Greater overall olfactory performance, explicit wanting for high fat foods and lipid intake during the mid-luteal phase of the menstrual cycle

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Abstract:

Increases in energy, lipid and carbohydrate intakes during the luteal phase have been previously observed. However, it is not known whether this is due to phase-dependent variations in the reward value of certain foods. Moreover, increases in olfactory sensitivity have been proposed and may be involved in these changes in food reward. Therefore, we examined olfactory performance and the reward value of foods varying in fat content and taste. Seventeen women (Body mass index: 22.3 ± 1.6 kg/m^2; Body fat-DXA: 28.5 ± 6.8%) were recruited to participate in 3 identical sessions, performed during distinct phases of the menstrual cycle – early follicular/menstruation, late follicular/ovulation and mid-luteal – verified by plasma sex-steroid hormones and oral temperature. Food preference, implicit wanting, and explicit wanting and liking for visual food cues, varying in fat content and taste, were measured with a validated experimental platform involving a forced choice computer task. Odour threshold, odour discrimination, odour identification and total odour scores were measured using odourized pens. *Ad libitum* energy and macronutrient intake was measured with a validated food menu. Results showed greater total odour scores ($p < 0.05$), explicit wanting for high fat foods ($p < 0.05$) and lipid intake ($p < 0.05$) during the mid-luteal phase. Inter-correlations between these variables were non-significant. These findings support previous observations of increased lipid intake during the luteal phase and provide evidence for phase-dependent variation in overall olfactory performance and explicit wanting for high fat foods.

Keywords: Menstrual cycle | Wanting | Liking | Olfaction

Article:

1. Introduction

It has been previously noted that energy intake decreases during the late follicular and ovulation phases, at which time levels of estradiol are elevated, while energy intake increases during the

luteal phase, which is characterized by increased estradiol and progesterone levels [1]. Furthermore, many studies have noted greater lipid [2], [3], [4], [5] and carbohydrate [3], [6] intakes during the luteal phase, which are most likely related to the changes in energy intake given the high energy density of fat and simple sugars [7]. Additionally, changes in food cravings have been related to menstrual cycle phase, with increases in the number and intensity of cravings for foods with a predominantly sweet and/or salty taste occurring during the luteal phase [8], [9]. High fat foods have also been reported to be more appealing during menses and the luteal phase (weeks 1, 3 and 4), in comparison to the late follicular phase (week 2) [10].

In regard to olfactory sensitivity, variations in odour threshold have been previously evaluated across the menstrual cycle but results are conflicting. Certain studies found differences in olfactory thresholds – defined by the minimum detectable concentration of an odourant – across the menstrual cycle, with increased sensitivity during ovulation and/or the mid-luteal phase [11], [12], [13], [14]. Conversely, other studies have reported no differences in olfactory threshold across the cycle [15], [16]. The differences in results noted by these studies may be in part due to the use of different odours when assessing olfactory sensitivity. More specifically, studies which measured olfactory sensitivity with different odours noted clearer increases in olfactory sensitivity during mid-cycle and/or the luteal phase in response to mammalian pheromones or musk-like odours [12], [14]. Additionally, despite noting no significant difference in olfactory sensitivity across the menstrual cycle, Hummel et al. [15] observed that women perceived the odour of androsterone as being more pleasant during ovulation, which may be in part mediated by the presence of higher levels of estradiol at this time [11].

The aim of this study was twofold. First, we investigated the variations in odour threshold, odour discrimination, odour identification and total odour scores (i.e. TDI) – together operationalized as olfactory performance – as well as the variations in implicit wanting (directional motivation to consume a food), explicit liking (hedonic ratings of food) and explicit wanting (declared intent to consume a food) for foods varying in fat content and taste [17]. Second, we wanted to investigate to what extent these variations were related to energy and macronutrient intakes. In an effort to increase the accuracy of menstrual cycle phase determination, plasma levels of luteinizing hormone (LH), follicle-stimulating hormone (FSH), estradiol and progesterone, as well as oral temperature were measured at the start of each experimental session. We hypothesized that odour threshold and TDI would be highest – indicating greater olfactory sensitivity and overall olfactory performance, respectively – during the late follicular/ovulation and mid-luteal phases. It was further hypothesized that greater implicit and explicit wanting for high fat sweet foods, as well as greater energy, carbohydrate and lipid intakes would be noted during the mid-luteal phase.

2. Materials and methods

2.1. Participants

A total of 18 women completed the study. However, one participant was subsequently excluded from analyses due to her measured LH, estradiol and progesterone levels being below the normal range [18], suggesting that an anovulatory cycle may have occurred. Thus, the results of 17 participants are presented herein. Participants were between the ages of 18–40 years, non-

smokers, weight stable (i.e. within a ± 2 kg weight variation), not taking prescribed medications and hormonal contraceptives (e.g. pill, patch, injection, intra-uterine device) within the past six months prior to the start of testing, and had a 24–34 day menstrual cycle. This study was conducted according to the guidelines laid down in the Declaration of Helsinki and all the procedures involving human participants were approved by the University of Ottawa ethics committee. Written informed consent was also obtained from all participants.

2.2. Design and procedure

During the preliminary session, anthropometric data was collected and it was also determined whether participants met the inclusion criteria prior to obtaining informed consent. Following this, 3 identical experimental sessions were conducted, each during the early follicular/menstruation (days 1–5 inclusively), late follicular/ovulation (days 11–14 inclusively) and mid-luteal (days 21–26 inclusively) phases of the menstrual cycle. These days were based on a 28-day cycle, and each participant was asked to count the number of days (length) of their menstrual cycle for at least one month prior to testing. This permitted the tailoring of individualized timing of testing according to the cycle length. For instance, the late follicular/ovulation and mid-luteal phase testing sessions were held earlier (e.g. days 9–12 and 17–22, respectively, for someone with a 24-day cycle) for participants with cycle lengths that were shorter than 28 days, or later for participants with cycle lengths that were longer than 28 days (e.g. days 14–17 and 27–32, respectively, for someone with a 34-day cycle). As for the early follicular/menstruation phase testing session, this was based on the length of menstruation noted during the past month(s).

For each session, participants arrived at the laboratory at 0800 following a 12-hour overnight fast. They were instructed not to consume any alcohol or engage in any type of structured physical activity (e.g. playing sports or training) for at least 24 h prior to the start of each session. All measurements described below were performed during the 3 experimental sessions.

2.3. Anthropometric measurements

Standing height was measured, without shoes, to the nearest centimeter using a Tanita HR-100 height rod (Tanita Corporation of America, Inc, Arlington Heights, IL). Body weight and body fat percentage were measured using a standard beam scale (HR-100; BWB-800AS, Tanita Corporation, Arlington Heights, IL., USA) and DXA scanner (Lunar Prodigy, General Electric, Madison, WI, USA), respectively. These measurements were taken at 0900. The coefficient of variation and correlation for body fat percentage measured by DXA scanner in 12 healthy participants were 1.8% and $r = 0.99$, respectively.

2.4. Blood sample and temperature measurement

A single blood sample was drawn from the antecubital vein of the non-dominant arm between 0915 and 0930 to determine the plasma levels of estradiol, progesterone, FSH and LH. Each blood sample was placed into a tube containing ethylenediaminetetraacetic acid and was centrifuged at 3500 rpm at 4 °C immediately after the blood was drawn and stored at − 80 °C until assayed. LH and FSH levels were assayed with a two step “sandwich” chemiluminescent

assay using the Beckman Coulter Dxl Unicel 800 (Beckman Coulter Canada Incorporated, Mississauga, Ontario, Canada). Progesterone levels were assayed by means of an electro-chemiluminescent immunoassay system, Elecsys 2010 disk system (Roche Diagnostics, Indianapolis, Indiana, USA). As for estradiol analyses, a carbonyl metallo immunoassay procedure was employed with an Architect estradiol reagent kit (Abbott Laboratories, Abbott Park, Illinois, USA). Temperature was measured orally with a digital thermometer (rapid digital thermometer, BD, Franklin Lakes, NJ, USA) between 0915 and 0930.

2.5. Food reward and food intake measurements

A validated experimental platform involving a forced choice computer task was used to evaluate the implicit wanting and subjective explicit wanting and liking for different visual food cues, varying in both fat content and taste [17]. A total of 16 different foods, divided into 4 categories (high fat savoury, low fat savoury, high fat sweet and low fat sweet) formed the array for this study. A list of the food items which compose each category are presented in Appendix 1. During the forced choice part of the test, each visual food cue was presented with every other visual food cue in turn. The participants were instructed to select the food they “most want to eat now” during each trial, which gave an indication of their relative preference for a certain type (or category) of food. Implicit wanting was determined according to each participant's reaction time in selecting a specific type of food during each forced choice trial, which is an indication of the strength of motivation for the type of food selected, relative to all other foods. Explicit wanting and liking was measured by rating each of the 16 randomized visual food cues in turn on a visual analogue scale (anchored by Not at all-Extremely), based on the following questions: “how much do you want some of this food now?” and “How pleasant would it be to experience a mouthful of this food now”, respectively. As previously described by Finlayson et al. [19], the question used to measure explicit liking was constructed to precisely evaluate the pleasure or affective reaction perceived during the experience of tasting a mouthful of a given food (i.e. an immediate hedonic impact of the stimuli), while trying to avoid the more general evaluation of the inherent properties related to the food item itself and intrinsic/physiological feelings of the individual (e.g. the implicit feelings of hunger and satiety, which may alter the "wanting" of the food, but not necessarily the “liking”). This test was administered before and after the test meal at 1130 and 1330. *Ad libitum* energy and macronutrient intakes were measured by a test meal (1200–1300) selected from a validated food menu, as previously described [20].

2.6. Odour threshold, discrimination and identification

Olfactory performance was determined using the “sniffin sticks” kit (Burghart Instruments, Wedel, Germany). This procedure is a 3-test battery of odourized pens that measure odour threshold, odour discrimination, and odour identification, each on 16 point scales and added together to form an aggregate total odour score (threshold, discrimination, identification: TDI), as previously described [21]. Briefly, the pens for the threshold test contained 16 concentrations (1–16, strongest to weakest concentration) of n-butanol and participants were presented with a triplet of pens, the other two being blanks (aqua-conservans). These 16 concentrations are converted into a 16-point scale to determine odour threshold (1–16, strongest to weakest concentration, weakest to strongest smell sensitivity). Participants were required to identify the pen with n-butanol and the threshold score was determined by a single up-down staircase

method, as previously described [21]. Greater scores on the odour threshold test revealed a better ability to identify the n-butanol pen at a lower concentration. In the discrimination task, subjects were again asked to identify the pen that smells different when presented with 16 triplets, the difference from threshold being that two pens have the same odour and one has a unique odour. The identification test consists of a forced-choice booklet of 16 pages, each with a choice of 4 odours. The participant is presented with 16 different pens (odours) and is required to circle the odour in the booklet that they believe identifies the pen. For the odour discrimination and threshold tasks, the number of correct answers revealed the participant's score. The order of each test was the same for all participants and they were administered at 1400.

2.7. Statistical analyses

Statistical analyses were performed using SPSS software (version 17.0; SPSS Inc, Chicago, IL). A two-way repeated measures ANOVA was used to determine the main effects of menstrual cycle phase (early follicular/menstruation, late follicular/ovulation and mid-luteal) on odour threshold, discrimination, identification and TDI, as well as energy, carbohydrate, lipid and protein intakes. Moreover, a two-way repeated measures ANOVA was performed to determine the main effects of menstrual cycle phase (early follicular/menstruation, late follicular/ovulation and mid-luteal), time (pre- and post-lunch), food taste (savoury and sweet) and food fat content (high and low) on the explicit liking, explicit wanting, relative preference and implicit wanting of foods. Post hoc tests were used to verify where significant differences existed. Bivariate correlations were calculated between body fat percentage, olfaction scores, hormone levels, pre-lunch explicit wanting and liking, implicit wanting and relative preference for foods during the different phases of the menstrual cycle. The potential relationships between olfaction scores, pre-lunch relative preference, explicit wanting and liking and implicit wanting with energy and macronutrient intakes were also evaluated with bivariate correlations. Values are presented as means ± standard deviation. Differences with *p*-values < 0.05 were considered statistically significant.

3. Results

The characteristics of the participants are shown in Table 1. No significant differences in body weight, body mass index and fat mass (%) were noted across the menstrual cycle. Furthermore, no significant difference was noted in oral temperature across the cycle (early follicular/menstruation: 36.1 ± 0.4 °C, late follicular/ovulation: 36.2 ± 0.4 °C, mid-luteal: 36.2 ± 0.4 °C; p = NS). However, significant differences were noted for FSH (early follicular/menstruation: 5 ± 2, late follicular/ovulation: 6 ± 2, mid-luteal: 4 ± 2 IU/L; $p < 0.0001$), LH (early follicular/menstruation: 4 ± 3, late follicular/ovulation: 9 ± 7, mid-luteal: 6 ± 6 IU/L; $p < 0.05$), estradiol (early follicular/menstruation: 93 ± 74, late follicular/ovulation: 284 ± 294, mid-luteal: 445 ± 154 pmol/L; $p < 0.005$) and progesterone (early follicular/menstruation: 2.7 ± 1.0, late follicular/ovulation: 2.4 ± 1.0, mid-luteal: 37.6 ± 25.2 nmol/L; $p < 0.0001$) levels. As expected, FSH and LH levels were higher during the late follicular/ovulation phase, in comparison to the mid-luteal ($p < 0.0001$) and early follicular/menstruation ($p < 0.05$) phases. Estradiol levels were higher during the mid-luteal phase than the early follicular/menstruation phase ($p < 0.0001$). Progesterone levels were also

highest during the mid-luteal phase, when compared to the early follicular/menstruation ($p < 0.0001$) and late follicular/ovulation ($p < 0.0001$) phases.

Table 1. Characteristics of the participants measured during each phase for one complete menstrual cycle.

	Baseline			Early follicular/menstruation			Late follicular/ovulation			Mid-luteal			Phase (p-value)
	Mean	**SD**	**Range**	**Mean**	**SD**	**Range**	**Mean**	**SD**	**Range**	**Mean**	**SD**	**Range**	
Age (years)	22.4	3.2	18–28										
Menstrual cycle length (days)	28.1	3.8	24–34										
Height (cm)	164.2	0.06	154.0–176.5										
Body weight (kg)	60.5	7.5	49.7–77.4	60.5	7.5	50.8–78.0	60.3	7.4	50.1–78.2	60.4	7.4	50.2–78.2	NS
BMI (kg/m^2)	22.3	1.7	20.0–25.0	22.4	1.8	19.8–25.1	22.3	1.6	19.9–25.1	22.3	1.6	20.3–25.1	NS
Fat mass (%)	28.5	6.9	11.5–42.9	28.0	6.7	12.6–41.1	28.3	6.9	11.6–42.8	28.2	6.9	12.1–41.9	NS

Note: SD, standard deviation; kg, kilogram; m, meter; cm, centimeter; BMI, body mass index.

No significant differences were noted in odour threshold, odour discrimination and odour identification scores across the menstrual cycle (Table 2). However, a significant difference in mean TDI score was noted across the menstrual cycle ($p < 0.05$), where TDI scores were higher during the mid-luteal phase in comparison to the late follicular/ovulation phase (Fig. 1). A significant difference in lipid intake, as well as a trend in energy intake was noted across the cycle (Table 3). Lipid intake was significantly higher during the mid-luteal phase in comparison to the early follicular/menstruation ($p < 0.05$) and late follicular/ovulation ($p < 0.05$) phases. There were no significant changes in food preference and implicit wanting and explicit liking for foods varying in fat content and taste across the menstrual cycle (Table 4). However, there was a significant interaction between menstrual cycle phase and fat content for explicit wanting ($p < 0.05$; Table 4). This effect was due to greater explicit wanting for high fat foods pre-lunch during the mid-luteal phase, compared to the late follicular/ovulation phase ($p < 0.05$; Fig. 2). There was also a significant effect of time on explicit liking and wanting [scores were lower post-lunch vs. pre-lunch ($p < 0.0001$)]. Lastly, positive correlations were noted between body fat percentage and the relative preference for high fat sweet foods during the early follicular/menstruation ($r = 0.644$; $p < 0.01$) and mid-luteal ($r = 0.569$; $p < 0.05$) phases, while a positive correlation between body fat percentage and the relative preference for low fat sweet foods was noted during the mid-luteal phase only ($r = 0.510$; $p < 0.05$). Positive correlations were also noted between body fat percentage and explicit liking and wanting for high ($r = 0.597$ and $r = 0.595$; $p < 0.05$) and low ($r = 0.493$ and $r = 0.585$; $p < 0.05$) fat sweet foods during the early follicular/menstruation phase only. However, no correlations were observed between body fat percentage and olfaction scores, or between the changes in olfaction scores and explicit wanting during the different phases of the menstrual cycle. Furthermore, no correlations were noted between estradiol and progesterone levels with olfaction scores, explicit wanting and lipid intake during the mid-luteal phase, or between the changes in hormone levels and olfaction scores, explicit wanting and lipid intake across the cycle. As for energy and macronutrient intakes, negative correlations were noted between odour identification scores and energy ($r = -0.597$ $p < 0.05$), carbohydrate ($r = -0.535$; $p < 0.05$) and lipid ($r = -0.624$; $p < 0.01$) intakes during the early follicular/menstruation phase. Negative correlations were also noted

between odour discrimination scores and energy ($r = -0.650$; $p < 0.01$) and lipid ($r = -0.689$; $p < 0.01$) intakes, as well as between TDI and lipid intakes ($r = -0.576$; $p < 0.015$) during the mid-luteal phase.

Table 2. Odour threshold, discrimination and identification scores measured during each phase for one complete menstrual cycle.

	Early follicular/menstruation		Late follicular/ovulation		Mid-luteal		Phase (p-value)
	Mean	SD	Mean	SD	Mean	SD	
Odour threshold	8.1	2.6	8.2	1.7	9.1	2.0	NS
Odour discrimination	13.0	1.6	12.3	2.1	13.3	2.1	NS
Odour identification	13.5	2.2	13.4	3.0	13.4	2.2	NS

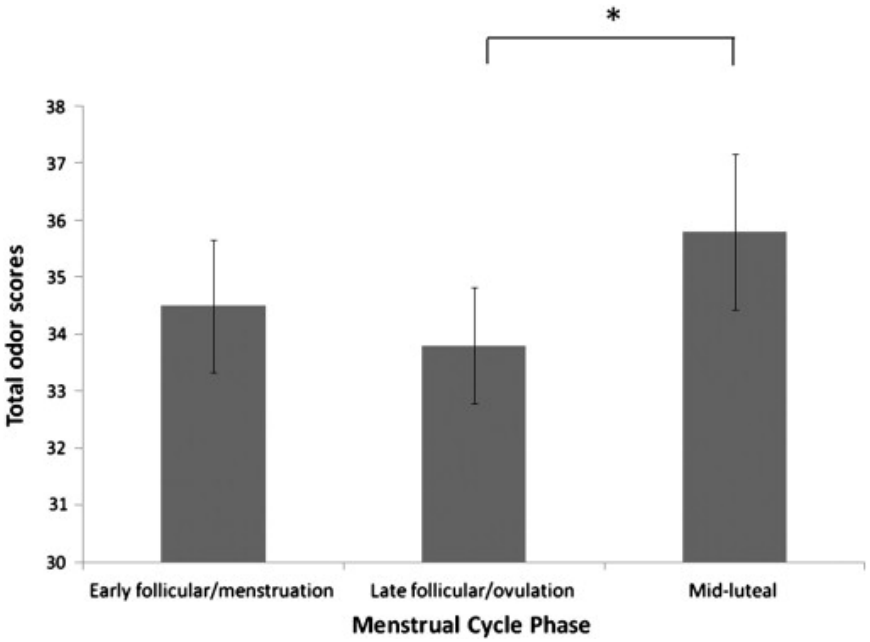

Fig. 1. Total odour scores (i.e. TDI) during different phases of the menstrual cycle.
Values are presented as means for 17 women with standard errors of the mean represented by vertical bars.
*$p < 0.01$.

Table 3. Energy and macronutrient intakes across the menstrual cycle.

	Early follicular/menstruation		Late follicular/ovulation		Mid-luteal		Phase (p-value)
	Mean	SD	Mean	SD	Mean	SD	
Energy intake (kcal)	669.5	292.9	525.3	289.2	710.7	334.0	0.05
Carbohydrate intake (kcal)	336.4	117.2	289.6	132.4	365.2	137.6	NS
Lipid intake (kcal)	193.5	160.2	165.6	126.0	273.6	190.8	0.03
Protein intake (kcal)	94.0	60.4	83.2	56.0	88.4	56.0	NS

Note: SD, standard deviation; kcal, kilocalorie.

Table 4. The relative preference, explicit liking and wanting, as well as implicit wanting for foods varying in fat content (high and low fat) and taste (sweet and savoury).

	Early follicular/menstruation				Late follicular/ovulation				Mid-luteal				Phase	Time	Fat content	Taste	Phase[a] Time	Phase[a] Fat content	Phase[a] Taste
	Pre-lunch		Post-lunch		Pre-lunch		Post-lunch		Pre-lunch		Post-lunch								
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD							
Relative preference													NA[a]	NA[a]	0.012	NS	NA[a]	NS	NS
HF – SW	24.5	11.3	28.6	9.4	22.2	10.3	26.5	9.3	24.5	11.6	26.5	11.1							
LF – SW	20.9	7.6	26.1	8.8	19.6	7.8	25.8	10.8	20.8	9.2	25.5	9.1							
HF – SA	27.6	8.0	26.2	7.6	28.8	8.7	24.4	9.2	28.6	7.8	25.6	8.9							
LF – SA	22.9	11.3	15.1	8.7	25.4	8.4	19.2	9.9	22.1	11.1	18.4	7.3							
Explicit liking													NS	0.000	NS	NS	NS	NS	NS
HF – SW	34.3	23.2	26.8	22.5	31.2	19.3	24.9	20.1	37.4	23.1	27.2	22.9							
LF – SW	32.3	16.8	21.3	17.7	32.3	17.5	25.4	17.3	37.9	17.6	29.6	22.4							
HF – SA	37.8	16.4	21.9	22.7	41.5	19.6	23.7	20.1	42.9	20.1	28.6	20.0							
LF - SA	31.9	20.4	16.3	12.6	38.1	19.5	19.1	16.9	35.1	18.5	20.9	16.3							
Explicit wanting													NS	0.000	NS	NS	NS	0.034	NS
HF – SW	30.0	24.4	20.9	26.6	26.5	21.4	18.7	19.4	34.1	22.0	21.4	21.4							
LF – SW	27.9	17.6	17.4	19.4	29.3	16.9	21.3	19.8	33.3	19.2	22.9	23.4							
HF – SA	31.7	16.8	16.7	21.8	34.6	19.7	17.1	18.0	39.6	19.5	21.8	20.2							
LF – SA	26.7	20.4	12.5	14.0	34.3	20.6	16.3	18.0	30.5	19.2	17.0	17.9							
Implicit wanting													NS	NS	NS	NS	NS	NS	NS
HF – SW	0.05	0.44	− 0.15	0.41	0.22	0.43	− 0.07	0.23	0.13	0.41	− 0.01	0.29							
LF – SW	− 0.08	0.23	− 0.14	0.40	0.06	0.42	− 0.09	0.47	− 0.12	0.35	− 0.19	0.42							
HF – SA	− 0.10	0.31	− 0.10	0.29	− 0.20	0.28	− 0.08	0.19	− 0.07	0.27	0.08	0.34							
LF – SA	0.16	0.47	0.39	0.44	− 0.08	0.43	0.24	0.49	0.054	0.44	0.11	0.34							

Note: SD, standard deviation; HF, high fat; LF, low fat; SW, sweet; SA, savoury.

[a] Non-applicable because the forced choice nature of this task provides the same number of responses each time this task is performed.

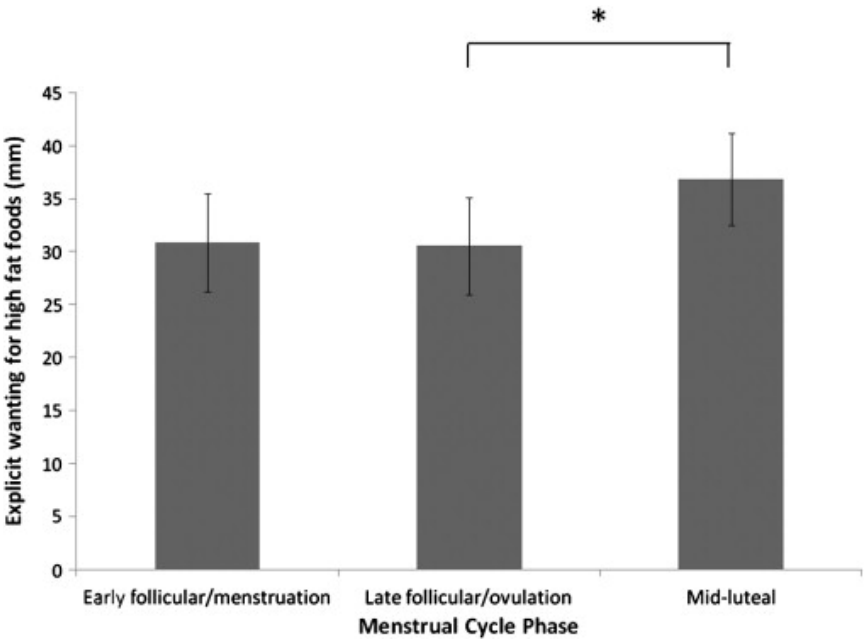

Fig. 2. Explicit wanting for high fat foods (mm) during different phases of the menstrual cycle. Values are presented as means for 17 women with standard errors of the mean represented by vertical bars. *$p < 0.05$.

4. Discussion

To our knowledge, this is the first study to examine variations in olfactory performance concurrently with differences in food reward across the menstrual cycle. Our results showed greater TDI scores, explicit wanting for high fat foods and lipid intake during the mid-luteal phase of the menstrual cycle. However, odour threshold, implicit wanting for high fat sweet foods, energy and carbohydrate intakes were not greater during the mid-luteal phase; thus rejecting our initial hypothesis. Additionally, olfactory threshold and TDI scores were not greater during the late follicular/ovulation phase. Lastly, the increase in TDI scores during the mid-luteal phase was unrelated to the increase in explicit wanting for high fat foods during this same phase.

Since wanting, when compared to liking, has been suggested to play a larger role in influencing ingestive behaviour [22], the novel finding of greater explicit wanting, but no difference in liking, for high fat foods during the mid-luteal phase may in part explain why some women appear to be prone to consuming more energy [2], [3], [4], [5], [6], [23], [24], [25] and lipids [2], [3], [4], [5] during this phase of the menstrual cycle. Our results support the abovementioned findings as indicated by a trend in absolute energy intake, as well as an increase in absolute lipid intake during the mid-luteal phase. Furthermore, Tucci et al. [26] did not see a significant increase in the hedonic ratings (most similar to explicit liking) of sweet snack foods during the luteal phase when compared to the follicular phase, even though the participants of this study consumed more sweet foods during the luteal phase. As expected, decreases in explicit liking and wanting for foods were seen post-lunch vs. pre-lunch with no significant interaction between menstrual cycle phase and time, suggesting that this decrease in food wanting and liking occurred independently of menstrual cycle phase. Lastly, the positive correlations between body fat percentage and the relative preference, explicit wanting and liking for sweet foods during the early follicular/menstruation and mid-luteal phases are in accordance with previous studies,

where overweight/obese women were willing to work harder in order to obtain a snack food versus receiving a low-fat food [27], consumed more calories when given the snack food [28], and found dietary fat to be more palatable [29]. Ouwehand and de Ridder [30] also noted that overweight women rated sweet tastes as being more pleasant when compared to normal-weight women, which corroborates the positive relationship noted between body fat percentage and the reward value of sweet foods in the current study.

Although previous studies have noted conflicting results in terms of potential variations in olfactory threshold across the menstrual cycle, the current study was to our knowledge the first to measure and show an increase in overall olfactory performance (i.e. TDI) during the mid-luteal phase of the menstrual cycle. Although olfactory threshold did not significantly increase during the mid-luteal phase, an increase in TDI during this phase suggests that changes in overall olfactory performance do occur across the cycle. Other studies have previously noted increases in olfactory sensitivity during ovulation and/or the mid-luteal phase [11], [12], [13], [14]. Even though these studies used different odours (e.g. amyl acetate, exaltolide, coumarin) to assess olfactory sensitivity across the menstrual cycle, those who employed musk-like odours noted clearer cyclic changes in olfactory sensitivity [12], [14]. These changes may be in part mediated by the large variations in estradiol levels across the menstrual cycle, with greater olfactory sensitivity coinciding with higher estradiol levels during ovulation and the luteal phase [11]. However, a study by Doty et al. [13] examined olfactory sensitivity for odours that were not related to pheromones (furfural and phenyl ethyl alcohol) across the menstrual cycle, and noted an increase in olfactory sensitivity during ovulation, the second half of menstruation and the mid-luteal phase regardless of whether the women were taking oral contraceptives or not. Furthermore, the current study did not observe any correlations between the changes in hormone levels and olfaction scores across the cycle, as well as between estradiol and progesterone levels with olfaction scores during the mid-luteal phase; thus suggesting that the increases in both estradiol and progesterone during the luteal phase does not coincide with the noted increase in overall olfactory performance. Taken together, it is unclear which physiological mechanisms may cause these alterations in olfactory sensitivity and overall olfactory performance across the menstrual cycle.

Lastly, Cameron et al. [31] showed that odour threshold, odour discrimination and TDI scores increased following 24 h of energy deprivation, and that greater smell identification scores coincided with increased carbohydrate consumption. Conversely, the current study observed negative correlations between odour identification, energy, carbohydrate and lipid intakes during the early follicular/menstruation phase, as well as between odour discrimination and TDI with energy and lipid intakes during the mid-luteal phase. Based on these results, the increase in lipid intake noted during the mid-luteal phase cannot be explained by greater overall olfactory performance noted during this same phase.

In the present study, n-butanol was the odour employed to measure olfactory sensitivity, which is neither a pheromone or an odour related to food. As such, the lack of an increase in olfactory sensitivity during the late follicular/ovulation and/or mid-luteal phases, as well as a positive relation between food intake, food reward and olfactory performance may be related to the type of odour employed. Future studies would be needed to measure olfactory sensitivity and overall olfactory performance with different types of odours in relation to food reward and food intake

across the menstrual cycle, in order to determine whether the type of odourant used influences olfactory performance, food reward and/or food intake differently.

In conclusion, increases in explicit wanting for high fat foods, lipid intake and overall olfactory performance occurred during the mid-luteal phase of the menstrual cycle. These results suggest that greater overall olfactory performance and explicit wanting, rather than liking, for high fat foods may help to explain why some women experience changes in their eating behaviour and increased food consumption during the mid-luteal phase of their menstrual cycle.

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