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Menstrual Cycle Phase and Duration of Oral Contraception Intake Affect Olfactory Perception

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Abstract

Although a significant impact of cycle phase on olfactory thresholds has been shown in females, limited data exist regarding discrimination and identification. Therefore, we investigated a broader range of olfactory performance and analyzed the impact of cycle phase and oral contraception. We measured 80 healthy Caucasians, including 20 females taking oral contraceptives and 40 females without oral contraception who were further divided into follicular and luteal phase. Olfactory performance of all participants was assessed twice using the "Sniffin' Sticks" battery and intensity and pleasantness ratings of *n*-butanol were collected. Data analysis revealed that females outperformed males in odor discrimination and odor identification. In the luteal phase, higher thresholds and higher intensity ratings for *n*-butanol emerged. Duration of oral contraception correlated positively with olfactory performance pointing to better performance with longer intake. Hence, our data show that odor performance is affected by menstrual cycle phase and duration of oral contraception intake and thus can be modulated by hormonal changes.

Key words: gender, menstrual cycle, *n*-butanol, odor processing, olfaction, oral contraceptives

Introduction

The detection of chemical stimuli is an important ability not only for animals but also for humans. Although human behavior is widely affected by olfactory perception, influencing factors on our sense of smell are hardly investigated. Considering gender differences, some previous studies showed greater olfactory performance for a variety of odors in females than in males (Larsson et al. 2004; for review see Doty and Cameron 2009). This female advantage seems to be due to hormonal factors (Russell et al. 1980; Evans et al. 1995) or derives from variables associated with these hormonal changes (Doty et al. 1995). Behavioral evidence documents that sex hormone concentration affects cognition, emotion, and nonverbal behavior, thus a broad spectrum of human behavior (for review see Hines 2010; van Wingen et al. 2011) and this might also apply to olfaction.

Regarding the influence of menstrual cycle phase, most previous studies reported significant differences, albeit results are quite heterogeneous. Most studies point to increased sensitivity at least for some substances around the time of ovulation or midluteal phase (Le Magnen 1952; Vierling and Rock 1967; Mair et al. 1978; Doty et al. 1981, 1982), whereas others reported higher sensitivity during the follicular phase (Henkin 1974) or around menses (Köster 1968). Adding to the complexity, several studies showed decreased sensitivity during menses (Le Magnen 1952; Schneider and Wolf 1955; Good et al. 1976; Mair et al. 1978; Moriyama and Kurahashi 2000) or no significant cycle-dependent changes (Amoore 1974; Herberhold et al. 1982; Filsinger and Monte 1986; Hummel et al. 1991, 2007; Kanamura and Takashima 1991).

Notably, Navarrete-Palacios et al. (2003a) demonstrated significantly differing odor thresholds with lowest during the ovulatory phase and highest during menses. Moreover, these cycle phase–dependent changes in odor sensitivity/threshold detection are accompanied by cytological changes in the nasal epithelium paralleling those in the vagina (Navarrete-Palacios et al. 2003b). It has also been demonstrated that the components of the olfactory evoked potentials in women are influenced by the phase of the menstrual cycle, which are followed by higher sensitivity during ovulation (Pause et al. 1996), possibly indicating shifts in arousal and attention performance. Besides these tests for olfactory sensitivity, studies have addressed whether the hedonic valence of odors is affected by menstrual cycle phase. Two studies found that androstenone, which is supposed to have pheromone-like characteristics, was perceived as most pleasant during ovulation (Hummel et al. 1991; Grammer 1993), while no changes occurred for nicotine or phenylethylalcohol (PEA, rose; Hummel et al. 1991). Further, Watanabe et al. (2002) investigated differences in hedonic and intensity ratings for cyclopentadecanol (musk) across the menstrual cycle and reported that the hedonic values were highest during the follicular phase and intensity ratings were higher during menses. Thus, hedonic and intensity ratings for specific odors are affected by cycle phase.

Less is known on the impact of oral contraceptives (OCs) on olfactory performance. Some studies observed changes in olfactory threshold across the cycle of females using OC (Doty et al. 1981, 1982; Caruso et al. 2001) paralleling those of females without OC use. Additionally, rhinomanometric tests showed significant differences for OC use indicating linear outlines similar to those of females during the luteal phase (Caruso et al. 2001). This might be driven by use of monophasic pills whose hormonal activities are mainly progestative, similar to natural events during the luteal phase (cf. Caruso et al. 2001). Directly comparing females with and without OC use showed better smell identification performance in OC users (Landis et al. 2004). Interestingly, this advantage seems to be dependent on the odor: while OC users show higher sensitivity for environmental odors (rose), they demonstrate reduced sensitivity for social odors (androstadienone) (Lundström et al. 2006).

The mentioned discrepancies of previous results might rely on several methodological factors, including small sample sizes, differences in time points of the cycle, or lack of non-cycling control samples. In the present study, it was, therefore, our aim to investigate a broader range of olfactory performance parameters (i.e., odor threshold, identification, and discrimination, cf. Hummel et al. 1997) in females with and without OC use and males serving as a control group. Moreover, to analyze cycle phase–dependent variations we measured all subjects twice. Based on previous results (cf. Doty and Cameron 2009), we hypothesized that females outperform males. Due to the heterogeneity of previous results, we further investigated cycle phase–dependent changes in olfactory performance and also assessed hedonic and intensity scores for *n*-butanol. Regarding OC users, we also analyzed impact of duration of OC intake.

Materials and methods

Subjects

Eighty-two healthy subjects (61 females), between 18 and 44 years (mean age: 26.5 years; standard deviation [SD]: 5.2 years), participated in the study. Two subjects (1 female) were excluded from the data set due to psychopharmaceutical medication and incomplete testing. All participants had no history of mental illness as assessed using the German version of the structured clinical interview (Wittchen et al. 1997).

It is known that sexual orientation influences perception and hedonics (Martins et al. 2005), as well as cerebral responses related to chemosensory signals (Savic et al. 2005; Berglund et al. 2006; Savic and Lindström 2008). Therefore, we controlled for sexual orientation of the subjects. All participants described themselves as having exclusively heterosexual contacts on a 7-point scale (Kinsey et al. 1953). All subjects were nonsmokers and were not taking any medication known to interfere with sensory perception (Doty and Bromley 2004).

All experiments were performed at the Faculty of Psychology, University of Vienna, in accordance with the 1975 Helsinki declaration and local ethics regulations. The study was approved by the local ethics committee and all subjects provided written informed consent to the study protocol.

Subjects were invited for 2 testing sessions and were divided into 4 groups: men, women using OCs (WP), women without OCs within follicular phase (WF; days 1–14), and women without OCs within their luteal phase (WL; days 18–28). Menstrual cycle phases among groups WF and WL were assigned by verbal information upon the first day of their last period and cycle length. All females had a cycle length of 28–32 days. For group WP only women using

1-phase (same amount of hormones for 3 weeks) micropills (very low dose of estrogen) were included. After the first testing session subjects were invited for a second testing session after 2–7 weeks. Subjects of groups WF and WL were invited within their contrary cycle phase for session 2 (t2), which means that women who were assorted to WF in the first test run were invited in their luteal cycle phase for the second test run.

Thus, the final sample consisted of 20 females comprising the WF group, 20 females comprising the WL group, 20 females comprising the WP group, and 20 men. All subjects were tested twice.

Testing

A schematic description of the 2 testing sessions is given in Figure 1. All subjects were tested by the same female investigator.

Session 1

Session 1 included a sociodemographic-based questionnaire and testing of cognitive ability using the verbal intelligence test (MWT-B) (Lehrl 1996), and the trail making test (TMT-A and -B) measuring executive functioning (Crowe 1998). Emotional states were tested using PANAS scales (Watson et al. 1988). As state of satiety is known to influence olfactory performance (Albrecht et al. 2009), subjects were also asked to rate their current state of hunger (1 = not hungry at all, 10 = very hungry), their desire for food (1 = very weak, 10 = very strong), and the fullness of their stomach (1 = not full at all, 10 = very full) on a visual analog scale.

The standard odors of the Sniffin' Sticks test battery (Burghart Instruments) were used to test olfactory performance, hedonic, and intensity ratings. The original Sniffin' Sticks test includes 3 subtests measuring nasal chemosensory function using pen-like devices for odor presentation: odor threshold, odor discrimination, and odor identification (Kobal et al. 1996; Hummel et al. 1997). Detection thresholds of *n*-butanol were determined using a single-staircase, 3 alternative forced choice (3-AFC) procedure, that is, subjects were presented with 3 sticks and had to decide which one contained *n*-butanol. Odor discrimination was tested using 16 triplets of odorants, again presented as a 3-AFC procedure, that is, subjects again were confronted with 3 sticks and had to indicate which one smelled different. The odor identification test consisted of 16 commonly known every day odorants (orange, shoe leather, cinnamon, peppermint, banana, lemon, liquorice, turpentine, garlic, coffee, apple, clove, pineapple, rose, anise, and fish) using a multiple-choice answering format with 4 odors each. The standard testing procedure was extended by the assessment of odor intensity and hedonics for *n*-butanol in the highest concentration.

All 4 olfactory tests were carried out birhinally. The results of the 3 Sniffin' Sticks subtests were summed up to the so-called "TDI score", which characterizes the individual olfactory performance as the sum of odor threshold, discrimination, and identification ability (Kobal et al. 1996; Hummel et al. 1997). Directly after the olfactory tests, emotional states using PANAS scales were assessed again.

Session 2

Session 2 (2–7 weeks after session 1) included the assessment of current mood using PANAS scales and satiety status (see session 1). Afterwards the olfactory function was retested using the Sniffin' Sticks test battery (see session 1) followed by a second assessment of current mood state.

Statistics

Statistical analyses were performed using the Statistical Package for the Social Sciences version 18.0 (SPSS). Mean and SDs were calculated. Analysis of variance for repeated measurements with the within-subject factor time (session 1 vs. session 2) and the between-subject factor group (males, WP, WL, and WF) was used for comparison of olfactory performance, PANAS scores, and hunger and satiety ratings. Due to violation of sphericity, Greenhouse Geisser corrected *P*-values are reported and post hoc analyses were Bonferroni corrected. Estimates of effect size (partial η^2) are listed for significant effects. Moreover, to investigate the relationship between duration of OC use and olfactory performance correlation analyses were performed. Analysis of variance was used to test for group differences for results of the cognitive questionnaires. Due to violations of normal distribution (Kolmogorov–Smirnov test), sociodemographic data (age, education, and profession) were analyzed using nonparametric tests. The alpha level for all statistical tests and comparisons was set at 0.05.

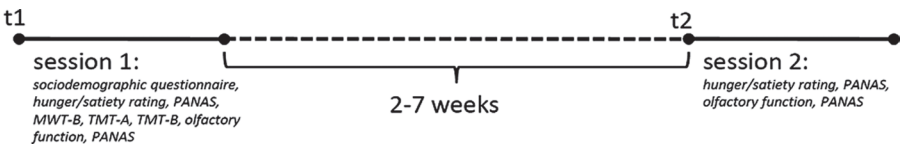

Figure 1 Graphic representation of the experimental design. The first session (t1) included sociodemographic questionnaires, hunger/satiety ratings, mood self-rating (PANAS), several neuropsychological tests (MWT-B, TMT-A/-B), and measurement of olfactory function. At session 2 (t2), only hunger/satiety ratings, mood ratings (PANAS), and olfactory function were investigated.

Results

Sociodemographic data and hunger ratings

Results of the sociodemographic questionnaire showed that subjects were of similar age (χ^2 = 2.51, P = 0.470) and had similar education (χ^2 = 4.81, P = 0.190). Moreover, no significant differences in distribution of students, subjects with an academic degree, and subjects with secondary school degree (χ^2 = 4.81, P = 0.190) occurred. Regarding cognitive abilities, no significant differences between male subjects and groups WP, WF, and WL using MWT-B, TMT-A, and TMT-B were obtained (all P > 0.282). Regarding mood scores, no significant differences emerged for session 1 or session 2 (all P > 0.220). Regarding hunter ratings, groups neither differed in their rating of current state of hunger (F(3,76) = 1.751, P = 0.164) nor desire for food (F(3,76) = 1.658, P = 0.183) or fullness of stomach (F(3,76) = 2.507, P = 0.065).

Odor threshold

Repeated measures analysis revealed neither a significant time (F(1,76) = 0.631, P = 0.429) nor group effect (F(3,76) = 0.451, P = 0.717) but a significant time-by-group interaction (F(3,76) = 4.397, P = 0.007, partial η^2 = 0.148). Post hoc analysis of the significant interaction demonstrated while males showed a lower threshold at session 2 (P = 0.035), WF exhibited a significantly higher threshold at session 2 (P = 0.007). The other 2 groups showed similar thresholds across both sessions (WP: P = 0.400; WL: P = 0.644).

Odor identification

Data analysis demonstrated no significant time effect (F(1,76) = 2.606, P = 0.111) but a significant group effect (F(3,76) = 3.187, P = 0.028, partial η^2 = 0.112) and a trend towards a time-by-group interaction (F(3,76) = 2.542, P = 0.063, partial η^2 = 0.091). Disentangling the significant group effect, post hoc analysis revealed that males showed significantly lower identification scores as WL (P = 0.031), whereas performance of the other groups did not differ significantly (all P > 0.158). Exploratory analysis of the time-by-group interaction trend demonstrated a significant difference for WF only (P = 0.019) indicating increased performance at session 2. All other groups showed similar performance at session 1 and session 2 (all P > 0.201).

Odor discrimination

Analysis revealed a significant time effect (F(1,76) = 7.201, P = 0.009, partial η^2 = 0.087) with higher scores at session 2, a significant group effect (F(3,76) = 4.089, P = 0.010, partial η^2 = 0.139) and a significant time-by-group interaction (F(3,76) = 3.829, P = 0.013, partial η^2 = 0.131). Regarding the significant group effect, post hoc analysis showed that WP and WF outperformed males (both P = 0.045) but males did not differ from WL (P = 0.737). The female groups did not differ from each other (WP vs. WF: P = 1.000; WP vs. WL: P = 0.372; WF vs. WL: P = 0.372). Post hoc analysis of the significant time-by-group interaction yielded a significant difference only for males (P = 0.001) who showed significantly better discrimination performance at session 2, whereas performance of the female groups did not change (all P > 0.269).

TDI scores

Regarding TDI scores, we observed a significant time effect (F(1,76) = 5.763, P = 0.019, partial η^2 = 0.070) with better values at session 2, no significant group effect (F(3,76) = 1.813, P = 0.152) but a significant time-by-group interaction (F(3,76) = 3.700, P = 0.015, partial η^2 = 0.127). Post hoc analysis of the significant interaction revealed only a significant effect for WF (P = 0.001) indicating better performance at session 2, while for the other groups no significant difference emerged (all P > 0.444). See Table 1 for details on behavioral performance.

Hedonic and intensity ratings of *n*-butanol

Regarding the hedonic ratings for *n*-butanol, data analysis revealed no significant group difference (F(3,76) = 1.710, P = 0.172), no time effect (F(1,76) = 0.077, P = 0.782) and only a trend for a time-by-group interaction (F(3,76) = 2.602,

Table 1 Olfactory performance results for all 3 subtests (threshold, discrimination, and identification) and resulting TDI score for male subjects and groups WP, WF, and WL for all sessions t1 and t2

	Threshold	Discrimination	Identification	TDI
t1 (total)	9.56 (2.59)	13.48 (1.18)	13.64 (1.15)	36.68 (3.30)
t2 (total)	9.78 (2.19)	13.90 (1.14)	13.86 (1.56)	37.55 (2.79)
P	0.457	0.018	0.155	0.025
Men (t1)	10.39 (2.63)	12.60 (1.19)	13.15 (1.18)	36.14 (3.31)
WP (t1)	9.59 (2.75)	13.85 (1.14)	14.10 (1.12)	37.54 (3.36)
WF (t1)	8.38 (2.48)	13.80 (1.01)	13.20 (1.77)	35.38 (3.49)
WL (t1)	9.90 (2.21)	13.65 (0.99)	14.10 (1.29)	37.65 (2.67)
P	0.083	0.004	0.031	0.078
Men (t2)	9.35 (2.22)	13.85 (1.14)	13.05 (1.76)	36.25 (2.36)
WP (t2)	10.10 (2.26)	14.15 (1.23)	13.95 (0.95)	38.20 (2.30)
WF (t2)	9.61 (2.50)	13.40 (0.88)	14.45 (1.57)	37.46 (3.12)
WL (t2)	10.08 (1.09)	14.20 (1.20)	14.00 (1.60)	38.28 (2.98)
P	0.649	0.075	0.029	0.075

Furthermore, the means for all subjects for both sessions (t1 (total), t2 (total)) are presented. Reported are means and SDs as well as *P*-values of the group comparisons.

$P = 0.058$). Exploratory analysis of this trend, however, revealed no significant difference for any group (all $P > 0.060$).

However, for the intensity ratings a significant group difference emerged ($F(3,76) = 6.031$, $P = 0.001$, partial $\eta^2 = 0.192$) but again no time effect ($F(1,76) = 1.537$, $P = 0.219$) and no significant interaction ($F(3,76) = 2.110$, $P = 0.106$). Post hoc analysis demonstrated that intensity ratings by WL were significantly higher than those by men ($P = 0.001$), while other groups did not differ (all $P > 0.109$). See Table 2 for means and SDs.

Corollary analyses

Correlation analysis revealed a significant positive association between duration of OC intake and mean TDI scores ($r = 0.522$, $P = 0.018$) as well as mean identification scores ($r = 0.52$, $P = 0.02$), while no significant influence was detected for the other 2 subtests (threshold: $r = 0.36$, $P = 0.12$; discrimination: $r = 0.33$, $P = 0.16$).

To control for the impact of age, we performed another correlation analysis between duration of OC use and mean TDI scores using partial correlation yielding an even higher correlation ($r = 0.555$, $P = 0.014$). For the separate tests, no significant association with duration of OC intake emerged (all $P > 0.116$). See Figure 2 for illustration.

Discussion

The present study aimed at analyzing the impact of menstrual cycle phase and usage of OCs on olfactory performance, targeting odor threshold, odor identification, and odor discrimination. Additionally, we investigated whether these factors also affect ratings of pleasantness and intensity of *n*-butanol. Four groups were investigated (WF: females with first session during their follicular phase; WL: females with first test session during their luteal phase; WP: females using OCs; and males). All subjects underwent 2 testing sessions. Notably, groups were matched for several sociodemographic variables and did not differ in mood and the assessed neuropsychological parameters.

The following section will be divided into different parts discussing olfactory performance related to menstrual cycle phase and the influence of OC use on female olfactory function as well as more general gender effects. Moreover, a comparison of the 2 testing sessions for all subjects and limitations of the conducted study will be reported.

Table 2 Means and SDs for the *n*-butanol ratings for WF, WL, WP, and men

	Hedonic	Intensity
WF	33.0 (26.5)	78.6 (18.9)
WL	25.2 (25.3)	87.1 (13.1)
WP	24.2 (18.2)	80.2 (11.9)
Men	38.6 (22.7)	70.3 (19.6)

Because we observed no time effect, we present global means across session 1 and session 2. Hedonic and intensity ratings ranged from 0 to 100.

Menstrual cycle phase

Looking at odor thresholds, we observed a significant time-by-group interaction with significantly lower thresholds in females tested during their follicular phase than during their luteal phase, which has been reported before (Grillo et al. 2001; Navarrete-Palacios et al. 2003a). During the luteal phase, estradiol and progesterone levels are significantly higher than during menses and the follicular phase (except for ovulation where estradiol has its maximum peak approximately after 13–15 days). It is assumed that this rise in hormone concentration affects sensory perception, including not only processing of emotionally visual stimuli (Derntl et al. 2008a, 2008b) but also odor perception.

We observed significant intraindividual differences in odor thresholds and TDI scores indicating that despite higher odor thresholds females show better identification during their luteal phase. Due to the medium effect size, these results have practical relevance. The indirect effect was obtained for women who were first tested in their luteal phase and whose second session was within their follicular phase, showing decreased olfactory performance scores despite training effects. Hence, our results point to rather subtle and probably task-specific effects of menstrual cycle phase, which might also rely on the broad specification of groups, including menses and parts of ovulation in the follicular phase. Interviewing subjects after olfactory testing showed that most females measured during the follicular phase perceived most odors as negative and unpleasant. However, we did not systematically assess these answers, which should be done in future studies to come.

Interestingly, odor discrimination was not affected by menstrual cycle, which has not been investigated before. It seems that menstrual cycle changes occur only on subtle parameters, that is, while females during their luteal phase might have a higher threshold for certain odors and thus smell them more slowly, they also rate other odors more intense, for example, *n*-butanol while the discrimination of odors, a more elaborate and more top-down process, remains unaffected. However, because we did not obtain actual hormone concentrations we can only speculate about the nature of these effects. Females during their follicular and luteal phase did not differ in any mood rating or in severity of menstrual molimen, thus we are convinced that the observed significant effects in olfactory performance are not modulated by these factors.

Influence of oral contraception

We observed a significant positive correlation of duration of OC usage and TDI scores as well as odor identification, while no significant influence was detected for the two other

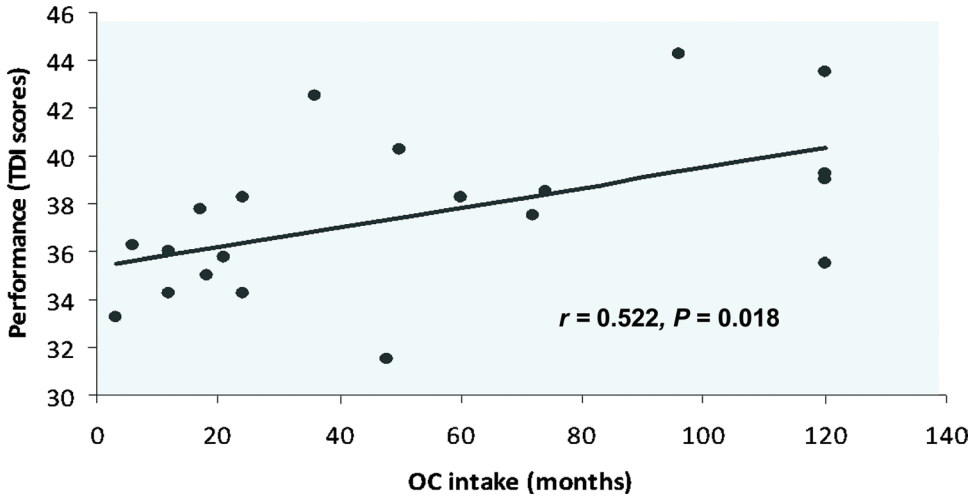

Figure 2 Correlation analysis between olfactory performance and oral contraception. Correlation analysis revealed a significant positive relation between duration of oral contraception and overall olfactory performance (TDI scores), indicating better performance with longer OC usage. This figure appears in color in the online version of *Chemical Senses*.

subtests. Hence, our data further support the notion that olfactory function is influenced by hormone levels (Hummel et al. 1991; Wedekind et al. 1995). Interestingly, the exact mechanisms by which ovarian hormones such as estrogen or progesterone interfere with olfaction are not fully understood yet and only very few studies investigated the effects of hormonal intake on olfactory performance. Animal research models discovered a protective effect of estrogen therapy towards olfactory loss (Dhong et al. 1999). A study by Landis et al. (2004) discovered that females taking OCs scored significantly higher in an odor identification task. Caruso et al. (2001) who investigated rhinomanometric and olfactometric measures in women with OC intake hypothesized olfactory threshold to depend on the variations of ovarian steroids during menstrual cycle and on the iatrogenic effects of OCs: Females with OC intake showed values similar to those of females in the luteal phase. However, a longitudinal study investigating the effects of hormone replacement therapy could not find differences related to olfactory function (Hughes et al. 2002), whereas other studies by Caruso et al. (2004, 2008) were able to reveal differences in olfactory threshold levels after a combined hormone therapy with estrogen and progestogens. Authors suggest that estrogens might modulate neural plasticity and neural conduction time in the olfactory system, which should be examined in future studies using neuroimaging tools. Landis et al. (2004) speculate that OC intake might balance normal fluctuations of olfactory performance during the menstrual cycle, thereby enabling higher mean scores than in females without OC intake.

Little is known on the long-term effects of OC usage on cognitive or sensory abilities (Kurshan and Neill Epperson 2006), however, our data indicate that olfactory performance is modulated by hormone levels and is permeable to changes. Recently, Pletzer et al. (2010) reported modulation of the volume of the parahippocampal gyrus via menstrual cycle and OC usage, supporting the assumption by Caruso et al. (2008) on the modulation of neural plasticity by hormonal intake. Hence, investigating the effect and alterations of duration of OC intake on olfactory measures as well as the underlying neural correlates is of high interest and can serve as a source adding additional facts to the questions of how olfactory performance is shaped through hormonal intake.

Gender effects

Data analysis revealed no significant gender differences for odor thresholds and the TDI score, thus supporting previous findings from Hummel et al. (2007). However, regarding odor identification and odor discrimination, we observed significantly better performance in females compared with males and thereby corroborate previous results (Cain 1982; Larsson et al. 2004). The underlying source of the observation of female superiority in identifying and discriminating of the selected odors still remains unclear—explanations might include sex differences in verbal abilities (Hyde and Linn 2006), prior experience (Cain 1982), and the controlling role of sex hormones on olfactory behavior (Doty et al. 1981).

While hedonic ratings for *n*-butanol showed no significant gender difference, indicating that this odor is desired similarly by both genders, we observed a significant group difference in intensity ratings. Men rated the highest concentration of *n*-butanol as significantly less intense than females. We did not expect this finding; however, several other studies also reported significant gender differences in hedonic ratings in the same direction, most odors were rated less pleasant by females (Doty et al. 1984). Gilbert and Wysocki (1991) reported that isoamyl acetate (banana) and mercaptan (skunk) were rated as more pleasant by males than by females, whereas rose and eugenol (clove) as more pleasant by women. Regarding the significant gender difference in

intensity ratings, our data are in line with previous studies on body odors, where males too report less intense rating for vaginal odors (Doty et al. 1975), as well as human axillary and breath odors (Doty et al. 1978, 1982).

Moreover, we observed significant time-by-group interactions for odor threshold, odor discrimination, and TDI scores, while for odor identification a trend toward a time-by-group interaction emerged. Interestingly, males showed lower thresholds and better discrimination performance at session 2 possibly indicating training effects because we did not observe any difference in mood states, nervousness, hunger, and satiety ratings. Females also showed different performance at the two testing sessions, which partly might also point to training effects but according to our hypothesis might also reflect menstrual cycle effects.

Limitations

Several limitations of the current study should be mentioned. Hormone concentrations that might help to further gain insight on the causality of hormonal changes in olfactory performance were not obtained. Here, particularly distribution of estradiol and progesterone is necessary, which has been shown to act differently in several studies tapping for instance emotion processing (Derntl et al. 2008a, 2008b). Moreover, several studies observed a significant association of cortisol with olfactory performance (Genazzani et al. 1975; Pause et al. 1996) thereby supporting the assumption of Doty (1986) that hormones of the pituitary–adrenal axis modulate olfaction. We did not assess any other relevant psychophysiological parameters, such as body temperature or pulse rate, which have been shown to strikingly affect odor sensitivity, particularly in females taking OCs (for review see Doty and Cameron 2009). Moreover, we only assessed intensity and pleasantness ratings for *n*-butanol; clearly other substances need to be investigated in this manner to gain more knowledge on what odors underlie cycle-dependent changes or more generally show different engagement of the 2 genders.

Conclusion

The aim of the study was to analyze the impact of menstrual cycle phase and OC use on a broader range of olfactory performance including odor identification, odor discrimination, odor threshold detection, and hedonic and intensity ratings of *n*-butanol. Therefore, we measured 40 females during their follicular and luteal phase, 20 females with OC usage and 20 males. All subjects were measured twice to determine intraindividual differences due to cycle phase and repeated measurement, respectively. Regarding menstrual cycle phase, we observed less sensitive odor thresholds during the luteal phase in those females who were measured first during their follicular phase. Despite this higher odor threshold, this group of females showed increased olfactory performance in the luteal phase (session 2). Females with OC usage showed comparable performance to females tested in the luteal phase. Interestingly, a significant correlation between duration of OC usage and olfactory performance emerged pointing to better performance with longer intake. Moreover, we observed significant gender differences in odor discrimination and odor identification with females outperforming males. Hence, our data show that odor performance is affected by menstrual cycle phase and OC intake and thus indicate that this ability is modulated by hormonal changes. Future research should clarify the exact mechanisms of hormonal interference with olfactory function probably by using neuroimaging tools.

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