactions to blue might decline and become less sensitive in these phases according to the theory of the relationship between hormone levels and visual sensitivity of the short-wavelength cones. The results in the scrambled face stimuli task only showed interaction effects between the conditions and red colour, which indicates that there was no difference in reaction time to red between the conditions. However, apart from these effects, participants reacted slightly faster to red (fastest), than to yellow and blue (slowest) on average in both the face and scrambled face stimuli tasks. Clarifying the relationship between female hormones and colour perception will require more detailed studies considering individual differences and hormonal conditions, but the results obtained thus far support the possibility that a decline in sensitivity to bluish colour may be related to low levels of estrogen.

Emotional facial expressions

It is fundamental for us to recognise emotional facial expressions in social life, and it is known that women are more accurate and sensitive in detecting facial expressions than men (Donges, Kersting, & Suslow, 2012; Hoffmann, Kessler, Eppel, Rukavina, & Traue, 2010; Sawada et al., 2014). However, women's perception of emotional facial expressions seems to vary according to female hormone changes. For instance, women in the follicular phase detect and remember emotional facial expressions better than women in the luteal phase (Derntl, Windischberger, et al., 2008; Derntl, Kryspin-Exner, et al., 2008), but they may have difficulties in perceiving specific expressions such as disgust and sadness in the follicular phase (Conway et al., 2007; Gasbarri et al., 2008). However, opposite results, such as delays of a response in the follicular phase have also been reported (Gasbarri et al., 2008). In the present studies, the author's findings showed no differences in reaction times or interference with colour judgement by different types of emotional facial expressions in either the menstrual phase or ovulation phase, and effects of emotional facial expressions may have been small. However, comparing the results obtained here between the menstrual and ovulation phases in the scrambled face stimuli task, only the happy scrambled face did not show any differences in reaction time between the participants' conditions. This may imply that participants tended to have greater attention to facial expressions with colours in the menstrual phases than the ovulation phase, but that attention to meaningless shapes with colours, particularly happy scrambled face in this study, might not differ between the two phases. In sum, the proportion of participants' attentions to stimuli types and colours may vary according to the menstrual cycle phase and the information in stimuli (either meaningful or meaningless). However, in this experiment design, participants simply focused on colours rather than emotional facial expressions, and the author used not real faces but iconic faces. Thus, the sensitivity to the icons may have been less affected by hormonal changes, and the icons may not have strongly influenced colour judgment. It will be necessary to re-examine the relationship between emotional facial expressions using real faces, colours and hormonal changes.

2.5 Conclusions

In conclusion, women showed different reaction times in a colour discrimination task depending on whether they were in the menstrual or ovulation phase, and their reaction times were significantly slower in the ovulation phase. Participants also reacted to blue more slowly on average in both the menstrual and ovulation phases, possibly according to the low level of estrogen. Emotional facial expressions did not interfere with the reactions to colours, while the results in the scrambled face stimuli task may suggest that participants had stronger attention to faces with colours in the menstrual phase than the ovulation phase, but not to scrambled shapes with colours. Changes in visual perception, including colour perception, caused by female hormones have remained controversial as many different methodologies have produced various results, but the author's results suggested a relationship between visual perception and hormonal changes during the menstrual cycle, implying a possible association of hormonal changes with a decline in the short-wavelength sensitivity and with facial expressions. In further studies, the author would like to examine changes in colour perception, particularly perception of bluish colours, and facial expressions using real human faces, by increasing the number of experimental time points within one menstrual cycle in order to fully reflect the increases and decreases of female hormones.

Acknowledgements

The author would like to thank all participants at Japan Women's University and the Primate Research Institute who joined the experiments conducted from October 2017 to March 2018. The author also thanks Elizabeth Nakajima for English proofreading of this paper.

Tables

Source	df	F	p-value	effect size	
Condition (menstrual/ovulation)	1, 1647.062	11.768	0.001	0.062	**
Stimuli type (happy/neutral/sad)	2, 1647.018	0.074	0.928	0.000	
Colour (red/yellow/blue)	2, 1647.024	0.215	0.807	0.016	
Condition x Stimuli type	2, 1647.016	0.134	0.874	0.002	
Condition x Colour	2, 1647.019	0.117	0.890	0.001	
Stimuli type x Colour	4, 1647.027	1.078	0.366	0.009	
Condition x Stimuli type x Colour	4, 1647.039	1.837	0.119	0.041	

*p < .05, **p < .01, ***p < .001

Table 2-1. Statistical results of linear mixed model analysis on the face stimuli task

Source	df	F	p-value	effect size	
Condition (menstrual/ovulation)	1, 1637.106	14.351	0.000	0.063	***
Stimuli type (happy/neutral/sad)	2, 1637.101	3.869	0.021	0.002	*
Colour (red/yellow/blue)	2, 1637.060	2.036	0.131	0.019	
Condition x Stimuli type	2, 1637.097	4.505	0.011	0.038	*
Condition x Colour	2, 1637.056	3.400	0.034	0.031	*
Stimuli type x Colour	4, 1637.079	0.570	0.684	0.009	
Condition x Stimuli type x Colour	4, 1637.093	0.781	0.537	0.018	

*p < .05, **p < .01, ***p < .001

Table 2-2. Statistical results of linear mixed model analysis on the scrambled face stimuli task

Figures

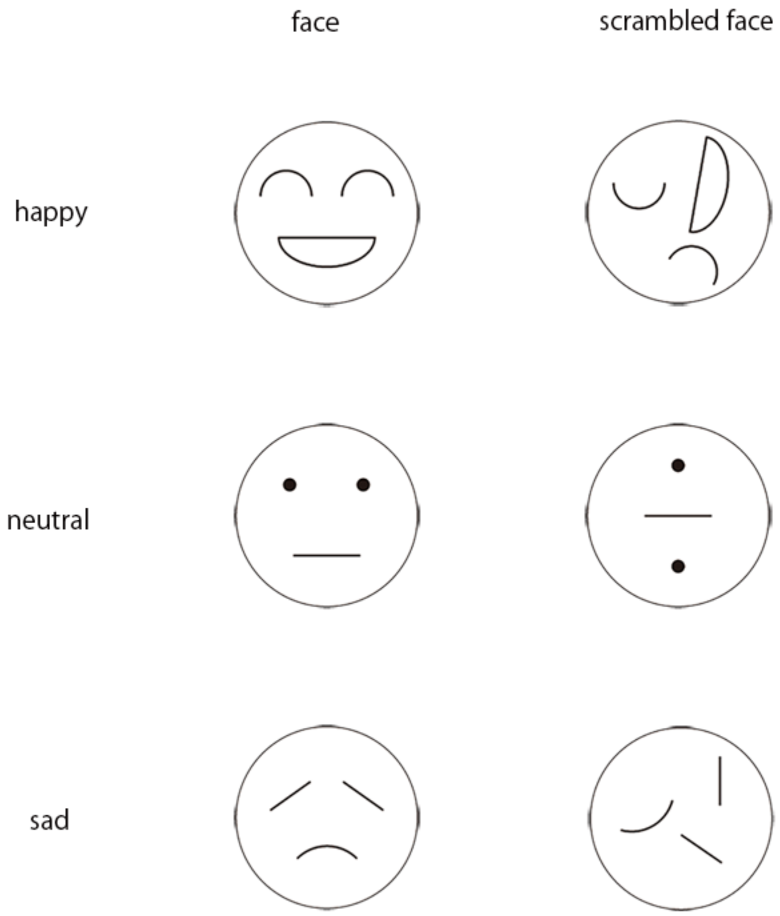

Figure 2-1. Types of stimuli: emotional face expressions included happy, neutral and sad (left), and scrambled stimuli contained their scrambled elements (right).

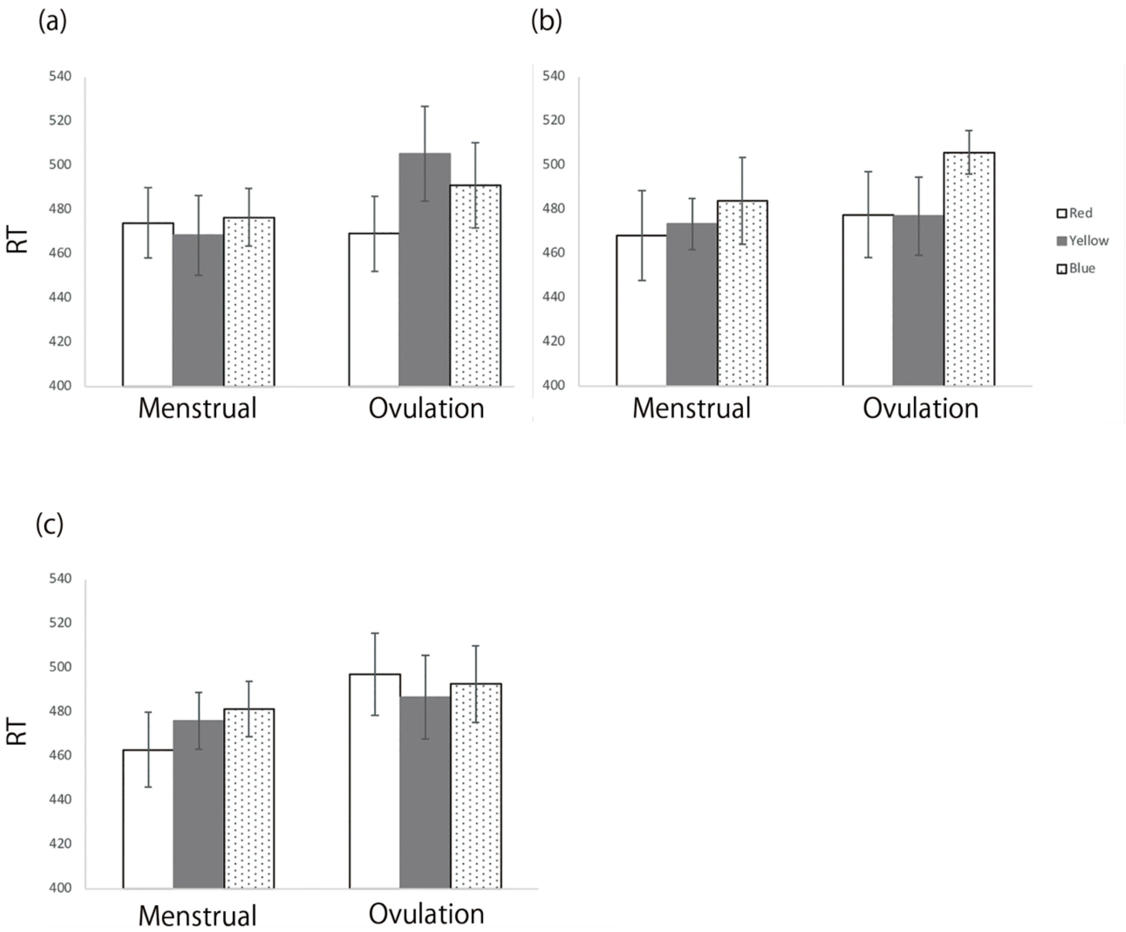

Figure 2-2. Reaction time (msec) in the face stimuli task with participants in menstrual phase (left) and ovulation phase (right) according to stimulus colour and type. Graph (a) shows reaction times to happy face, graph (b) shows those to neutral face, and graph (c) shows those to sad face. In these graphs, bars indicate the colour of each stimulus: white bar for red, grey bar for yellow and black-dotted bar for blue.

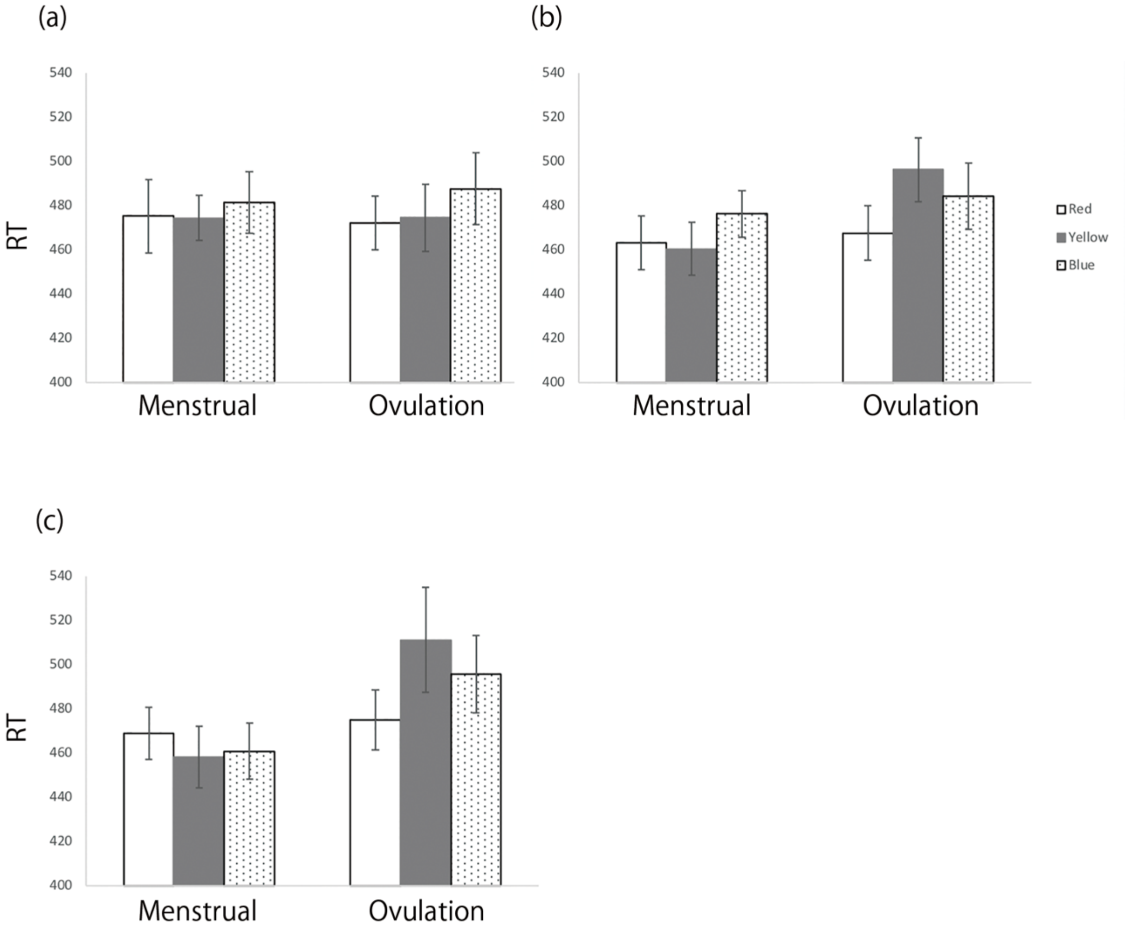

Figure 2-3. Reaction time (msec) in the scrambled face stimuli task with participants in menstrual phase (left) and ovulation phase (right) according to stimulus colour and type. Graph (a) shows reaction times to happy scrambled shape, graph (b) shows those to neutral scrambled shape, and graph (c) shows those to sad scrambled shape. In these graphs, bars indicated the colour of each stimulus: white bar for red, grey bar for yellow and black-dotted bar for blue.

Chapter 3

Colour Perception Characteristics of Women in Menopause

Abstract

Female hormones affect perception, cognition and mental condition of women in the menstrual cycle and menopause. However, how menopause affects colour perception, and whether mental condition, especially depression, is related to colour perception remain unclear. Here, the author investigated the influences of menopause on colour perception, recording the response times to three types of face and scrambled face stimuli: happy, neutral and sad, with three colours: red, yellow and blue. The author predicted that colour perception of participants would be interfered with and delayed by emotional facial expression, as emotional facial expressions are connected with specific colours. The author also examined depression states in women using the Center for Epidemiologic Studies Depression Scale (CES-D Scale) to understand the relationship between colour perception and depression. Fifty-nine female participants participated in the experiments. The author analysed the data of 23 pre-menopausal and 20 post-menopausal participants. The results showed that the pre-menopausal women reacted to all stimuli faster than the post-menopausal women, and the post-menopausal women reacted to only blue significantly more slowly than to the other colours. Colour perception had no clear association with reaction time to emotional facial expression or with depression. The results suggest that menopause could influence colour perception of women as one of the possible factors, as well as aging, with such influence, and imply that the perceptual differences of blue between pre- and post-menopausal women result from a deficit in short wavelength sensitivity cones possibly caused by menopause-associated hormonal changes.

Keywords: visual perception, colour, menopause, emotional facial expression, depression

3.1 Introduction

Women's health condition is strongly affected by female hormones (e.g., estrogen and progesterone) during the menstrual cycle and menopause. In particular, women in menopausal transition tend to suffer from vasomotor symptoms including hot flashes and night sweats, vaginal dryness and sleep disturbance (Judd et al., 2012). Many studies have also suggested that women could experience changes in perception, cognitive function (such as general cognitive ability, emotional cognition, memory, concentration, and visual sensitivity), and mental condition during menopausal transition. For example, some studies showed that women who entered menopause might have decreased visual-perception abilities (Rosic, Rosic, Samardzic, & Kendic, 2014) and a great acceleration in the age-related decline of functioning in cognitive tests such as driving simulation and reaction time (Halbreich et al., 1995) and verbal fluency and memory for words and stories (Berent-Spillson et al., 2012; Maki, 2015). In contrast, some studies showed that menopause did not strongly affect visual search speed or concentration (Kok, Helen S.; Kuh, Diana; Cooper, Rachel; van der Schouw, Yvonne T.; Grobbee, Diederick E.; Wadsworth, Michael E. J. and Richards, 2006) and had no clear relationship with visual cognitive functioning (Berent-Spillson et al., 2012). Thus, the results varied depending on the study and have therefore remained controversial.

Female hormones also influence colour perception in women. During the ovulatory period in the peak of estrogen secretion, women have better colour discrimination (Giuffrè et al., 2006), while women who use hormonal contraceptives usually have lower colour perception (Da Silva et al., 2015). In the luteal phase during the menstrual cycle, with high estrogen and progesterone levels, women might have a decrease in short-wavelength sensitivity (Akar et al., 2005; Apaydin et al., 2004). Thus, changes of hormones could strongly affect colour perception in women, but whether colour perception is particularly influenced by menopause is not clear.

In addition, hormones affect perception of emotional facial expressions. When detecting and remembering emotional facial expressions, the performance of a group of women in the follicular phase with low progesterone level was better than that of another group of women in the luteal phase (Derntl, Windischberger, et al., 2008; Derntl, Kryspin-Exner, et al., 2008). However, comparison of the performance of the same group of women showed a delayed response to a working memory task using emotional facial expressions in the follicular phase (Gasbarri et al., 2008). Regarding various types of emotional facial expression, women in the follicular phase had higher error rates for the sadness and disgust expressions (Gasbarri et al., 2008). Thus, menstrual cycle hormones might influence perception of emotional facial expressions and types of emotion.

Women's perception, cognitive functioning and mental condition could thus be strongly influenced by changes of hormones, including those involved in the menstrual cycle and menopause. However, whether colour perception differs in women before and after menopause has not been determined. In addition, as emotional facial expressions are often connected with colours, emotional facial expressions might possibly interfere with colour perception when both of these types of information are presented at the same time. In the present study, the author investigated colour perception of women in various stages of menopausal change using coloured face and scrambled face stimuli and comparing the reactions between pre- and post-menopause. Moreover, the author conducted a test to gauge depression in order to examine the mental health of women and its possible association with colour perception.

3.2 Materials and methods

Ethics

All experiments were carried out in accordance with the Guidelines for the Research in Human Participants, issued by the Human Research Ethics Committee of the Primate Research Institute, Kyoto University, and the experimental protocol was approved by the Committee (Permit No. 2017-05). Before the experiments, the author obtained written informed consent from all participants.

Participants

Fifty-nine female participants (mean age and standard deviation, 49.88 +/- 4.96 yrs, range 42-59 yrs) participated in the experiments. The author asked all participants to answer a questionnaire about their menstrual cycle or menopause conditions, by choosing one from pre-, peri-, post-menopausal or unknown status, and by stating how many years had passed since they had undergone menopause. The responses to the questionnaire indicated that there were 23 pre-menopausal participants (age: 46.17 +/- 2.50 yrs, range: 42 - 52) who had a menstrual cycle, and 20 post-menopausal participants (age: 55.05 +/- 3.00 yrs, range: 48 - 59) who stated that their menopausal period had continued for more than two years. The author excluded 9 participants in peri-menopause, 4 whose menstrual status was unknown, and 3 who had had a hysterectomy, and the author then divided the participants into two groups: a pre-menopause and a post-menopause group, for the analysis. All participants in these two groups were Japanese and right handed, and participants did not show any cognitive disorder when tested by the Raven Coloured Progressive Matrices or colour blindness when tested by the Ishihara Colour Vision Test.

Stimuli

In the experiments, the author used images of faces as social stimuli and scrambled faces as non-social stimuli, and these stimuli were same as those used in Chapter 2. Face stimuli included three types of emotional expressions: happy, neutral, and sad faces, and these faces were scrambled as three types of scrambled face stimuli (Figure 2-1). Each stimulus had one of three colours: red, yellow or blue (Table 3-1). The author converted all stimuli to a size fitted in 250 x 250 pixels.

Materials

Apparatus. All experiments were performed using a custom-made program written using OpenSesame software ver. 3.1.6 (Mathôt, 2010-2016) in Microsoft Surface Pro 2, and using a USB-numeric keypad that was connected to a tablet computer. Participants judged the colours of face or scrambled face stimuli, red, yellow or blue, and their responses were recorded on the keypad during the experiments.

The Center for Epidemiologic Studies Depression Scale (CES-D Scale). During or after experiments, participants were asked to answer some questions in the Center for Epidemiologic Studies Depression Scale (CES-D Scale). The CES-D Scale included 20 questions related to the condition of the body and mind during one week.

Procedure

Participants were asked to sit in front of the Surface screen (the resolution: 1920 x 1080 pixels) and the keypad, which were on a desk. First, in a single trial, a fixation dot with 8 pixels radius appeared at the centre of the screen with a grey background. After 0.5-1.5 seconds, the fixation dot was replaced with one of either a happy, neutral or sad stimulus at the centre of the screen. Participants were required to judge the colour (red, yellow or blue) of stimuli by pressing the one of three buttons of the keypad that corresponded with the colour, using their right hand (Figure 3-1). The positions of buttons were counterbalanced for each participant. After the reactions were completed, the next trial was started. The experiment consisted of an initial practice, and then the main phases. The main phases included a total of 81 trials. Three types of stimuli, happy, neutral and sad, appeared in any one of 3 colours, red, yellow or blue, 9 times in random order during the main phases (3 types x 3 colours x 9 times). All participants performed both face stimuli and scrambled face stimuli tasks, with a total of 162 trials (81 trials x 2 tasks). During the experiments, the reaction times of keypad pressing were always recorded.

Participants were also required to answer questions in the Center for Epidemiologic Studies Depression Scale (CES-D Scale) during or after the experiments. The questions were about the body and mind during one week when they participated in the experiments.

Analysis

The reaction times were analysed by analysis of variance tests (ANOVA) based on linear mixed models in SPSS ver. 24. In the models for each face and scrambled face task, the author set the condition of participants (pre-menopause or post-menopause), the stimulus type (happy, neutral or sad) and the colour (red, yellow or blue) with its interaction effect terms (menopause condition x stimulus type x colour) as the fixed main effect terms, and participant ID as a random effect term. When a significant interaction effect was observed, as a post-hoc comparison, the author computed the 95% confidence intervals of the estimated marginal means between two comparison levels for each level of the other condition, and examined whether the two levels differed significantly.

3.3 Results

Age differences

In order to examine age differences between the pre-menopause and post-menopause groups, the author carried out a T-test. The result showed a significant difference in age between the two groups ($t = -10.588$, $df = 41$, $P < 0.001$).

Reaction time in the face and scrambled face stimuli tasks

Conducting a multi-way 2 x 3 x 3 ANOVA, the author found a significant interaction effect between the menopausal condition of participants and colour in the face stimuli task ($F_{2,\ 327.919} = 4.493$, $P = 0.012$, partial $\eta^2 = 0.003$ Table 3-2, Figure 3-2). Then the author conducted post-hoc comparisons by computing the estimated marginal means. Participants in the post-menopause group reacted to blue significantly more slowly than to red or yellow, while the reaction times to these colours for participants in the pre-menopause group were not significantly different. Moreover, the interaction effect between type of face and colour was close to significant ($F_{4,\ 327.898} = 2.370$, $P = 0.052$, partial $\eta^2 = 0.004$). The post-hoc analysis showed that the reaction time to the sad face in blue was delayed compared with that to the neutral face in blue.

In the scrambled face stimuli task, the author also found a significant interaction effect between menopausal condition and colour ($F_{2,\ 331.050} = 3.776$, $P = 0.024$, partial $\eta^2 = 0.003$ Table 3-3, Figure 3-3) and between type of scrambled face and colour ($F_{4,\ 331.013} = 2.550$, $P = 0.039$, partial $\eta^2 = 0.004$). Participants in the post-menopause group reacted to blue significantly more slowly than to yellow, but participants in the pre-menopause group did not have any significant differences in reaction time. In addition, for the happy scrambled face, the reaction time to blue was significantly slower than that to red.

Scores on the CES-D Scale

During or after experiments, 22 pre-menopause and 19 post-menopause participants answered the CES-D Scale. The test had 20 questions, and the answer to each question counted for 0 to 3 points. Participants with higher score tended to have a stronger tendency toward depression. After excluding scores for 2 participants as outliers, the author obtained scores for 21 pre-menopause participants (mean with standard deviations of scores: 6.62 +/- 4.35 points, range: 0 - 13) and 18 post-menopause participants (score: 9.06 +/- 4.73 points, range: 2 - 18) for analysis. The author found no significant differences in the scores between the pre-menopause and post-menopause groups ($t = -1.674$, $df = 37$, $P = 0.103$).

Correlation between reaction time and scores on the CES-D Scale

In order to examine the relationship between colour perception and depression, the author analysed the correlation between reaction time and scores on the CES-D Scale for every combination of menopause group and colour by regression analysis. The results did not show any correlation between reaction time and depression.

3.4 Discussion

Colour perception

The results clearly showed differences in reaction time between women in the pre-menopause and post-menopause groups. In the both face and scrambled face stimuli tasks, the post-menopausal women responded to the stimuli more slowly than the pre-menopausal women (Figure 3-2, 3-3). In addition, the difference of reaction time to the face stimuli between the two groups seemed to be affected by the colour of the stimuli. Women in the post-menopausal group responded to blue stimuli more slowly than to red or yellow ones, and the speed of the response to yellow was the fastest in both the face and scrambled face stimuli tasks. Although the pre-menopause women showed no obvious difference in reaction time according to colour, their response was fastest in the order blue, red and yellow in the face stimuli task, and blue, yellow and red in the scrambled face task. Thus, the reaction time to blue relative to the other two colours was opposite between the pre- and post-menopausal groups.

Evidence about colour perception of women according to the menstrual cycle, and particularly about women in menopause, is fragmentary, compared with evidence about colour cognition (such as preference) in women during ovulation. However, changes of female hormones, such as those in different phases of the menstrual cycle and menopause, could possibly influence colour perception. For instance, women in the ovulation phase, with the highest secretion of estrogens, have better colour discrimination than women in the beginning or end of the menstrual cycle (Giuffrè et al., 2006), and during the luteal phase, with high estrogen and progesterone, both healthy and diabetic women have decreased short-wavelength light sensitivity (Akar et al., 2005; Apaydin et al., 2004). Similar phenomena regarding the sensitivity of perception of short-wavelength colour have also been observed in women in menopause. In experiments asking participants to recognise the stimulus colour of 440 nm by naming it as either blue, lavender or white, middle-aged women using tamoxifen to block the estrogen-receptor showed a greater tendency to name the stimulus colour white than healthy middle-aged women, and longer tamoxifen users showed a greater such tendency than shorter tamoxifen users (Eisner & Incognito, 2006), while healthy women in peri- and post-menopause named the stimulus colour lavender (Eisner & Toomey, 2008). Women who eat phyto-estrogen-rich foods also have better short-wavelength sensitivity than women who do not (Eisner & Demirel, 2011). These evidences indicate a strong relationship between hormones and colour perception, specifically short-wavelength sensitivity.

Based on these evidences, the author can explain why the post-menopausal women in this study reacted more slowly to blue than to the other colours, while the pre-menopausal women did not. The short-wavelength sensitivity cones work to perceive light as colours in the range between blue and purple, so a decline of sensitivity of these cones would make it difficult to detect bluish colours. Women in post-menopause have lower hormone levels than women in pre-menopause, and if hormones such as estrogen and progesterone affect short-wavelength sensitive cones, the response to blue would be expected to differ between pre- and post-menopausal women, according to the hormone levels. Such a difference could explain why the post-menopausal women showed a delayed response to blue stimuli in the author's results. However, some reports also mention that deficit in the short-wavelength sensitivity cones are related to aging (Kraft & Werner, 1999a, 1999b, Schefrin & Werner, 1990, 1993), and as menopause happens as a part of aging, it has been problematic to distinguish between menopause and aging regarding the influences on the short-wavelength sensitivity cones.

Colour perception and depression

Many women suffer from depression specifically because of hormone changes in pregnancy and menopausal transition (Soares & Zitek, 2008), and women have double the risk of depression compared with men (Kessler, McGonagle, Swartz, Blazer, & Nelson, 1993). Women, especially during the menopausal transition and thereafter, could have increased the risk of greater symptoms of depression (Mulhall, Andel, & Anstey, 2018). However, the levels of depression in this study did not vary largely between the pre- and post-menopausal groups, unlike in previous studies (Kessler et al., 1993; Mulhall et al., 2018; Soares & Zitek, 2008), and in disagreement with the author's prediction that women would have higher levels of depression during and after menopausal transition. The results suggest that menopause could not affect depression in a simple manner, and instead the effect may depend on individual body conditions such as the length of exposure to endogenous estrogen and the reproductive period (Georgakis et al., 2016), personal experiences including history of depression during pregnancy and the menstrual cycle, adverse life events and negative attitudes about menopause and aging (Vivian-Taylor & Hickey, 2014).

Furthermore, the author did not find a clear correlation between colour perception and depression. High depressive levels were reported to be correlated with selections of specific colours such as yellow (Cohen & Hunter, 1978), or darker colours such as black and brown (Nolan, Dai, & Stanley, 1995). In addition, impairments in brain function by depressive conditions might affect retina function (Barrick, Taylor, & Correa, 2002). In contrast, a lack of association between depression and colour perception was reported in spite of lower colour perception resulting from use of hormonal contraceptives (Da Silva et al., 2015). The relationship between colour perception and depression thus seems to be controversial. Depression influenced by hormones may be associated with alterations of cognitive functions such as colour selection and preference, but appears not to have a direct strong association with colour perception.

Discrimination of emotional facial expression

Understanding of facial expressions is crucial in social life, and there are sex differences in reaction time and arousal according to types of emotional facial expression (Hoffmann et al., 2010; Sawada et al., 2014). Among women, perception of emotional facial expressions differs according to changes of hormones. For example, women in the follicular phase performed better at detecting and remembering emotional facial expressions than women in the luteal phase (Derntl, Windischberger, et al., 2008; Derntl, Kryspin-Exner, et al., 2008), although those studies compared two different groups of women. In contrast, when the same group of women was compared between the follicular and luteal phases, they had slower reaction time in the matching-to-sample of working memory task for emotional facial expressions and more errors for the sadness and disgust expressions in the follicular phase (Gasbarri et al., 2008). Hormone levels may be strongly related to perception of emotional facial expressions and of types of emotion.

In the author's experiments, however, the author did not see any influence of emotional facial expression on colour perception. The author used faces as social stimuli and scrambled faces as non-social stimuli and expected the Stroop-like effects, in which colour perception was interfered with by emotional facial information in the face stimuli task while there was no interference in the scrambled face stimuli task. The Stroop effect is the phenomenon of interference with response time by incongruence between colour terms and actual colours (Stroop, 1935). Emotional facial expressions are often connected with specific colours: a happy face with yellow and a sad face with blue, so we predicted that facial expressions would interfere when recognising colours in incongruent conditions such as a happy face with red or a sad face with yellow. However, the results showed a significant interaction effect between types of stimuli and colours in not only the face stimuli task but also the scrambled face stimuli task. Participants did not experience strong interference against perceiving colours by emotional facial expressions, and the post-menopausal women tended to react to blue relatively slowly regardless of the stimuli type.

3.5 Conclusions

In summary, the author examined colour perception of women in pre- and post-menopause, and interference with colour perception by emotional facial expressions. The results showed a significant difference between the pre- and post-menopausal women in reaction time, particularly in reaction time to blue, and suggested that changes of short-wavelength sensitivity might be caused by changes of hormone levels that occur in menopause. However, the author was unable to exclude the aging effects from the data, so we need to consider this matter in further studies. The possible relationship between changes of colour perception based on the changes of short-wavelength sensitivity and hormonal functions will be an interesting topic, and more specific colour variations and experimental paradigms (such as visual search) could be used. However, the author did not find any influence of emotional facial expressions or depression on colour perception. These two factors are clearly affected by hormonal changes, but might be related to colour perception indirectly. The findings revealed a possible association between colour perception and menopause, and could contribute to understanding of women in menopause.

Acknowledgements

The author would like to thank all participants who joined the experiments conducted from July to October 2017 and the persons involved in this research. The author also appreciates Elizabeth Nakajima for English proofreading in this paper.

Tables

Colour	Y	x	y
Red	23.0	0.533	0.367
Yellow	80.9	0.436	0.486
Blue	24.1	0.222	0.263

Table 3-1. Colours of stimuli in the experiment by Yxy (CIE)

Source	df	F	p-value	effect size	
Condition (pre/post)	1, 40.993	5.965	0.019	0.037	*
Stimuli type (happy/neutral/sad)	2, 327.910	0.246	0.782	0.000	
Colour (red/yellow/blue)	2, 327.919	1.628	0.198	0.001	
Condition x Stimuli type	2, 327.910	0.399	0.671	0.000	
Condition x Colour	2, 327.919	4.493	0.012	0.003	*
Stimuli type x Colour	4, 327.898	2.370	0.052	0.004	
Condition x Stimuli type x Colour	4, 327.898	0.389	0.816	0.001	

*p < .05, **p < .01, ***p < .001

Table 3-2. Statistical results of linear mixed model analysis on the face stimuli task

Source	df	F	p-value	effect size	
Condition (pre/post)	1, 40.988	4.326	0.044	0.026	*
Stimuli type (happy/neutral/sad)	2, 331.032	0.230	0.795	0.000	
Colour (red/yellow/blue)	2, 331.050	0.289	0.749	0.000	
Condition x Stimuli type	2, 331.032	2.507	0.083	0.002	
Condition x Colour	2, 331.050	3.776	0.024	0.003	*
Stimuli type x Colour	4, 331.013	2.550	0.039	0.004	*
Condition x Stimuli type x Colour	4, 331.013	1.023	0.395	0.002	

*p < .05, **p < .01, ***p < .001

Table 3-3. Statistical results of linear mixed model analysis on the scrambled face stimuli task

Figures

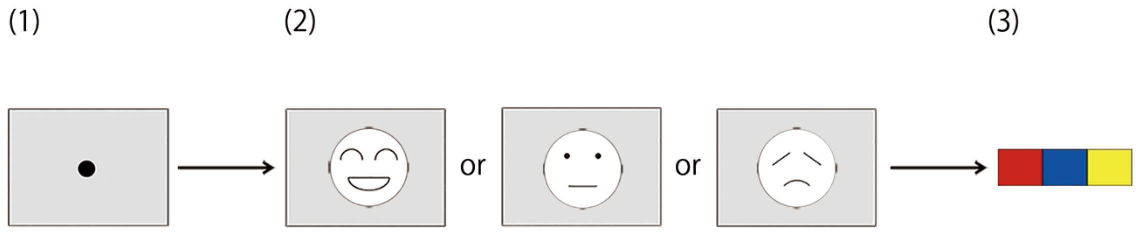

Figure 3-1. Experimental procedure for the face stimuli task: (1) fixation dot appeared and disappeared, (2) after 0.5-1.5 sec. interval, stimulus (either happy, neutral or sad face) appeared with one of 3 colours, and (3) participant answered the colour by pressing one of 3 buttons.

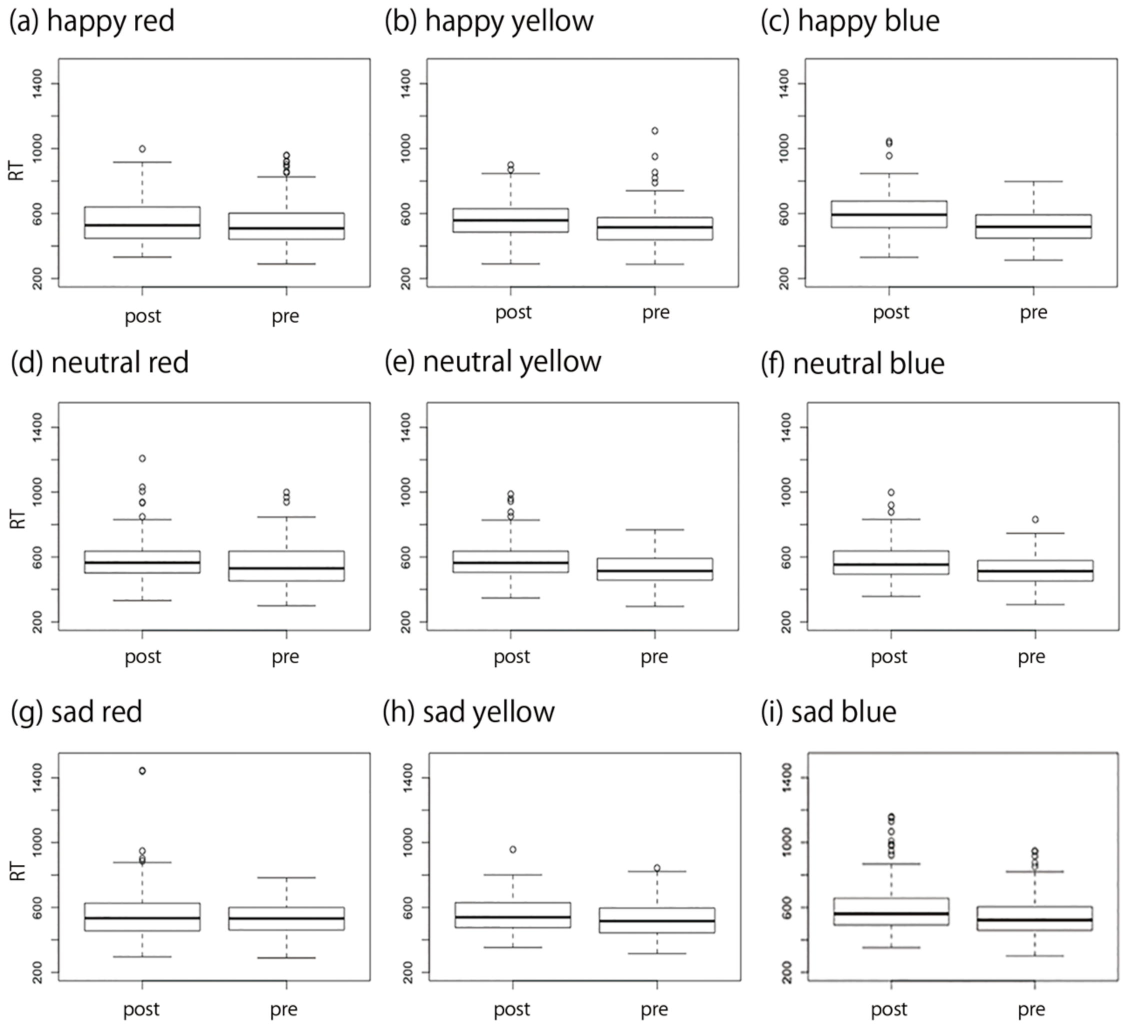

Figure 3-2. Reaction time (msec.) of pre- (right) and post-menopause (left) by stimulus in the face stimuli task.

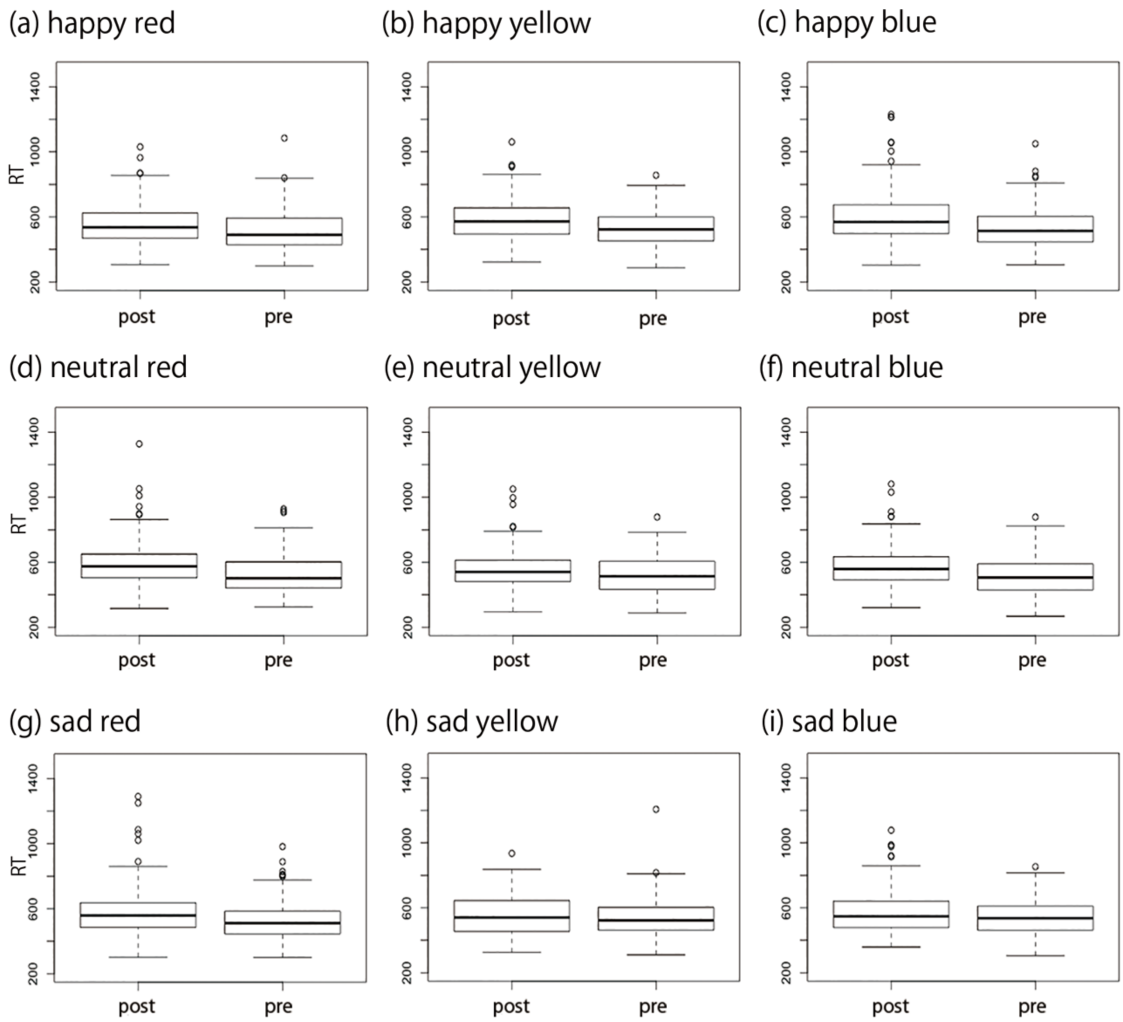

Figure 3-3. Reaction time (msec.) of pre- (right) and post-menopause (left) by stimulus in the scrambled face stimuli task.

Chapter 4

Colour-Odour Correspondences in Women during the Menstrual Cycle: Comparison between the Menstrual and Ovulation Phases

Abstract

Women have various changes in perception, cognition and social behaviours during the menstrual cycle. Previous studies suggested that women might have modulation of their perception and cognition of colours and odours and behave in various different ways during the menstrual cycle, but how women's impressions and images of colours and odours differ according to hormonal changes remained unknown. Here the author experimentally examined women's perceptions and impression of colours and odours, and how they relate these two different sensory systems, comparing two phases: the beginning of menstruation and ovulation. The author examined women's performance of several tasks, including evaluation of impressions of colours and odours, matching/nonmatching of colours with odours and identification of odours. The results showed that the women had similar impressions of colours and odours, and made similar colour choices for odours in both the menstrual and ovulation phases, while "pleasant-unpleasant" impressions of colour and odour varied according to the menstrual cycle. The author found no significant differences in odour identification between the phases. The findings suggest that hormonal changes during the menstrual cycle can affect "pleasant-unpleasant" impressions of colour and odour, but not other features regarding impressions or cross-modal correspondence.

Keywords: cross-modal correspondence, colour, odour, impression, menstrual cycle

4.1 Introduction

Cross-modal correspondence between colour and odour

When we sniff an odour, we try to recall or imagine the type of its source, and thus we often connect and use more than two different sensory modalities simultaneously, e.g., olfactory and visual, auditory or gustatory senses. These cross-modal correspondences between two different types of sensory information have been of interest to researchers, and in particular, correspondences between visual sensing such as sensing of shapes or colours, and auditory sensing as sensing of sounds, a type of synaesthesia, have been well studied (e.g. Hubbard, Arman, Ramachandran, & Boynton, 2005; Maurer, Pathman, & Mondloch, 2006; Nunn et al., 2002; Ramachandran & Hubbard, 2001). Such correspondences had been thought to occur only in specific persons, but Ramachandran and Hubbard (2001), and Maurer et al. (2006) revealed that humans commonly had similar cross-modal correspondences in spite of differences such as age (e.g., bouba/kiki phenomenon). However, apart from visual and auditory correspondence, other types of sensory correspondences have been unclear.

Cross-modal correspondence between colour and odour, has been studied by some researchers, and they found that humans fundamentally associate specific colours with odours, and darker colours are related to stronger odours according to the intensity (Gilbert et al., 1996; Kemp & Gilbert, 1997; Zellner & Kautz, 1990; Zellner & Whitten, 1999). More recent studies based on many types of odour provided insights into how humans associated odours with colours (Miura & Saito, 2012a, 2012b). However, whether cross-modal correspondence between colour and odour is a common phenomenon like the bouba/kiki phenomenon, or whether this correspondence differs according to physiological factors such as age, sex or hormonal changes such as those that occur during the menstrual cycle, has remained unknown.

Modulation of perception, cognition and behaviour during the menstrual cycle

The menstrual cycle may cause various symptoms in women's health condition, and also various perceptual, cognitive and behavioural modulations. Women typically have about a 28-day cycle, and ovulation occurs about 14 days before the first day of the next menstruation. However, the length of one regular cycle varies according to the individual and the health condition, and some women are reported to suffer from premenstrual syndrome (PMS) or premenstrual dysphoric disorder (PMDD) about one week before the menstruation (Biggs & Demuth, 2011; Jukic et al., 2008; Makhanova & Miller, 2013). Regarding physical and psychological changes experienced in PMS or PMDD, some women have headache, weight gain, or mood changes such as more feelings of anger, irritability or anxiety (Biggs & Demuth, 2011). Many behavioural studies also showed that women near ovulation have more frequent times of attendance at social gatherings, and more use of cosmetics and products to enhance their physical appearance, possibly for attracting men for reproduction (Durante et al., 2011, 2008; Guéguen, 2012; Haselton & Miller, 2006).

During the menstrual cycle, differences in perception and cognition have also been reported in many studies. For instance, women have menstrual-cycle-dependent differences in visual perception tasks related to asymmetries and spatial information, and it was reported that they showed better performance in the luteal phase, while the opposite results, with better performance in the menstrual phase, were also reported (Bibawi et al., 1995; Hampson, 1990; Hatta & Nagaya, 2009; McCourt et al., 1997). Hormonal changes during the menstrual cycle could affect colour and odour perception. Women have better abilities in colour perception and discrimination tasks at ovulation or in some conditions which regulate hormone levels, and some studies reported that hormonal changes possibly affect perception of short-wavelength light and decrease the sensitivity to blue colour, although this effect might be varied and small depending on the individuals (Akar et al., 2005; Apaydin et al., 2004; Da Silva et al., 2015; Eisner et al., 2004; Giuffrè et al., 2006). Some women are also more likely to prefer red or pink for attractiveness to men near ovulation, the phase when they have more possibility of conceiving for reproduction (Beall & Tracy, 2013; Elliot, Tracy, Pazda, & Beall, 2013). In the ovulation phase, women experience lower sensitivity to odour, although the opposite results or no significant differences were reported in some studies (Doty et al., 1981; Navarrete-Palacios et al., 2003; Nováková et al., 2014; Pause et al., 1996).

Changes of colour and odour perception and cognition during the menstrual cycle have thus been debatable according to various different research methods and results. However, female hormones could be a fundamental factor that modulate women's perception and cognition, and they might influence cross-modal correspondence between colour and odour. Here the author predicted that there would be declines of performance in perception according to declines of female hormonal level, and the author examined to what extent perceptual and cognitive features regarding colour and odour, and the cross-modal correspondence between colour and odour, differed according to changes of female hormones in women during the menstrual cycle.

4.2 Materials and methods

Ethics

The author conducted all experiments in accord with the Guidelines for Research in Human Participants, issued by the Human Research Ethics Committee of the Primate Research Institute, Kyoto University. The experimental protocol was approved by the Committee (Permit No.2017-05). The author obtained a written form of consent from all participants before starting the experiment.

Participants

Twenty-six Japanese female undergraduate and postgraduate students (mean with standard deviation of age: 21.62 +/- 1.499 yrs, range 20-24 yrs) participated in the experiments, and they had a regular menstrual cycle (mean with standard deviation of menstrual cycle: 29.73 +/- 2.82 days) without taking contraceptives or hormonal medicine, and recorded each start date of their menstrual period. After the author obtained consent for their participation, the author asked participants about their menstrual cycle history for the past several months. Based on these records, the author calculated the next starting date of a menstrual period, and the approximate date of ovulation, which is about 14 days before the next starting date of a menstrual period. All participants participated in the experiments twice: once on a date during the first 4 days of the menstrual period, and the other on the estimated date for ovulation. Some participants participated in the first experiment at the menstrual period and the second experiment at the estimated ovulation period, while the others participated in them in the opposite order, according to the participants' menstrual cycle. After the experiment at the estimated ovulation time, the next start date of the menstrual period was always informed from participants in order to determine whether the author's estimation of ovulation time was appropriate or not. The experiment dates for 15 out of 26 participants were shifted earlier or later than the first 4 days from the beginning of the menstrual period, or more than 3 days earlier or later than the calculated ovulation time, so the author excluded the data of these participants from the analysis. The remaining 11 participants participated in the experiments twice, within the first 4 days of the menstrual period, and at the estimated time of ovulation period without a shift of more than 3 days, and the author carried out the analysis using the data of these 11 participants (age: 22.00 +/- 1.67 yrs, range: 20-24 yrs, menstrual cycle: 30.55 days +/- 2.50 days). Participants had no cognitive disorder tested by the Raven Coloured Progressive Matrices or colour blindness tested by the Ishihara Color Vision Test.

Stimuli

Colour stimuli. Eighteen colours from the Practical Color Coordinate System (PCCS) were used. The PCCS is the colour system commonly used in Japan and was developed by the Japan Color Research Institute. The author arranged the size of each colour chart as 8.75 x 12 cm, and used 15 chromatic colours: 5 hues (red, yellow, green, blue and purple) x 3 tones (pale, vivid and dark), and 3 achromatic colours (white, medium grey and black) (Table 4-1).

Odour stimuli. The author used 12 types of odour from OSIT-J, produced by Takasago International Corporation, Ltd. (Tokyo, Japan). The odours included perfume, rose, condensed milk, Japanese orange, curry, roasted garlic, sweaty socks, domestic gas for cooker, menthol, India ink, wood and Japanese cypress (hinoki). Japanese people are familiar with these odours in daily life.

Apparatus

In the experiments, the author conducted two tasks of evaluating colour and odour impressions, controlled by a custom-made program written using the OpenSesame software ver. 3.1.6 (Mathôt, 2010-2016) in Microsoft Surface Pro 2, and a USB keypad that was connected to a tablet. Participants pressed one of the buttons on the keypad corresponding to the Semantic Differential (SD) scales to indicate their impressions of colours and odours.

Procedure

All participants performed the same tasks twice: at the beginning of the menstrual phase and at the ovulation phase. The experiments included the following tasks: evaluation of colour impression, odour impression, matching/nonmatching between colour and odour, and odour identification. First, the participant performed the evaluation of colour impression task. Then she was asked to evaluate her impression of one odour sample, match/nonmatch colours with the odour, and identify the odour. After completing these tasks for one sample, she performed the same tasks for the next odour sample. All participants carried out the same tasks both in the menstrual and ovulation phases.

Colour impressions. Participants sat in front of a Surface screen (resolution: 1920 x 1080 pixels) and a keypad on a desk. In the first step, a participant looked at one of the 18 colour cards from the PCCS colour chart and evaluated her impressions of the colour on the Surface screen by pressing a button of the keypad. For the evaluation, the following 12 adjective word pairs were applied: "warm-cool", "shallow-deep", "ordinary-characteristic", "soft-hard", "clear-muddy", "gentle-harsh", "simple-complicated", "sweet-non sweet", "bright-dark", "like-dislike", "feminine-masculine", and "pleasant-unpleasant”. These pairs were based on the studies of colour and odour classification by words (Higuchi, Shoji, & Hatayama, 2004; Miura & Saito, 2012a, 2012b; Oyama, Soma, Tomiie, & Chijiiwa, 1965). Each pair appeared randomly on the screen with a 5 point scale based on the Semantic Differential (SD) method. Participants evaluated each colour by answering one number from the 5 point scale for each of the adjective word pairs, and completed all 12 types of adjective word pairs.

Odour impressions. For the evaluation of odour impression, the same method and procedure were used as for the colour impression. The author used odours in OSIT-J, including 12 different types. Each odour was enclosed in microcapsules and mixed into an odourless solid cream, in a lipstick-like shaped container. Following the instructions of OSIT-J, an examiner put one odour in a circle of about 2 cm diameter on a piece of paraffin paper, folded the paper in half, rubbed it, and passed it to the participants. Then the participants sniffed the odour, and they evaluated their impressions of the odour by answering one number from a 5 point scale for the 12 adjective word pairs listed above. Participants evaluated their impressions of all 12 types of odours.

Matching/nonmatching between colour and odour. After participants evaluated one odour, they chose the top three colours that were most suitable for the odour, and the top three colours that were most unsuitable, from the 18 types of colours in the PCCS colour chart.

Odour identification. Participants also identified what each odour was, by choosing one answer from six possible choices. These choices included four choices with names of entities related to the odours: only one of the choices was correct, and the other three were incorrect, one choice was “unknown”, and one choice was “undetectable”. The author counted the correct choice as one point in a score. Participants answered all 12 types of odour, so the maximum score was 12 points.

Analysis

The author analysed points in the SD method for the evaluation of both colour and odour impressions by a factor analysis with the maximum likelihood estimation and varimax rotation in SPSS ver. 25, in order to determine whether women had common impressions about colour and odour or not. After obtaining factors, the author examined the internal consistency with Cronbach's formula, and compared factor scores for each factor between the menstrual and ovulation phases by paired t-test in order to determine how these impressions differed according to the menstrual cycle.

In the matching/nonmatching task between colour and odour, participants chose three matched or nonmatched colours with each odour. For the analysis, one colour choice was counted as 1 point, and the numbers of matched or nonmatched points for each colour with each odour were compared between the menstrual and ovulation phases by a $\chi 2$ test.

The author also analysed the scores in the odour identification task by a two-way (participant phase: menstrual or ovulation; and odour type: perfume, rose, condensed milk, Japanese orange, curry, roasted garlic, sweaty socks, domestic gas, menthol, India ink, wood or Japanese cypress) repeated ANOVA. Here the author treated participant phase as repeated measurements, nested in the participant block. When a significant interaction effect was observed, as a post-hoc comparison, the author computed the 95% confidence intervals of the estimated marginal means between two comparison levels for each level of the other condition, and examined whether the two levels differed significantly.

4.3 Results

Colour and odour impressions. In order to examine common and different features of the colour and odour impressions in the menstrual and ovulation phases, the author conducted a factor analysis with the maximum likelihood estimation and varimax rotation. In the results, three factors which influenced the evaluations were observed: the first factor was named "Mild", the second "Pleasant" and the third "Clear" for both the menstrual and ovulation phases (Tables 4-2, 4-3 and Figures 4-1, 4-2). These three factors mainly shared the same features. However, the pair "shallow-deep" was observed in the Mild factor only in the menstrual phase, and in the Pleasant factor only in the ovulation phase. The author examined the internal consistency for these three factors by using Cronbach's formula. The α values for Mild, Pleasant and Clear were 0.880, 0.892 and 0.853 in the menstrual phase, and 0.896, 0.870 and 0.888 in the ovulation phase, respectively.

The author also conducted a paired t-test using factor scores for each factor in both phases in order to examine the significance of differences between the menstrual and ovulation phases. As a result, the author found significant differences in the Pleasant factor for colour impressions between the phases ($t\ (17) = -2.748$, $P = 0.014$), while no significant differences were found in the Mild or Clear factors between the phases (Mild: $t\ (17) = -0.280$, $P = 0.783$, Clear: $t\ (17) = -1.484$, $P = 0.156$). A similar pattern was also shown in the Pleasant factor for odour impression between the phases, although the result was close to but not significant ($t\ (11) = 2.129$, $P = 0.057$), while the Mild and Clear factors between the phases showed no significant differences (Mild: $t\ (11) = 1.110$, P =

0.291, Clear: $t(11) = -1.220$, $P = 0.248$). As the Pleasant factor mainly included variables such as “like-dislike” and “pleasant-unpleasant”, the author also closely analysed average SD scores in these two types of variable for each colour and odour type by ANOVA in order to determine whether they varied between the menstrual and ovulation phases. The results showed no significant interaction effect between the phases of participants and types of colour or odour for average SD scores for both the “like-dislike” and “pleasant-unpleasant” variable. However, a significant main effect of the phases of participants was found for average SD scores of only the “pleasant-unpleasant” variable in the evaluation of colour impressions ($F_{1, 360} = 4.428$, $P = 0.036$, partial $\eta^2 = 0.012$ Figure 4-3), and that in the odour evaluation was close to significant ($F_{1, 232} = 3.620$, $P = 0.058$, partial $\eta^2 = 0.015$). Average SD scores of the “pleasant-unpleasant” variable for colour were lower in the menstrual phase than those in the ovulation phase, while those for odour were lower in the ovulation phase than those in the menstrual phase, indicating a lower score as a more pleasant evaluation and a higher score as more unpleasant.

Matching/nonmatching between colour and odour. The author used a $\chi 2$ test in order to examine whether there were any significant differences of the matched or nonmatched colour choices for each odour between the menstrual and ovulation phases, and the author found that there was no significant difference between these two phases. Participants seemed to choose the same or similar colours in both phases for most types of odour, for example, vivid yellow matched with Japanese orange and domestic gas with olive, and black and pale pink as nonmatched colours, respectively (Table 4-4).

Odour identification. The author conducted two-way repeated ANOVA, and found no significant interaction effect between the phases of participants and types of odour in the odour identification task ($F_{11, 120} = 0.835$, $P = 0.605$, partial $\eta^2 = 0.071$ Figure 4-4). In the post-hoc comparison between types of odour, no statistically significant differences with below 5% probability were found.

4.4 Discussion

Impressions of colour and odour, their correspondence and female hormone levels

To summarise the results of the author's experiments, colour or odour impressions were similar for women between the menstrual and ovulation phases. However, the "pleasant-unpleasant" evaluation of colour and odour found in the Pleasant factor differed, and thus women's "pleasant-unpleasant" preference (but not "like-dislike") of colour and odour could vary according to the menstrual cycle. Women were more likely to feel unpleasant regarding colour in the ovulation period, while they were more likely to feel unpleasant regarding odour in the menstrual period. However, cross-modal correspondence examined by a matching/nonmatching task was largely similar between the menstrual and ovulation phases. Thus, these cognitive features might not be modulated by hormonal changes during the menstrual cycle, and women commonly have similar colour and odour impressions, except for "pleasant-unpleasant" impression, and colour choices for odour, possibly based on individual experience and memory about colours and odours.

Components of each factor obtained by evaluation of colour and odour impressions were also similar to those found in previous studies (Higuchi, Shoji, & Hatayama, 2002; Higuchi et al., 2004; Miura & Saito, 2012a, 2012b). However, these factors showed no clear associations with hue, brightness or chroma, in contrast to previous studies that revealed that Mild factor was related to brightness and Clear factor to chroma (Miura & Saito, 2011, 2012b; Oyama et al., 1965).

The study which focused on menopausal women and is discussed in Chapter 5 also found no clear relationship between impressions of colour and odour or their correspondence, and women's menopausal status of either pre- or post-menopause (Iriguchi, Koda, & Masataka, in press). In the case of menopausal women, however, significant differences in the identification of odours were found between pre- and post-menopause, and how confident participants were for identifying odour types may have influenced their evaluation of odour impressions and colour choices for odour. In the present study, women showed no significant differences in the identification of odours between the menstrual and ovulation phases, and odour identification seemed not to influence the evaluation of odour impressions or colour choices. The different hormonal phases of the menstrual cycle may not be fundamentally associated with colour and odour impressions or cross-modal correspondence between colour and odour, but the "pleasant-unpleasant" impression for colour and odour could be associated with changes during the menstrual cycle.

Perceptual characteristics of women during the menstrual cycle

A number of studies have shown changes in women's perception, cognition and social behaviour during the menstrual cycle. Differences of colour perception and discrimination were reported for women using versus not using hormonal contraceptives, with women using hormonal contraceptives showing lower ability compared with women not using them; and also women near ovulation were reported to show better performance than women who were not close to ovulation (Da Silva et al., 2015; Giuffrè et al., 2006). Some studies also suggested that the perception of bluish colours conveyed by short-wavelength light was possibly influenced by hormonal changes during the menstrual cycle (Akar et al., 2005; Apaydin et al., 2004; Eisner et al., 2004) and by menopausal status (Eisner & Toomey, 2008; Iriguchi, Koda, & Masataka, 2018), although the various possible effects of the menstrual cycle on the sensitivity to short-wavelength light remain controversial. In addition, women near ovulation are more likely to prefer red or pink to dress themselves for making themselves attractive to men (Beall & Tracy, 2013; Elliot, Greitemeyer, et al., 2013; Elliot & Pazda, 2012), but this colour preference did not appear in the impressions of colours in the present study. Which colour women like may depend on the individuals, and may be more strongly associated with various cultural, social and living contexts than hormonal changes.

Many studies found that sensitivity of odour perception may also vary according to hormonal changes, although this modulation also seemed to differ according to the different studies (Doty et al., 1981; Navarrete-Palacios et al., 2003; Nováková et al., 2014). In the present study, women showed no significant differences in the identification of odour according to the menstrual cycle, and this result disagreed with the previous studies. The possible reasons include the fact that the number of participants in the present experiments was not large, and odour sensitivities can vary greatly depending on the individual regardless of hormonal changes. However, odours' "pleasant-unpleasant" impressions in women during the menstrual cycle might be related to reproductive strategy. Women' odour sensitivity is known to increase in the ovulation phase for specific odours such as androstenone and androsterone produced by men (Lundström et al., 2006; Renfro & Hoffmann, 2013). "Pleasant-unpleasant" impressions of odour could be a kind of cognitive sensor for efficient reproduction. In future studies, it will be necessary to examine odour perception according to different hormonal levels during the menstrual cycle, with various types of odour and a larger number of participants, and also to consider the individual differences in odour sensitivity.

4.5 Conclusions

The author's study focused on possible variation of colour-odour cross-modal correspondence according to hormonal changes during the menstrual cycle. The results revealed that women had basically common impressions of colour and odour and their correspondence in both the menstrual and ovulation phases, but "pleasant-unpleasant" impressions of colour and odour can be affected by hormonal changes during the menstrual cycle. Women also showed no significant differences in the identification of odours during the menstrual cycle, and examinations with more participants and individual differences will be necessary. Hormonal changes during the menstrual cycle may affect "pleasant-unpleasant" impressions of colour and odour, but not other cognitive features, and cross-modal correspondence between colour and odour may possibly result from women's individual experiences and memories of seeing colours and sniffing odours.

Acknowledgements

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Tables

Pale Pink 4R 8.0/3.5	Pale Yellow 5Y 9.0/3.0	Pale Green 3G 8.0/3.0	Pale Blue 3PB 7.5/3.0	Pale Purple 7P 7.5/3.0
Vivid Red 4R 4.5/14.0	Vivid Yellow 5Y 8.0/13.0	Vivid Green 3G 5.5/11.0	Vivid Blue 3PB 3.5/11.5	Vivid Purple 7P 3.5/11.5
Dark Red 4R 2.5/6.0	Olive 3G 3.0/4.5	Dark Green 3G 3.0/4.5	Dark Blue 3PB 2.0/5.0	Dark Purple 7P 2.0/5.0
White N9.5	Medium Grey N5.5	Black N1.5		

Table 4-1. Fifteen chromatic and 3 achromatic colours from PCCS with Munsell notation.

		Factor		
Variable	Mild	Pleasant	Clear	Communality
soft-hard	0.863	0.467	-0.031	0.964
feminine-masculine	0.816	0.290	0.163	0.777
warm-cool	0.730	-0.023	0.229	0.585
sweet-non sweet	0.727	0.540	0.209	0.864
shallow-deep	0.453	0.380	0.221	0.398
like-dislike	0.183	0.899	0.360	0.972
pleasant-unpleasant	0.195	0.896	0.355	0.967
gentle-harsh	0.645	0.684	0.006	0.883
ordinary-characteristic	0.194	0.572	0.098	0.374
bright-dark	0.598	-0.017	0.800	0.999
clear-muddy	0.224	0.266	0.744	0.675
simple-complicated	-0.050	0.339	0.710	0.622
Total	3.613	3.330	2.137	9.080
Variance (%)	30.110	27.752	17.810	75.672

Table 4-2. Results of factor analysis with colour and odour impressions in the menstrual phase, including factor loading of three major factors, Mild, Pleasant and Clear factors, and communality.

	Factor			
Variable	Mild	Pleasant	Clear	Communality
feminine-masculine	0.875	0.027	0.345	0.886
sweet-non sweet	0.859	0.348	0.211	0.904
soft-hard	0.782	0.526	-0.192	0.925
warm-cool	0.735	0.018	-0.034	0.542
like-dislike	0.150	0.860	0.445	0.960
pleasant-unpleasant	0.200	0.841	0.411	0.917
gentle-harsh	0.596	0.710	-0.154	0.883
shallow-deep	0.099	0.567	0.176	0.363
ordinary-characteristic	0.024	0.461	0.420	0.389
clear-muddy	-0.013	0.331	0.879	0.883
simple-complicated	-0.035	0.232	0.874	0.819
bright-dark	0.449	0.113	0.730	0.747
Total	3.287	3.062	2.869	9.218
Variance (%)	27.395	25.517	23.909	76.821

Table 4-3. Results of factor analysis with colour and odour impressions in the ovulation phase, including factor loading of three major factors, Mild, Pleasant and Clear factors, and communality.

	Menstrual		Ovulation	
Odour type	Colour choice with proportion (%)		Colour choice with proportion (%)	
Indian ink	White	21.4%	pGreen	28.6%
wood	pGreen	21.4%	pGreen, pBlue	14.3%
perfume	pPurple	21.4%	pPink, pYellow, pGreen	14.3%
menthol	vBlue	35.7%	pBlue	21.4%
Japanese orange	vYellow	42.9%	vYellow	42.9%
curry	dkRed	35.7%	dkRed	28.6%
domestic gas	Olive	35.7%	Olive	28.6%
rose	pPink	28.6%	pPink	42.9%
Japanese cypress	dkGreen	50.0%	pGreen, vGreen	21.4%
sweaty socks	Olive	42.9%	Olive	50.0%
condensed milk	pYellow	50.0%	pYellow	50.0%
roasted garlic	dkRed	28.6%	dkRed	35.7%

Table 4-4. The best matched colour choices with each odour in the menstrual and ovulation phases. The proportion of choices shows what percentage of participants chose the colour as matching the odour.

Figures

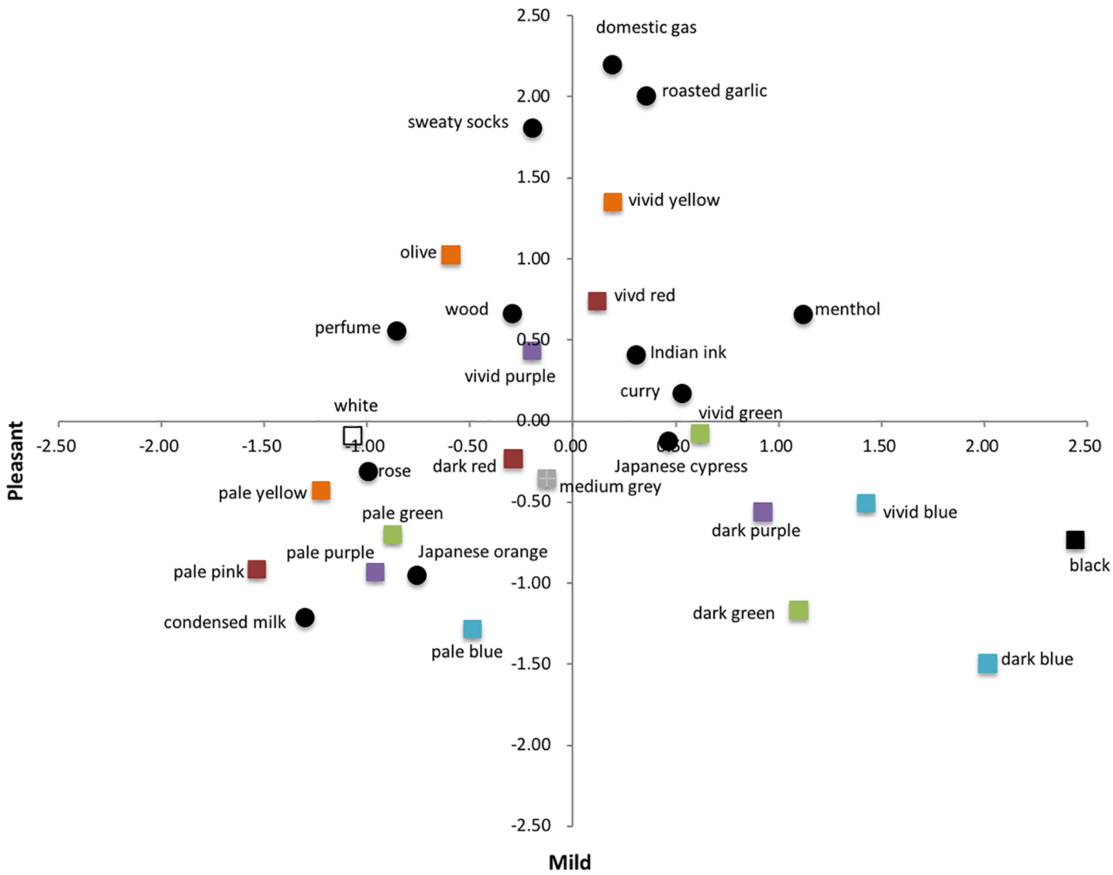


Figure 4-1. Factor scores of colour and odour impressions in the menstrual phase plotted for the Mild and Pleasant factors. Squares show factor scores of colour impressions, and circles show factor scores of odour impressions.

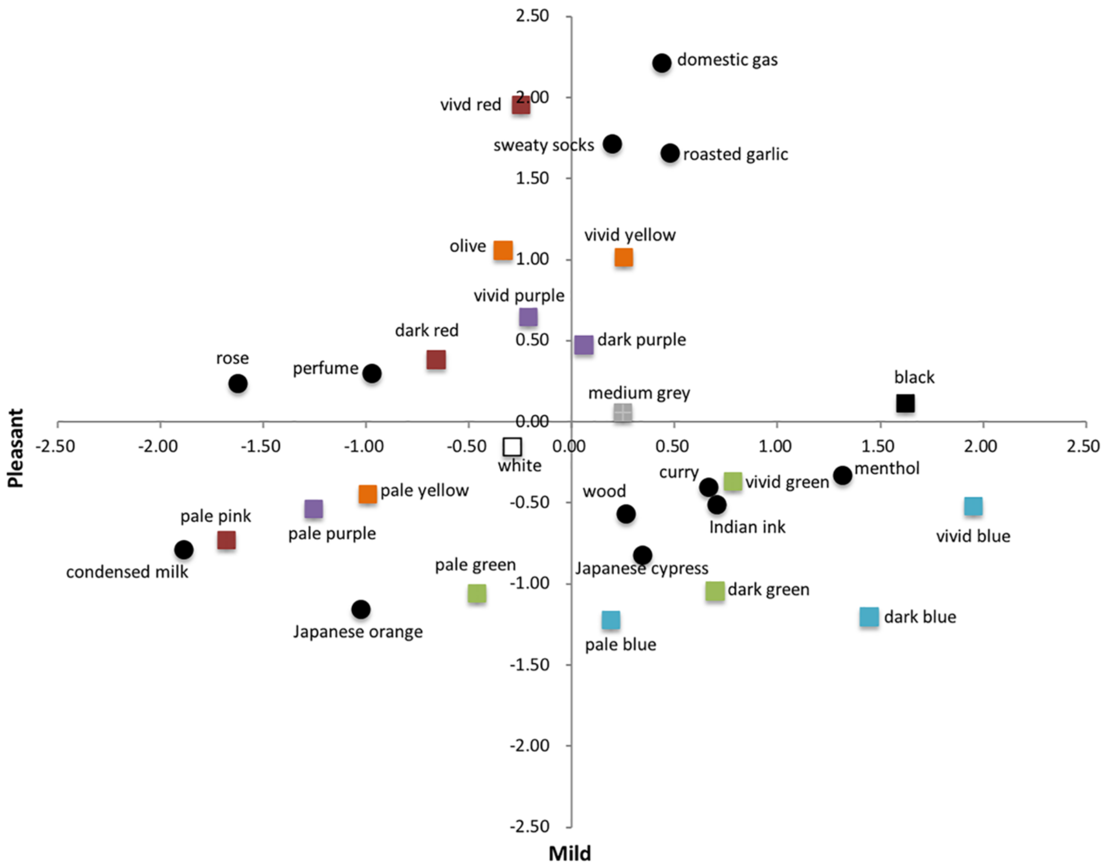
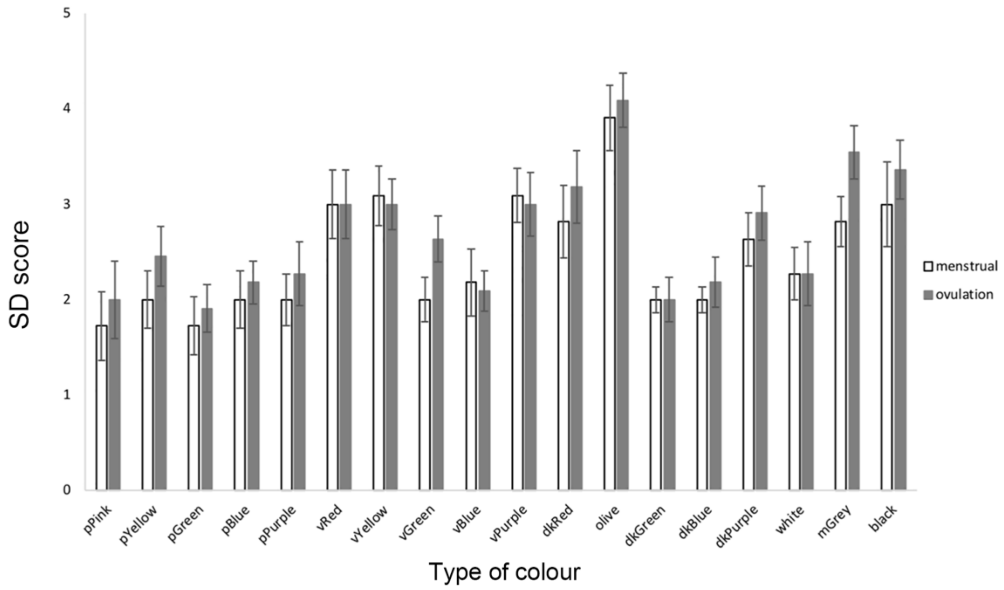


Figure 4-2. Factor scores of colour and odour impressions in the ovulation phase plotted for the Mild and Pleasant factors. Squares show factor scores of colour impressions, and circles show factor scores of odour impressions.



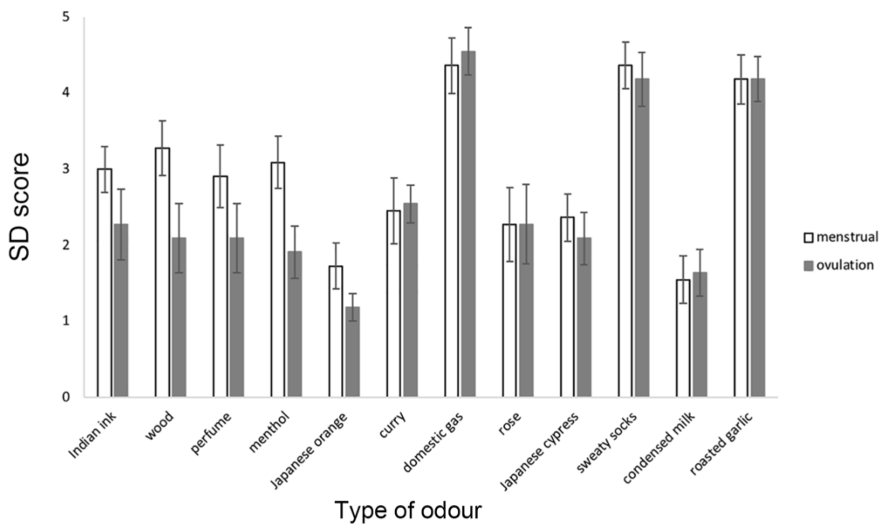


Figure 4-3. Average SD scores of "pleasant-unpleasant" variable with the standard error (SE) for evaluation of colour impressions (above) and evaluation of odour impressions (below). The white bars show the average SD scores in the menstrual phase, and the grey bars show those in the ovulation phase. Higher score shows more unpleasant evaluation, and lower score shows more pleasant evaluation.

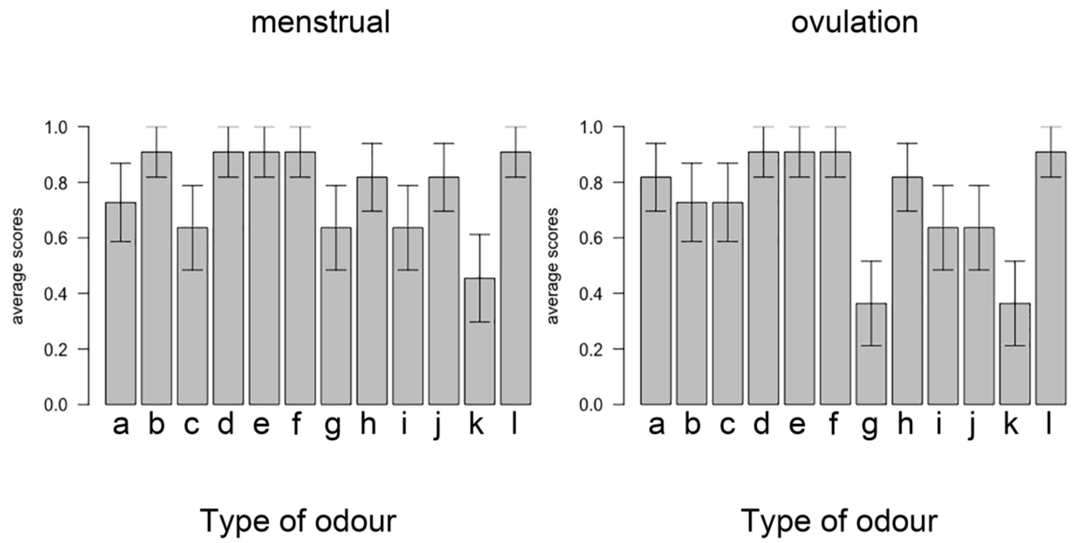


Figure 4-4. Average scores of odour identification task with the standard error (SE). The left graph shows the average scores in the menstrual phase, and the right graph shows those in the ovulation phase. Types of odour were (a) Indian ink, (b) wood, (c) perfume, (d) menthol, (e) Japanese orange, (f) curry, (g) domestic gas, (h) rose, (i) Japanese cypress, (j) sweaty socks, (k) condensed milk, (l) roasted garlic.

Chapter 5

Correspondence between Colour and Odour for Women in Pre-Menopause and Post-Menopause

Abstract

Cross-modal correspondences in the human sensory systems often appear for different levels of sensory inputs. Bimodal correspondence between colour and odour is an example, but whether there is hormonal modification of such colour-odour correspondence has remained unclear. Given the well-known sexual differences of colour and odour perceptions, the basis of colour-odour correspondences would be predicted to depend on the endocrine background. Here, the author experimentally investigated the influence of hormonal changes in menopausal women by conducting evaluations of colour and odour impressions, matching tasks between colour and odour, and odour identification tasks, comparing two groups of women: pre- and post-menopausal. The results showed that both pre- and post-menopausal women had similar impressions and images of colours for odours, while post-menopausal women had significantly lower abilities of odour identification than pre-menopausal women. This suggested that the degree of conviction about an odour's identification might slightly affect the subjects' impressions of odours and their corresponding colour choices. Menopause might not directly affect cognitive aspects regarding colour or odour, but might instead affect their perceptions, and these perceptual aspects might also possibly result in differences in cognition.

Keywords: Colour, odour, impression, cross-modal correspondence, menopause

5.1 Introduction

Colour-odour cross-modal correspondence

Humans use more than two sensory functions at once and relate two different types of information to each other. These cross-modal or multimodal correspondences, known as synesthesia, have been studied, particularly regarding correspondences between auditory and visual senses, such as associations between sounds and colours or shapes (Hubbard et al., 2005; Maurer et al., 2006; Nunn et al., 2002; Ramachandran & Hubbard, 2001). Auditory and visual sensory correspondences have been studied more than correspondences of any other senses, and these correspondences can be observed not only for specific persons but also for humans in general (Ramachandran & Hubbard, 2001). However, other types of sensory correspondences, such as association between visual and olfactory senses, have not been well studied. Some studies about colour-odour cross-modal associations show that humans relate odours to specific colours (Gilbert et al., 1996), and stronger intensity of odour is more often associated with darker colours than lighter colours (Kemp & Gilbert, 1997; Zellner & Kautz, 1990; Zellner & Whitten, 1999). Recent studies have also provided more systematic data about cross-modal correspondences between colour and odour by examining numerous odour types, such as spices and aromatic oils, and led to creation of a colour-odour model showing how people relate specific odours and colours (Miura & Saito, 2012a, 2012b; Saito, 2016). However, human visual and olfactory perception and cognition are often affected and altered by physiological changes, age or sex, and how these factors influence colour-odour cross-modal correspondence has remained unclear.

Perceptual and cognitive changes in women in menopause

Physiological changes, particularly female hormones (e.g. estrogen and progesterone), influence women's life cycle, and women have various changes in perception, cognition, mental condition and behaviour during the menstrual cycle and menopause. Women in menopause, for example, experience health and mental changes such as hot flashes, night sweats, vaginal dryness, sleep disturbance and depression (Judd et al., 2012; Vivian-Taylor & Hickey, 2014). In addition, during menopausal transition following aging, cognitive dysfunction, including decreased verbal fluency and word-narrative memory, appears in women (Berent-Spillson et al., 2012; Maki, 2015). Regarding perception, women are likely to have decreased abilities of visual perception, as shown by such indicators as declines of reaction time (Halbreich et al., 1995; Rosic et al., 2014; Zilberman et al., 2015), and also to have changes of olfactory senses, according to the hormonal changes in menopause (Caruso et al., 2004; Devanand et al., 2000; Doty et al., 2015; Pouliot et al., 2008). However, some studies showed no strong associations between menopause and perceptual or cognitive functioning (Epperson, Sammel, & Freeman, 2013; Kok, Helen S.; Kuh, Diana; Cooper, Rachel; van der Schouw, Yvonne T.; Grobbee, Diederick E.; Wadsworth, Michael E. J. and Richards, 2006), and menopausal symptoms can vary according to their individuals' health conditions and experiences (Nelson, 2008; Vivian-Taylor & Hickey, 2014). Menopausal women may also have deficits in colour perception, particularly perception related to short-wavelength cones (Eisner & Demirel, 2011), but the colour perceptual and cognitive functions affected by menopause have not been clearly identified.

Moreover, possible cross-modal correspondences, except for auditory-visual associations, have remained unclear. The influences of various factors such as physiological changes of female hormones on these correspondences is also unknown. To explore the possibility that female hormones might affect perception and cognition in vision and olfactory sensing, here the author experimentally examined the correspondence between colour and odour in women in menopause, based on methods used in previous studies (Miura & Saito, 2012a, 2012b), and considering the physiological transition between the pre- and post- menopausal phases. The author hypothesised that menopause affected the impressions of colour and odour, and the correspondence between them.

5.2 Materials and methods

Ethics

All experiments were carried out in accordance with the Guidelines for the Research in Human Participants, issued by the Human Research Ethics Committee of the Primate Research Institute, Kyoto University, and the experimental protocol was approved by the Committee (Permit No.2017-05). Before starting experiments, the author obtained agreements from all participants.

Participants

Fifty-nine female participants (mean with standard deviation of age, 49.88 +/- 4.96 yrs, range 42-59 yrs) joined the experiments. All participants answered a questionnaire about their menopause conditions, stating either pre-, peri-, post-menopause or unknown. According to the results of the questionnaire, the author obtained 23 pre-menopause participants (age: 46.17 +/- 2.50 yrs, range: 42 - 52) who had a menstrual cycle, and 20 post-menopause participants (age: 55.05 +/- 3.00 yrs, range: 48 - 59) who had menopausal conditions that had continued for more than two years. The author also excluded 1 participant whose menopausal condition had lasted for only three months, 8 participants in peri-menopause who were in a transitional phase to menopause, 4 whose conditions were unknown, and 3 who had had a hysterectomy, from the analysis. All participants in the pre- and post-menopause groups were Japanese and right handed, and participants did not have any cognitive disorder tested by the Raven Coloured Progressive Matrices or colour blindness tested by the Ishihara Color Vision Test.

Stimuli

Colour stimuli. The author used 18 colours from the Practical Color Coordinate System (PCCS). The PCCS is a colour system commonly used in Japan and developed by the Japan Color Research Institute. The size of each colour chart the author used was 8.75 x 12 cm. Colours included 15 chromatic colours: 5 hues (red, yellow, green, blue and purple) x 3 tones (pale, vivid and dark), and 3 achromatic colours (white, medium grey and black) (Table 5-1).

Odour stimuli. The author used 12 types of odour from OSIT-J, produced by Takasago International Corporation, Ltd. (Tokyo, Japan), including odours of perfume, rose, condensed milk, Japanese orange, curry, roasted garlic, sweaty socks, domestic gas for cooking, menthol, India ink, wood and Japanese cypress (hinoki). These odours were familiar to Japanese people in daily life.

Apparatus

Experiments were controlled with a custom-made program written using OpenSesame software ver. 3.1.6 (Mathôt, 2010-2016) in the Microsoft Surface Pro 2, and were performed using a USB keypad connected to a tablet. On the tablet screen, one of the Semantic Differential (SD) scales was shown, and participants indicated their impression of colours or odours by pressing a button of the keypad during the experiments.

Procedure

All participants performed the following tasks: evaluation of colour impression, odour impression, matching/nonmatching between colour and odour, and odour identification. First, the participant performed the evaluation of colour impression task. Next, the participant was presented with a single odour, which she evaluated using three tasks (odour impression, matching/nonmatching between colour and odour, and the odour identification), before being presented with another sample odour to evaluate in the same way.

Colour impressions. Participants were asked to sit in front of the Surface screen (the resolution: 1920 x 1080 pixels) and the keypad on a desk. First, an examiner showed a participant one of the 18 colour cards from the PCCS colour chart, and the participant evaluated her impressions of the colour on the Surface screen by pressing a button of the keypad. To express their impressions, participants were presented with 12 adjective word pairs: “warm-cool”, “shallow-deep”, “ordinary-characteristic”, “soft-hard”, “clear-muddy”, “gentle-harsh”, “simple-complicated”, “sweet-non sweet”, “bright-dark”, “like-dislike”, “feminine-masculine”, and “pleasant-unpleasant”, based on previous studies of colour and odour classification by words (Higuchi et al., 2004; Miura & Saito, 2012a, 2012b; Oyama et al., 1965). Each pair appeared randomly on the screen with a 5-point scale based on the Semantic Differential (SD) method. Participants provided one number from the 5-point scale for each adjective word pair, and thus evaluated each colour with the 12 adjective word pairs.

Odour impressions. The author used the same method and procedure for the evaluation of odour impressions as described above for the colour impression. For this, the author used the 12 different types of odour in OSIT-J. Each odour was enclosed in microcapsules and was mixed into an odourless solid cream, shaped like a lipstick. Following the instructions of OSIT-J, an examiner put cream containing one odour in about a 2-cm circle on a sheet of paraffin paper, folded the paper in half, rubbed it, and passed it to the participants. The participants sniffed the odour, and evaluated their impressions of it using a 5-point scale for the 12 adjective word pairs listed above. All participants evaluated their impressions of the 12 types of odour.

Matching/nonmatching between colour and odour. After evaluating one odour, participants were required to choose the top three colours which were most suitable for matching with the odour, and top three colours which were most unsuitable, from the 18 types of colours in the PCCS colour chart.

Odour identification. Participants were also asked to name each odour, choosing one answer from six possible choices, including four choices with names of entities related to the odours: only one of these four choices was correct, and the other three were incorrect. In addition, one choice was "unknown", and one choice was "undetectable". When participants answered the correct choice, the author counted one point in the score. Participants were required to answer 12 types of odour, and the maximum score was 12 points.

Analysis

The colour and odour impressions evaluated using the 5 points scale were analysed by a factor analysis with the generalized least squares method and varimax rotation in SPSS ver. 25. After obtained factors, the author examined the internal consistency with Cronbach's formula, and analysed factor scores between pre- and post-menopause groups by the analysis of variance tests (ANOVA).

In the matching/nonmatching task between colour and odour, participants had three matched or nonmatched colour choices with each odour. The author counted 1 point for 1 colour choice and determined how many matched or nonmatched points were counted in each colour for each odour, and conducted a $\chi2$ test to compare total points between the pre- and post-menopause groups for every colour in either matched or nonmatched with odour choices.

The scores in the odour identification task were analysed by ANOVA. In the models, the author set the condition of participants (pre-menopause or post-menopause) and the type of odour (perfume, rose, condensed milk, Japanese orange, curry, roasted garlic, sweaty socks, domestic gas, menthol, India ink, wood or Japanese cypress) with the interaction effect term (menopausal conditions x odour types) as the fixed main effect terms, and participant ID as a random effect term. When the author observed a significant interaction effect, as a post-hoc comparison, the author computed the 95% confidence intervals of the estimated marginal means between two comparison levels for each level of the other condition, and examined whether two levels differed significantly.

5.3 Results

Colour and odour impressions. The factor analysis revealed three factors that affected the participants' evaluations, the first factor was named "Mild", and the second "Clear" for both the pre-and post-menopause groups, and the third factor "Shallow" for the pre-menopause group and "Gentle" for the post-menopause group (Tables 5-2, 5-3, Figures 5-1, 5-2). Adjective word pairs in the Mild and Clear factors did not differ greatly between pre- and post-menopausal women. For post-menopausal women, the pairs, "gentle-harsh", "like-dislike" and "pleasant-unpleasant" moved from the Mild or Clear factor to the Gentle factor.

The internal consistency for major factors was examined using Cronbach's formula, and the α values for the Mild, Clear and Shallow/Gentle factors obtained were 0.949, 0.948 and 0.835 for the pre-menopause group, and 0.942, 0.894 and 0.918 for the post-menopause group, respectively. The author also used factor scores for comparison between the pre- and post-menopause groups by one-way ANOVA and found no significant differences between the two groups (Mild, Clear and Shallow/Gentle: $F_{1, 59} = 0.000$, $P = 1.000$).

The author then focused on the distances between each factor score and the origin, particularly, for the Mild and Clear factors in odour impression. Most of the factor scores for odour impressions, except for wood, perfume and curry, had longer distances from the origin for pre-menopause participants than for post-menopause participants. Thus, pre-menopause participants evaluated odours more clearly using a 5-point scale, while post-menopause participants evaluated them less clearly.

Matching between colour and odour. Based on the scores of matched or nonmatched choices of each colour for each odour, the author conducted a $\chi 2$ test to compare the scores between the pre- and post-menopause groups. The author did not find a significant difference in matching and nonmatching of colours with odours between the pre- and post-menopause groups. Both groups of participants were likely to choose the same or similar colours and tones for odours (Table 5-4). For instance, both pre- and post-menopausal participants chose pale yellow and vivid yellow for matched colours with Japanese orange, while they chose black and olive for nonmatched colours. Domestic gas was matched with olive while it was nonmatched with pale pink and pale yellow. As can be seen from these examples, participants tended to select the same or similar colours and tones for odours.

Odour identification. Conducting a two-way 2 x 12 ANOVA, the author found no significant interaction effect between participants' menopause condition and types of odour in the odour identification task ($F_{11, 492}$ = 0.681, P = 0.757, partial η^2 = 0.015 Figure 5-3). In a post-hoc comparison for identification of odour, only wood was significantly different between pre- and post-menopause participants ($F_{1, 492}$ = 4.201, P = 0.041, partial η^2 = 0.008), with pre-menopause participants having a higher score than post-menopause participants. However, the main effects of menopause condition and odour type were significant (menopause condition: $F_{1, 492}$ = 9.935, P = 0.002, partial η^2 = 0.020; odour types: $F_{11, 492}$ = 5.501, P = 0.000, partial η^2 = 0.110). The pre-menopause participants had higher scores than the post-menopause participants for most types of odour. Comparing the odour types, participants in both groups had difficulty in identifying several types of odour, especially domestic gas, wood and condensed milk.

5.4 Discussion

The results of the present experiments showed no statistically significant difference of colour or odour impressions between pre- and post-menopausal groups of women. Both groups had similar impressions of colours and odours. In the colour-odour matching/nonmatching task, both groups also tended to choose similar colours or tones for matched or nonmatching odours. However, in the odour identification task, the scores of pre- and post-menopausal women differed significantly. The pre-menopausal participants identified types of odour better than the post-menopausal participants, while both groups showed some similar odour-identification patterns, namely, they were unable to identify specific types of odours such as domestic gas, wood and condensed milk. The differences in the degree of odour identification between pre- and post-menopausal participants might have slightly affected their odour impressions and colour choices for odours.

Colour and odour impressions, and visual images of odours according to menopausal status

The pre- and post-menopausal women had basically similar impressions of colours and odours, and visual images for odours, and thus physiological changes such as those that occur during menopause may not largely determine these cognitive features. Although previous studies of these cognitive features did not include comparative examinations between different groups of participants, the results of the author's examinations suggest that humans may generally have similar impressions of colours and odours. In particular, colour and odour impressions seem to be commonly categorised by two (or possibly three) main factors: one factor named Mild (including "warm-cool", "soft-hard", “feminine-masculine” and “sweet-non sweet”) and another factor named Clear (including “clear-muddy” and “bright-dark”), observed in previous studies (Higuchi et al., 2002, 2004, Miura & Saito, 2011, 2012a, 2012b; Wakata & Saito, 2014). The colour and odour impressions of women in menopause generally showed these same patterns of categorization, although the impressions were found here to include one more factor, designated as Shallow factor, which included “shallow-deep” and “ordinary-characteristic” in pre-menopausal participants, and also one more factor designated as Gentle factor, which included “gentle-harsh”, “like-dislike” and “pleasant-unpleasant” in addition to the characteristics of Shallow factor, in post-menopausal participants.

However, comparison of the factor scores of colour impressions in both pre- and post-menopausal women gave results that differed from those of previous studies of factor scores categorised by three factors, which corresponded to the three colour attributes: hue, brightness and chroma, respectively (Oyama et al., 1965). Previous studies found that Clear factor was related to chroma, including vivid colours and white, and Mild factor was related to brightness, including bright and warm colours and less bright and cold colours (Miura & Saito, 2011, 2012b), while the author’s results showed no clear and straightforward relationship with hue, brightness or chroma. Regarding odour impressions, Clear factor in pre-menopausal women included “like-dislike” and “pleasant-unpleasant”, and these women might have found the domestic gas, sweaty socks and roasted garlic odours to be more disliked or unpleasant odours, while post-menopausal women categorised these types of odour in Gentle factor, which included “like-dislike” and “pleasant-unpleasant”, and had more moderate impressions.

In both the pre- and post-menopausal groups, odours such as domestic gas, sweaty socks and roasted garlic tended to be matched with lower brightness colours such as medium grey or black and darker tone colours, possibly reflecting the relationship between intensity of odours and brightness (Kemp & Gilbert, 1997; Zellner & Kautz, 1990; Zellner & Whitten, 1999). Moreover, participants were more likely to choose matched colours for which they could imagine colours of the actual objects, for example, Japanese orange matched with pale yellow/green, and to choose nonmatched colours opposite to the matched colours in hue, brightness or chroma, based on their experience and memory of sniffing. However, it is important to note that the first choices for some odours, such as Indian ink, wood and Japanese cypress, clearly showed differences between pre- and post-menopausal women (Table 4), and this might have been affected by how the women identified the odours.

Perception of women in menopause

In odour identification in the experiments, post-menopausal women had more difficulty identifying types of odour than did pre-menopausal women. It is known that women are greatly influenced by changes of female hormones, particularly during the menstrual cycle and menopause, and some women experience perceptual, cognitive and mental changes. In particular, for women in menopause, visual perception and the response to visual stimuli decline, and olfactory perception is likely to be decreased (Berent-Spillson et al., 2012; Caruso et al., 2004; Doty et al., 2015; Kalantari, Kalantari, & Hashemipour, 2017; Maki, 2015; Pouliot et al., 2008). Some studies about colour perception showed that female hormones could affect short-wavelength light sensitivity, by which humans perceive bluish colour (Akar et al., 2005; Apaydin et al., 2004; Eisner & Demirel, 2011; Eisner & Incognito, 2006; Eisner & Toomey, 2008). The author also revealed that women in menopause had a difference in colour perception in a study comparing pre- and post-menopausal women, and that post-menopausal women had slower responses to blue in Chapter 3 (Iriguchi et al., 2018). Thus, according to the menopausal transition accompanying aging, women could experience functional declines in visual and olfactory sensitivity, and the author's experiments also revealed that post-menopausal women had weaker abilities of odour identification than pre-menopausal women.

Conviction about colours evoked by odours

Pre- and post-menopausal women commonly had similar impressions of colour and odour, and they related similar colours to odours. However, the identification of odours was significantly different between pre- and post-menopausal women, suggesting that these differences may influence odour impressions and choices of colour evoked by odours, although the differences may be small. Odour classifications have been problematic because of individual differences and poor vocabulary for classifying odours, and several studies revealed relationships between olfaction and individual experiences of sniffing and emotional characteristics (Lawless, 1989; Willander & Larsson, 2007; Zald & Pardo, 1997). Thus, odour impressions may differ depending on various factors. When the author examined the distances between factor scores and the origin in odour impression, pre-menopausal women had longer distances and more scattered plots than post-menopausal women. This suggests that pre-menopausal women made clearer evaluations of odour impressions, while post-menopausal women might have evaluated these impressions more moderately or ambiguously. This might have resulted from how confident participants were about what the odour was, that is, their degree of conviction for identifying odour types. Post-menopausal women might have had more difficulties in identifying and verbalising what the odour was, so they may have evaluated odour impressions ambiguously and also may have chosen ambiguous colours when they were less confident.

5.5 Conclusions

In conclusion, the findings revealed that pre- and post-menopausal women had similar colour and odour impressions, and colour images of odours. However, when the author analysed factor scores in colour impressions, factors were not categorised following hue, brightness and chroma, unlike in previous studies, and the author's results suggested that colour impressions might not be straightforward for women in menopause. Moreover, regarding identification of odours, post-menopausal women identified types of odour less accurately than the pre-menopausal women, and this may affect odour impressions and colour choices of odours, which differed between pre- and post-menopausal women. Menopause physiologically influences visual and olfactory perception, but does not directly affect cognitive functions such as impressions of, and correspondence between, colour and odour. However, these cognitive aspects might be affected by the degree of conviction about perception.

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Tables

Pale Pink (pR) 4R 8.0/3.5	Pale Yellow (pY) 5Y 9.0/3.0	Pale Green (pG) 3G 8.0/3.0	Pale Blue (pB) 3PB 7.5/3.0	Pale Purple (pP) 7P 7.5/3.0
Vivid Red (vR) 4R 4.5/14.0	Vivid Yellow (vY) 5Y 8.0/13.0	Vivid Green (vG) 3G 5.5/11.0	Vivid Blue (vB) 3PB 3.5/11.5	Vivid Purple (vP) 7P 3.5/11.5
Dark Red (dkR) 4R 2.5/6.0	Olive (dkY) 3G 3.0/4.5	Dark Green (dkG) 3G 3.0/4.5	Dark Blue (dkB) 3PB 2.0/5.0	Dark Purple (dkP) 7P 2.0/5.0
White (W) N9.5	MediumGrey (mGY) N5.5	Black (Bk) N1.5		

Table 5-1. Eighteen types of colours from PCCS stated with Munsell notation.

Variable	Factor Mild	Clear	Shallow	Communality
warm-cool	0.889	0.151	-0.042	0.969
sweet-non sweet	0.872	0.354	0.205	0.973
soft-hard	0.814	0.115	0.481	0.968
feminine-masculine	0.810	0.285	0.152	0.870
gentle-harsh	0.716	0.294	0.602	0.975
clear-muddy	0.079	0.954	0.213	0.991
like-dislike	0.481	0.791	0.234	0.990
bright-dark	0.410	0.783	0.154	0.981
pleasant-unpleasant	0.496	0.783	0.330	0.993
simple-complicated	0.108	0.755	0.352	0.899
shallow-deep	0.112	0.295	0.921	0.980
ordinary-characteristic	0.299	0.318	0.770	0.941
Total	4.147	3.848	2.459	10.454
Variance (%)	34.562	32.07	20.492	87.124

Table 5-2. Results of factor analysis with colour and odour impressions of pre-menopausal participants. There were three major factors, the first as Mild, the second as Clear and the third as Shallow factors. The table shows factor loading of three factors and communality.

Variable	Factor Mild	Clear	Gentle	Communality
warm-cool	0.856	0.161	-0.053	0.945
feminine-masculine	0.828	0.182	0.325	0.957
soft-hard	0.825	0.068	0.535	0.988
sweet-non sweet	0.813	0.288	0.385	0.989
clear-muddy	0.216	0.906	0.247	0.957
simple-complicated	-0.011	0.830	0.198	0.890
bright-dark	0.632	0.772	0.032	0.999
gentle-harsh	0.561	0.085	0.802	0.981
ordinary-characteristic	0.114	0.338	0.778	0.904
like-dislike	0.176	0.668	0.677	0.983
pleasant-unpleasant	0.214	0.655	0.673	0.988
shallow-deep	0.335	0.304	0.630	0.983
Total	3.722	3.341	3.200	10.263
Variance (%)	31.018	27.842	26.668	85.528

Table 5-3. Results of factor analysis with colour and odour impressions of post-menopausal participants. There were three major factors: Mild, Clear and Gentle. The table shows factor loading of three factors and communality.

Odour type	Menopause	First colour choices with proportion (%)	
Indian ink	Pre	pPurple	21.7%
	Post	mGrey	20.0%
wood	Pre	pYellow	17.4%
	Post	pGreen	25.0%
perfume	Pre	pPink	17.4%
	Post	pPink	30.0%
menthol	Pre	pGreen, White	21.7%
	Post	pBlue, White	25.0%
Japanese orange	Pre	vYellow	34.8%
	Post	pYellow	30.0%
curry	Pre	vYellow, Olive	30.4%
	Post	Olive	30.0%
domestic gas	Pre	Olive, Black	21.7%
	post	Olive	35.0%
rose	Pre	pPink	30.4%
	Post	pPink, vPurple	20.0%
Japanese cypress (hinoki)	Pre	Olive	17.4%
	Post	pPurple	20.0%
sweaty socks	Pre	Olive	65.2%
	post	Olive	45.0%
condensed milk	Pre	pYellow	34.8%
	Post	pPink	30.0%
roasted garlic	Pre	Olive	65.2%
	Post	Olive	25.0%

Table 5-4. Top matched colour choices with each odour by pre- and post-menopausal groups, including proportion of choices. The proportion expresses the percentage of participants who chose the indicated colour as matching the listed odour.

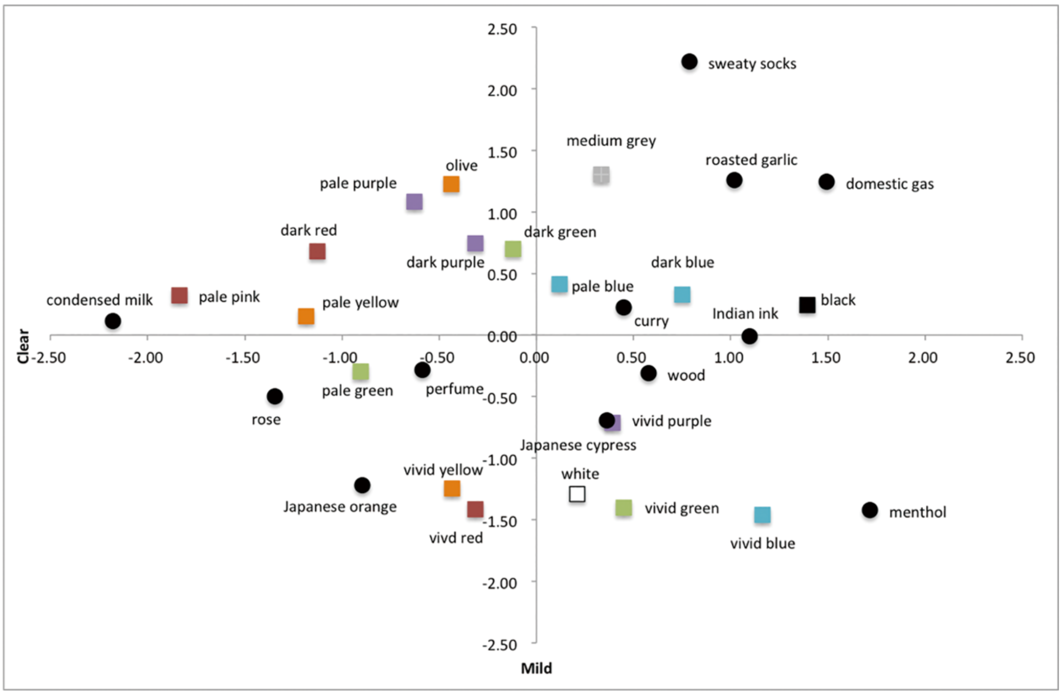

Figure 5-1. Factor scores of colour and odour impressions of pre-menopausal participants plotted for the first factor, Mild, and the second factor, Clear. Squares show factor scores of colour impressions, and circles show factor scores of odour impressions.

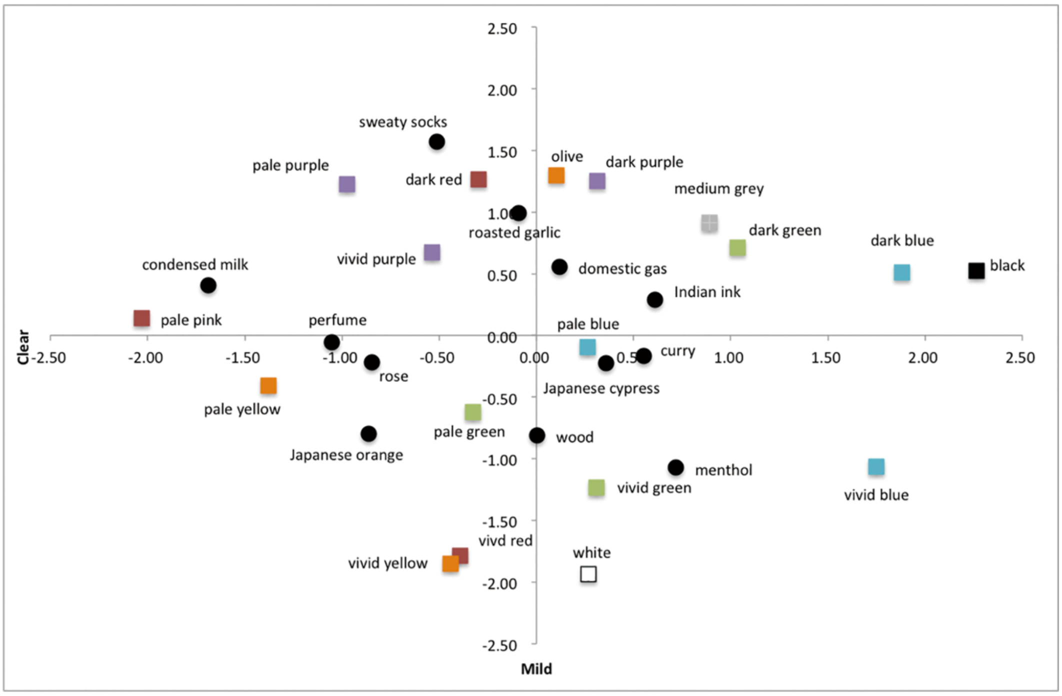

Figure 5-2. Factor scores of colour and odour impressions of post-menopausal participants plotted for the first factor, Mild, and the second factor, Clear. Squares show factor scores of colour impressions, and circles show factor scores of odour impressions.

Figure 5-3. Average scores of identifications of each odour. A correct answer is counted as one point, and an incorrect answer or an answer of unknown or undetectable is counted as zero. The left graph shows the average scores of pre-menopausal women, and the right graph shows those of post-menopausal women for each odour. Types of odour: (a) Indian ink, (b) wood, (c) perfume, (d) menthol, (e) Japanese orange, (f) curry, (g) domestic gas, (h) rose, (i) Japanese cypress, (j) sweaty socks, (k) condensed milk, (l) roasted garlic.

Chapter 6

General Discussion

6.1 Summary and discussion of the study

In the present thesis, the author examined possible modulations of colour and odour perception, cognition and cross-modal correspondences according to hormonal changes during the menstrual cycle and menopause, by comparisons between women in the menstrual and ovulation phases, and between women in pre- and post-menopause. Many studies revealed various perceptual and cognitive differences regarding colour and odour, so the author assumed that hormonal changes during the menstrual cycle and menopause might modulate these perceptual and cognitive features, and also cross-modal correspondences between colour and odour. The author also predicted that when hormonal levels were low, performance of participants would decline.

Colour perception

In the examinations of colour perception using face and scrambled face stimuli, women in the post-menopause group clearly showed differences from women in the pre-menopause group (Chapter 3). Post-menopausal women had slower reaction times only to blue, while pre-menopausal women did not have any differences in reaction time to any colours. This result may agree with the previous studies which found that declines of hormonal secretion are associated with dysfunction in the short-wavelength sensitivity, and thus in subjects' reactions to bluish colours (Eisner et al., 2004; Eisner & Demirel, 2011; Eisner & Incognito, 2006; Eisner & Toomey, 2008). The methods in the previous studies mainly focused on answering colour names of stimuli, but this thesis study used a method of measuring reaction times to colour stimuli, and thus the present findings revealed more direct perceptual processing and responses towards colours.

The results for women during the menstrual cycle showed that performance in both the face stimuli and scrambled face stimuli tasks was better in the menstrual phase than in the ovulation phase (Chapter 2). However, in the face stimuli task, no significant differences of reaction time to colours were found according to the phase of the participants. The results in the scrambled face stimuli task showed the interaction effect between the condition and colour, and reaction times only to the happy scrambled face and those to red were similar between the phases while reaction times to the other two scrambled faces and colours were faster in the menstrual phase than the ovulation phase. This implies that women in the menstrual phase paid more attention to faces with colours, but less to shapes with colours.

Studies by Apaydin et al. (2004) and Akar et al. (2005) compared the short-wavelength sensitivity between the follicular (7-10th day of the cycle, phase with increasing level of estrogen) and the luteal (3-6 days before menstruation, phase with decreasing levels of estrogen and progesterone) phases, and revealed declines of the sensitivity in the luteal phase. The findings of those studies suggested that hormonal changes during the menstrual cycle are possibly associated with the sensitivity to short-wavelength light, while the present study did not find a clear association between the menstrual cycle and the sensitivity. This implies that the phenomenon might depend on individual differences, and it might not be simple and straightforward to understand colour perception in women in the menstrual cycle. The results obtained in this thesis study support only the possibility of an association between the menstrual cycle and short-wavelength sensitivity, as women's reaction times to blue in the face stimuli task tended to be slower than to the other colours in both the menstrual phase and ovulation phase, although there were no statistically significant differences. However, this association needs to be examined in more detail with larger numbers of participants and various methods such as more frequent times of examinations according to the secretion levels of both estrogen and progesterone during the menstrual cycle.

Odour perception

In this study, women showed significant differences in the identification of odours depending on the menopausal status, but no statistically significant differences depending on the phase of the menstrual cycle. During the menstrual cycle, women had no differences in sensitivity to odours between the menstrual and ovulation phases (Chapter 4). The features of olfactory perception according to the phase of the menstrual cycle remain controversial because some studies showed that odour sensitivity became lower in the ovulation phase, but others found higher sensitivity in the same phase (Navarrete-Palacios et al., 2003; Nováková et al., 2014; Pause et al., 1996). Moreover, odour sensitivity might vary depending on the type of odour: for example, women during the ovulation phase seemed to become more sensitive to specific odours, such as androstenone and androsterone, which are produced by men (Lundström et al., 2006; Renfro & Hoffmann, 2013). Hormonal changes during the menstrual cycle could play important roles in modulating odour perception, probably resulting in promotion of women’s reproduction. However, the results obtained in the present study revealed differences from the previous studies. During the experiments, participants in this thesis study were found to have individual differences in odour sensitivities, so these individual differences might influence the results in olfactory identification tasks.

Regarding odour identification by women in menopause, post-menopausal women had lower sensitivity than pre-menopausal women (Chapter 5). In a number of publications, menopausal women were shown to have difficulties in olfactory perception. Hormonal declines in menopause could decrease functions of nasal airflow and odour detection thresholds (Pouliot et al., 2008). On the other hand, menopausal women who received hormonal replacement therapy for several months could show improvement of their odour detection threshold (Caruso et al., 2004; Doty et al., 2015). Hormones could be associated with menopausal women's odour sensitivity, while other factors such as diseases might also affect it. Age-related diseases such as Alzheimer's disease and Parkinson's disease may be related to olfactory disfunction (Koskinen et al., 2004; Kovács, 2004; Murphy et al., 2002). These diseases are also related to hormones, and women are at higher risk for them than men, and post-menopausal women are at higher risk than pre-menopausal women, so hormones, olfactory perception and these age-related diseases may be interrelated (Labandeira-Garcia, Rodriguez-Perez, Valenzuela, Costa-Besada, & Guerra, 2016; Li & Singh, 2014; Pines, 2016).

Odour perception can also be problematic because classification of odours may vary depending on the vocabulary used for categorisation and on the individual, and possibly depending on their experiences of sniffing odours, and moreover, emotions are also related to odour perception (Lawless, 1989; Willander & Larsson, 2007; Zald & Pardo, 1997). Many researchers have suggested that the vocabulary available to describe odours is extremely poor compared with the number of odour types (Higuchi et al., 2002, 2004), and this might be one of the factors causing ambiguous categorisation and evaluation of impressions about odours. Individual differences can also be large, because each individual has various experiences, memories and emotional states related to odours (Berglund, Berglund, Engen, & Ekman, 1973; Willander & Larsson, 2007; Zald & Pardo, 1997). Individual memories coupled with odours often last longer than memories coupled with verbal and visual information, and memories coupled with odours tend to be associated with higher emotional arousal (Chu & Downes, 2000; Willander & Larsson, 2006, 2007). Thus, the individual who has had experiences and memories coupled with certain odours may use these experiences and memories in order to recognise the odours, and these factors may influence their categorisation and impressions of odours. In fact, participants in both the menstrual and menopause groups in the present study seemed to make various identifications and labellings of odours, and some individuals were good at these tasks while others were not, probably in regardless of their hormonal situations.

Cross-modal correspondence between colour and odour

Studies about cross-modal correspondence between colour and odour have revealed a fundamental association of these two different types of sensory modality simultaneously (e.g., Gilbert et al., 1996; Kemp & Gilbert, 1997; Miura & Saito, 2012a, 2012b; Zellner & Whitten, 1999). Effects of physiological differences (such as differences of age or sex) on perception were not examined in these previous studies about cross-modal correspondence. However, sex differences have been reported for both colour and odour perception (Bimler, Kirkland, & Jameson, 2004; Doty et al., 1984; Jain et al., 2010), and many studies have suggested differences in colour and odour perception and cognition according to female hormones' changes (e.g., Akar et al., 2005; Da Silva et al., 2015; Eisner & Toomey, 2008; Navarrete-Palacios et al., 2003; Pouliot et al., 2008). Based on this evidence, the question of how hormonal changes such as those during the menstrual cycle and menopause affect the cross-modal correspondence between colour and odour has been addressed in this thesis.

Regarding cross-modal correspondence between colour and odour with comparison between pre- and post-menopause women, and between women in the menstrual and the ovulation phases, the results revealed that the menstrual cycle and menopause may not modulate the cross-modal correspondence greatly. Women with all these different statuses seemed to have very similar impressions of colours and odours, and matched/nonmatched colour choices for odours (Chapter 4 and 5). First of all, colour and odour impressions were categorised into three factors for both pre- and post-menopausal women, and women in the menstrual and ovulation phases, and these characteristics were basically similar, although some of the components of factors were shifted to other factors. Colour and odour impressions are basically thought to categorise into two or three main factors (Higuchi et al., 2002, 2004, Miura & Saito, 2012a, 2012b), and the results in this thesis study showed similar phenomena. However, in both the menstrual and menopause groups, the factors of colour impressions were not associated with hue, brightness or chroma, unlike in previous studies (Miura & Saito, 2011, 2012b; Oyama et al., 1965). The top three matched/nonmatched colour choices for odours were also similar in both pre- and post-menopausal women, and women in the menstrual and ovulation phases, indicating that both pre- and post-menopausal women, and women in both the menstrual and ovulation phases, had specific colour images for odours.

However, women during the menstrual cycle had different colour and odour impressions of "pleasant-unpleasant". Women were more likely to feel unpleasant for colours in the ovulation phase, while they did so for odours in the menstrual phase. "Pleasant-unpleasant" impressions, particularly for odours, might be related to women's mating and reproduction behaviour as women's odour sensitivity, particularly for odours from men, increases near the ovulation phase at the peak of fertility (Lundström et al., 2006; Renfro & Hoffmann, 2013). Comparison between pre- and post-menopausal women also showed that both odour impressions and the best-matched colour choices were slightly different between these two groups, although these differences were not statistically significant. Regarding odour impressions, pre-menopausal women had clearer evaluation of odour impressions, while post-menopausal women had more moderate or ambiguous evaluation. The best-matched colour choices included different choices for some odours between pre- and post-menopausal women. One possible interpretation of these findings is that post-menopausal women had lower sensitivity of odour identification, so they may have had more ambiguous impressions and colour choices for odours. According to these findings, female hormones during the menstrual cycle and menopause may not directly modulate impressions or cross-modal correspondences between colour and odour, while "pleasant-unpleasant" impressions of colours and odours for women in the menstrual cycle could vary between the menstrual and ovulation phases. Perception, in particular odour sensitivity for post-menopausal women, may also cause slight differences in impressions and cross-modal correspondences.

Comparison between findings in the menstrual cycle and menopause

In this thesis study, exactly the same tasks were performed during the experiments examining women in both the menstrual cycle and menopause. The findings in these studies showed modulation of the perception of colour for both groups of women and modulation of the perception of odour only for the menopause group, but no modulation of cross-modal correspondences between colour and odour in different phases during the menstrual cycle or in women in menopause versus pre-menopausal women, by comparing the data between women with different hormonal status. Regarding the comparison between the menstrual and ovulation phase, and between pre- and post-menopause, the menstrual and menopause groups of women showed some similar and some different phenomena. Women had similar impressions of colour and odour, and similar colour choices for odours, regardless of whether they had different hormonal levels (in either the menstrual or ovulation phases, and either pre- or post-menopause). However, the characteristics of colour and odour perception were different between the menstrual and menopause groups of women. Women in the menstrual groups did not show any clear differences of colour perception between the menstrual and ovulation phases, except for red in the scrambled stimuli task. On the other hand, women in the menopause group showed a clear difference of colour perception compared to pre-menopausal women, namely a significant delay in reaction times to blue for post-menopausal women. Odour sensitivity was increased or decreased according to hormonal changes in menopause, but not during the menstrual cycle. In addition, the "pleasant-unpleasant" impression for colour and odour could differ for women between the menstrual and ovulation phases.

It is not straightforward to simply compare the results between the menstrual and menopause status, but based on the evidences obtained in the present study, women in menopause accompanied by aging, particularly post-menopausal women, might have more significant influences on perceptual features due to hormonal declines than women in the menstrual cycle. During the menstrual cycle, the levels of secretion of the hormones estrogen and progesterone change dramatically, but these changes might cause only slight modulations in perception, and individual differences are more likely to affect perception than hormonal changes.

Influences on perception and cognition: aging

Apart from hormonal changes such as the menstrual cycle and menopause, individual differences might be significant to women's perception and cognition. For example, aging is one of the factors that might modulate and often decrease abilities of perception and cognition, and abilities of visual and olfactory perception decline with aging. Elderly people seemed to have difficulties in visual sensitivity, particularly for the blue-green spectrum (Shinomori & Werner, 2003; Werner, 1996; Wijk, Berg, Sivik, & Steen, 1997). However, individual differences in visual sensitivity among the elderly can be large according to their life experiences (e.g., how much the eyes have been exposed to ultraviolet rays) (Shinomori & Werner, 2003; Werner, 1996). Declines in olfactory perception are also reported during normal aging (Markopoulou et al., 2016; Masurkar & Devanand, 2014; Seubert et al., 2017). However, olfactory dysfunction is also associated with age-related diseases such as Alzheimer's disease and Parkinson's disease (Koskinen et al., 2004; Kovács, 2004; Murphy et al., 2002). As the etiology of olfactory dysfunction in these diseases is unclear, whether olfactory dysfunction results from normal aging or reflects symptoms of such diseases may also be a difficult issue.

According to aging, the speed of cognitive processing and physical responses, tested by a number of tasks such as the Stroop, memory and word fluency task, generally slow down, and this results from declines in white matter integrity in the brain (Salthouse, 1996; van den Heuvel et al., 2006; Vernooij et al., 2009; Ylikoski et al., 1993). In this thesis study, women in the menopause study had a clear age difference between the pre- and post-menopause groups, and differences between pre- and post- menopausal participants that were found in the perception of colour and odour (Chapter 3 and 5) might have been affected by aging rather than hormonal changes. It was not possible to control or distinguish the age effect from the hormonal effect on perception of colour and odour in the present study, so it will be essential to consider this issue in further studies.

However, it is also important to note that not all types of cognitive functioning are influenced by aging in the same manner (Mather, 2010). Semantic and implicit memory revealed slight declines with aging, and elderly adults often perform better than younger adults in aspects of memory such as vocabulary or general knowledge (Fleischman, Wilson, Gabrieli, Bienias, & Bennett, 2004; Laver, 2009; Verhaeghen, 2003). Moreover, the aged were reported to show no dysfunction in working memory for emotional images, and the memory of positive emotional images was better than that of negative emotional images, while younger adults showed the opposite result (Carstensen & Mikels, 2005).

Moreover, effects of aging on brain functioning seem to have sex differences, as shown by a report of negative correlations between aging and grey matter concentration in the occipital regions related to visual processing for women, while such a concentration was found in the medial frontal regions for men (Takahashi, Ishii, Kakigi, & Yokoyama, 2011). In addition, for women, grey matter concentration in the hippocampus can be affected by menopause, and the decrease of hippocampal volume seems to accelerate drastically in the post-menopausal period (Goto et al., 2011). It is also reported that use of estrogen therapy might prevent the decrease of hippocampal volume (Lord, Buss, Lupien, & Pruessner, 2008). Thus, aging itself is strongly related to hormones, and it is also difficult to understand perception and cognitive functioning by distinguishing between aging effects and hormonal effects. Therefore, it is important to consider the interrelationship between hormones and aging, and their effects on perception and cognition.

Influences on perception and cognition: individual differences

In addition to aging, individual mental conditions might play important roles in perception and cognition. Individual conditions, such as stress, could affect performance in perception and cognition. Many studies suggest that stress might cause deficits such as higher errors or slower reaction time in various types of cognitive tasks related to verbal and spatial working memory, problem solving and attention (K Klein & Barnes, 1994; Kitty Klein & Boals, 2001; Olver, Pinney, Maruff, & Norman, 2015; Sandi, 2013; Sliwinski, Smyth, Hofer, & Stawski, 2006). Thus, participants in the experiments in the present study might have been influenced by stress according to either experimental situations or daily life events, and the stress might have affected the results of the experiments.

However, stress may not always cause negative effects such as deficits of performance, and it also gives positive effects such as enhancement of performance (e.g. better memory of information related to emotion) (Wolf, 2009). Under optimal stress, performance becomes best while it declines at above or below the optimal stress or arousal state, but the relationship between stress and performance is also dependent on the task difficulty (Hebb, 1955; Mendl, 1999; Teigen, 1994; Yerkes & Dodson, 1908). Interaction between stress and cognitive performance may also vary more complicatedly according to the individual life style, experiences and social situation as well as sex and age (Mcewen, 2002). Thus, individual differences such as stress might be one of the important factors which might affect the results in the experiments either negatively or positively, so use of psychological scales for individuality as well as hormonal level and comparison between the results of these scales and the experimental results should be necessary in future studies.

6.2 Limitations of this thesis study

A few limitations of this thesis study could be addressed. First, female hormone levels could differ according to the individual. For example, hormones during the menstrual cycle could be affected by various factors such as dietary habits and stress, and could cause irregularity of the cycle (Kaplan & Manuck, 2004; Rowland et al., 2002; Yamamoto et al., 2009). The age of menopausal shift could also vary depending on the individual and on factors such as smoking, which can lead to earlier menopause (Hayatbakhsh, Clavarino, Williams, Sina, & Najman, 2012). Thus, individuals have various different hormonal conditions. In this thesis study, the conditions of the menstrual cycle and menopause were judged based on individuals' statements, and individual differences of hormonal levels were not experimentally examined. Even though individuals were in the same menstrual phases or had the same menopausal status, their hormonal conditions may have been different, and these conditions should be considered for more precise examinations of the relationship between hormones and perceptual and cognitive characteristics, and hormonal effects separated from aging effects.

In addition, the number of participants in the menstrual group with available data was 11, which might have been too few to reveal some significant inter-group differences. Individual differences, particularly in odour identification associated with personal experiences and memories, may have influenced the results, and during the experiments, participants in both the menstrual and menopause groups seemed to show various odour sensitivities according to these differences. Variations of individual hormonal secretion and mental conditions such as stress may also result in various modulations in colour and odour perception. In this thesis study, the number of participants in the menstrual group was limited, so in a future study, examination with more participants would be necessary for drawing more accurate conclusions.

6.3 Conclusion

In conclusion, this thesis study showed that female hormone changes during the menstrual cycle and in menopause could modulate perception, but not cognitive features such as impressions and cross-modal correspondences. Regarding colour perception, post-menopausal women clearly had delays in reaction time to blue compared with pre-menopausal women, while women in the menstrual cycle did not have clear differences between the menstrual and ovulation phases. Regarding odour perception, women in the menopause groups showed declines of sensitivity in post-menopausal women, but not women in the menstrual cycle, and various individual sensitivities based on participants' experiences and memories might also have influenced odour perception. The findings showed that perception of colour and odour could be modulated according to female hormones. However, colour and odour impressions, and cross-modal correspondences showed similar patterns between the menstrual and ovulation phases, and between pre- and post-menopause, except for "pleasant-unpleasant" impressions for women in the menstrual cycle. This indicated that these cognitive characteristics did not differ largely according to the menstrual cycle or menopause, and they might result from individual experiences and memories formed through seeing colours and sniffing odours rather than modulation during the menstrual cycle or menopause.

6.4 Future perspectives

The present thesis study revealed that colour perception was modulated by female hormones, particularly in menopause, and it suggested a possible association of this modulation with dysfunction of the short-wavelength light sensitivity. Some studies showed the changes of the short-wavelength sensitivity (e.g., Akar et al., 2005; Apaydin et al., 2004; Eisner et al., 2004; Eisner & Demirel, 2011; Eisner & Toomey, 2008), but what range of bluish colours could be subject to dysfunction has not been determined, and what types of blue colour women have difficulties or delays of perceiving according to hormonal changes should be considered in future research.

Regarding odour perception, only 12 types of odour were used in this study, and the results indicated that women in all groups were likely to have difficulties in perceiving the same odours, such as domestic gas and condensed milk. Therefore, more systematic types of odour should be examined in order to determine which kinds of odour (possibly chemical components) are difficult for women to perceive during the menstrual cycle and menopause. In addition, odour intensity might be related with women's perceptual sensitivity, and cross-modal correspondence might also differ according to odour intensity, as shown in previous studies (Kemp & Gilbert, 1997; Zellner & Kautz, 1990; Zellner & Whitten, 1999). How women perceive odours and choose colours that correspond with the odours according to the odour intensity and female hormone changes would be a possible study topic.

As mentioned regarding the limitations of this thesis study, hormone secretion levels during the menstrual cycle and menopause could vary according to individuals' differences such as their life styles and stress (Hayatbakhsh et al., 2012; Kaplan & Manuck, 2004; Rowland et al., 2002; Yamamoto et al., 2009). Regardless of women's menstrual cycle and menopause status, their actual hormone levels should be examined. Based on this examination, the correlation between hormone levels and modulation in perception and cognitive features could be studied. Moreover, more participants would be necessary, particularly in the menstrual group, because the available data were limited in this study. Considering various individual differences of hormonal secretion levels and experiences, such as increase of available data could provide more robust results and examinations of hormonal modulation of perception, cognition and cross-modal correspondences.

It is of fundamental importance to understand how female hormones affect women's physical and mental conditions. Female hormones are related to not only biological reproduction but also women's social lives themselves. Some women suffer from symptoms such as premenstrual syndrome (PMS) or premenstrual dysphoric disorder (PMDD) during the menstrual cycle (Biggs & Demuth, 2011; Jukic et al., 2008), and many symptoms also occurred during the menopausal transition (Dennerstein, 1996; Judd et al., 2012; Soares, 2008; Vivian-Taylor & Hickey, 2014). Moreover, female hormones might be related to diseases including Alzheimer's disease and Parkinson's disease, and women have a higher risk for these diseases than men (Labandeira-Garcia et al., 2016; Li & Singh, 2014; Pines, 2016). Understanding of female hormones might provide some insights about precautions and treatments of the symptoms and diseases.

Colour and odour are possibly useful tools to improve and enhance mental conditions, and living and social environments, and these tools are often used for therapy. Both colour and odour are known to be related to human emotions. For example, specific colours were associated with specific types of emotion (e.g., happiness and anger with the red-yellow axis, and sadness with the blue-green axis), and colours can be categorised by four emotional dimensions such as warm-cool, heavy-light, active-passive and hard-soft (Ou, Luo, Woodcock, & Wright, 2004; F. Takahashi & Kawabata, 2018; Thorstenson et al., 2018). Association between colours and emotion are also considered and used for individual space and living environments to promote health and well-being (Foley & Kistemann, 2015; Lengen, 2015), and examinations of colour in art or drawing therapy for people who have mental problems such as depression have been conducted (Jue & Kwon, 2013). Odour is also widely used for therapy, and some kinds of odour such as saffron (Crocus sativus) give psychological effects such as decline of symptoms or relaxation for people who have premenstrual syndrome (PMS), depression, anxiety and posttraumatic stress disorder (PTSD) (Aiken & Berry, 2015; Fukui, Toyoshima, & Komaki, 2011; Shafiee, Arekhi, Omranzadeh, & Sahebkar, 2018). Correspondence between colour and odour, particularly when colour choices are matched with odours, can be associated with stress reduction (Saito, 2016).

Thus, colour and odour, and their correspondences have many possibilities to contribute to psychological therapy and enhancement of human health, living environment and well-being. Women particularly have various physiological and psychological changes according to the menstrual cycle, menopause and individual roles in family and society, and these changes often cause health and mental problems, and perceptual and cognitive dysfunction. Studies about associations between female hormones and perception and cognition have used various methods and produced various results, and possible cross-modal correspondences of various groups still remain unclear. However, this thesis study provided some advances in examinations of the associations between female hormones both in the menstrual cycle and menopause, and the perception of and cross-modal correspondences between colour and odour. Use of colour and odour, and their harmonious correspondence are expected to reduce mental problems and promote an environment of well-being, and these characteristics can be expected to apply for not only women but also children, the aged and people who have physical and mental difficulties in society in the future.

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