

# Sleep changes vary by odor perception in young adults

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Received 15 March 2005; accepted 26 July 2005

Available online 6 September 2005

## Abstract

Peppermint, a stimulating odor, increases alertness while awake and therefore may inhibit sleep. This study examined peppermint's effects on polysomnographic (PSG) sleep, alertness, and mood when presented before bedtime. Twenty-one healthy sleepers (mean age  $\pm$  S.D.,  $20.1 \pm 2.0$  years) completed three consecutive laboratory sessions (adaptation, control, and stimulus nights). Peppermint reduced fatigue and improved mood and was rated as more pleasant, intense, stimulating, and elating than water. These perceptual qualities associated with sleep measures: subjects rating peppermint as very intense had more total sleep than those rating it as moderately intense, and also showed more slow-wave sleep (SWS) in the peppermint than control session. Furthermore, subjects who found peppermint stimulating showed more NREM and less REM sleep while those rating it as sedating took longer to reach SWS. Peppermint did not affect PSG sleep, however, when these perceptual qualities were not considered. Peppermint also produced gender-differentiated responses: it increased NREM sleep in women, but not men, and alertness in men, but not women, compared with the control. Thus, psychological factors, including individual differences in odor perception play an important role in physiological sleep and self-rated mood and alertness changes.

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*Keywords:* Perception; Peppermint; Aromatherapy; Intensity; Hedonics; Mood; Polysomnography; Sleepiness; Fatigue; Gender

## 1. Introduction

Aromatherapeutic essential oils produce physiological and psychological effects, including sleep and mood changes, though most data obtain from case reports and small studies (Buckle, 2001; Gyllenhaal et al., 2000; Price and Price, 1999; Tisserand, 1988). For example, exposure to various essential oils improved sleep—including decreased time awake, increased total sleep time and efficiency and reduced daytime sleepiness—in young, elderly, and demented subjects (Connell et al., 2001; Hardy, 1991; Henry et al., 1994; Hudson, 1996; Raudenbush et al., 2003; Sano et al., 1998; Svoboda et al., 2002; Wolfe and Herzberg, 1996). More recently, lavender, a sedating odor, increased deep or slow-wave PSG sleep in healthy young adults (Goel et al., 2005). Other than this experiment, however, the aforementioned studies were uncontrolled, with small sample sizes and subjective sleep evaluations. Therefore, further studies are necessary to determine

whether other odors—including stimulating ones such as peppermint—produce different effects than sedating odors on objective sleep.

Peppermint is stimulating when presented during wakefulness: it decreases theta activity (Klemm et al., 1992), increases contingent negative variation amplitude (Torii et al., 1988), and reduces the pupillary unrest index, a physiological daytime sleepiness measure (Norris and Dwyer, 2005). Similarly, peppermint exposure during sleep increases EEG speed and heart rate (Badia et al., 1990) and produces EEG and behavioral arousals during stage 1 sleep (Carskadon and Herz, 2004). Moreover, peppermint increases alertness and performance on various tasks (Barker et al., 2003; Raudenbush et al., 2001, 2002, 2004; Stampi et al., 1996; Sullivan et al., 1998; Warm et al., 1991), reduces self-rated fatigue and increases vigor (Raudenbush et al., 2002, 2004), and improves mood (Ilmberger et al., 2001; Klemm et al., 1992; Warm et al., 1991).

Peppermint also ranks highly on self-rated perceptual scales. Peppermint is rated as very pleasant (Klemm et al., 1992; Warm et al., 1991) and intense (Klemm et al., 1992) compared with other odors. Moreover, it is perceived as

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highly stimulating (Gould and Martin, 2001; Klemm et al., 1992; Warm et al., 1991). Finally, subjects rate peppermint as more pleasant, intense, and stimulating than water (Ilmberger et al., 2001). Such perceptual qualities relate to experimental measure variations. The sedating/stimulating quality of odors is associated with differential physiological changes (Badia et al., 1990; Bensafi et al., 2002a,b; Klemm et al., 1992; Lorig and Schwartz, 1988; Romine et al., 1999) as are odor hedonics (Bensafi et al., 2002a,b,c; Brauchli et al., 1995; Ehrlichman and Bastone, 1992; Henkin and Levy, 2001; Kline et al., 2000; Millot and Brand, 2001; Miltner et al., 1994) and intensity (Bensafi et al., 2002a; Carskadon and Herz, 2004; Wang et al., 2002). We assessed whether such perceptual measures associated with peppermint-induced sleep changes, a relationship thus far unexplored.

Gender differences in olfaction also have been investigated, whereby women show superior abilities (see reviews, Brand and Millot, 2001; Velle, 1987). In addition, many odors produce gender-differentiated physiological responses, often with greater responses in women (Becker et al., 1993; Evans et al., 1995; Henkin and Levy, 2001; Levy et al., 1999; Yousem et al., 1999). Moreover, we found that lavender produced gender-differentiated changes in specific sleep measures, with opposite effects in women and men (Goel et al., 2005).

This study examined peppermint oil's effects on PSG sleep in healthy young men and women. We hypothesized that peppermint, a stimulating odor, would disrupt sleep and produce gender-differentiated effects, with larger changes in women. We also predicted that peppermint's perceptual or psychological qualities (assessed by pleasantness, intensity, depressing/elating, and sedating/stimulating ratings) would relate to physiological sleep changes. Finally, peppermint was predicted to reduce sleepiness and fatigue and increase vigor.

## 2. Methods

### 2.1. Subjects

Twenty-one subjects, 11 women and 10 men, ages 18–26 years (overall mean age  $\pm$  S.D.,  $20.1 \pm 2.0$  years; men:  $20.4 \pm 2.3$  years; women:  $19.9 \pm 1.8$  years) participated in the study. All subjects were in good physical and psychological health, were healthy sleepers, and were not using central nervous system medications. Subjects with extreme morningness or eveningness, assessed by the Morningness–Eveningness Questionnaire (Horne and Östberg, 1976), or with a history of respiratory disease such as chronic asthma or sinus problems were excluded during the initial interview. To test olfactory function, subjects were exposed to several odors and water and asked whether they could detect each. Those with detection difficulties were excluded. This supra-threshold detection approach insured

that each subject had a similar minimal level of olfactory functioning and avoided possible expectancy or suggestion effects which may emerge with sub-threshold concentrations (Campenni et al., 2004; Torii et al., 1988).

Smokers, subjects scoring  $\geq 10$  on the Beck Depression Inventory (Beck et al., 1961) and women on oral contraceptives or with irregular menstrual cycles also were excluded. A nearly equal number of women were in the luteal ( $n = 5$ ) or follicular ( $n = 6$ ) menstrual cycle phases. For one week before study entry, subjects maintained a habitual bedtime of 24:00 h and wake-up time of 08:00 h, verified by sleep logs and daily call-ins at bedtime and upon awakening to an answering machine with time stamp. Wesleyan University's Institutional Review Board approved the study and all procedures conformed to the Declaration of Helsinki. Subjects received monetary compensation for participation and signed informed consent before study entry.

### 2.2. Polysomnographic (PSG) recordings

Central and occipital electroencephalographic (EEG), electrooculographic (EOG), and submental electromyographic (EMG) measures were recorded from 24:00 h (lights off) to 08:00 h (lights on). During the adaptation night, subjects were screened for sleep pathologies, including apneas, oxygen desaturation, and periodic limb movements by monitoring respiratory effort, nasal airflow, arterial oxygen saturation level, bilateral anterior tibialis EMG, and heart rate (EKG). Sleep records were visually scored in 30-s epochs according to Rechtschaffen and Kales' (1968) standard scoring criteria by two trained scorers blind to the experimental conditions. Inter-rater reliability for the two scorers was 93.5%.

### 2.3. Subjective sleepiness and mood questionnaires

The Stanford Sleepiness Scale (SSS; Hoddes et al., 1973) quantifies the progressive, subjective stages of the sleep-alertness continuum, with a scale from 1 to 7 (1, feeling active, vital, alert, or wide awake; 7, sleep onset soon; lost struggle to remain awake), and has been tested with repeated acute sampling periods (e.g., 15 min).

The Profile of Mood States Questionnaire (POMS; McNair et al., 1992), a 65-item self-report scale, assesses transient affective states in response to various stimuli including olfactory cues (Bensafi et al., 2002c; Goel et al., 2005; Jacob and McClintock, 2000; Jacob et al., 2001; Schiffman et al., 1995). The POMS has been validated in repeated measures designs (see Schiffman et al., 1995) and sleep studies (Dollins et al., 1994; Goel et al., 2005; Jockovich et al., 2000). Moreover, it has been tested with repeated acute sampling periods (e.g., 3 min; McNair et al., 1992). Each item is rated on a scale from 0 to 4 (0, not at all; 4, extremely), on one of six factors: depression–dejection (Depression), tension–anxiety (Tension), anger–hostility

(Anger), confusion–bewilderment (Confusion), vigor–activity (Vigor), and fatigue–inertia (Fatigue). The total score for each factor is calculated by adding together the respective set of adjectives corresponding to that factor. The total mood disturbance score (TMD), a global estimate of affective state, derives from summing the factors together, with vigor–activity weighted negatively.

2.4. Likert scales for stimulus perception

Likert scales assess the perception of peppermint or distilled water using a seven-point scale. Subjects rated stimulus hedonics (1, very unpleasant; 7, very pleasant) and intensity (1, very weak; 7, very intense), as well as its effects on mood (1, very depressing; 7, very elating) and on sleepiness (1, very sedating; 7, very stimulating).

2.5. Odor

The olfactory stimulus was commercially available pure peppermint essential oil (Lotus Brands Inc., Twin Lakes, WI); the oil did not contain any solvent materials as verified by gas chromatography. Distilled water served as the control.

2.6. Procedure

Subjects slept in a sleep laboratory for three consecutive overnight sessions (Fig. 1). Each session lasted from approximately 21:00 h to 08:30 h. On the second and third intervening days, subjects left the laboratory between 08:30 h and 21:00 h and engaged in their habitual activities. On these study days, subjects refrained from napping and

exercise, and from alcohol or caffeine intake. In addition, subjects were not permitted to wear scented products (e.g., perfume and lotion) during their overnight laboratory stays.

Electrode placement for PSG recordings occurred at 21:30 h on all nights. Subjects then engaged in recreational activities until bedtime (24:00 h) on the first night and until 23:10 h on the second and third nights. PSG data were collected from 24:00 h to 08:00 h each night. Subjects remained in bed if they awakened before 08:00 h.

The first night served as an adaptation session. During the second and third nights, subjects received either peppermint essential oil or distilled water from approximately 23:10 h to 23:40 h. The subjects were not told what odors they were receiving, nor were they informed about the odors’ intensity, hedonics or stimulating/sedating properties. They also were not told that one of the vials contained water. The session order was counterbalanced; furthermore, gender was counterbalanced within order assignment. Of the 21 subjects, 10 (6 women and 4 men) received the odor first, and 11 (5 women and 6 men) received the control first.

During the experimental session, subjects received peppermint oil intermittently from 23:10 h to 23:40 h. The stimulus was presented for the first four min of each 10-min period (23:10 h, 23:20 h, 23:30 h, and 23:40 h). Subjects held the peppermint oil vial at chin level while wearing odorless vinyl gloves, and breathed normally and steadily with their eyes closed. The experimenter ensured that subjects remained awake and that no other competing stimuli were present during odor exposure. The control session was identical to the experimental session except that subjects held and sniffed a vial containing distilled water. The various components of this experimental procedure, including intermittent odor exposure, the odor

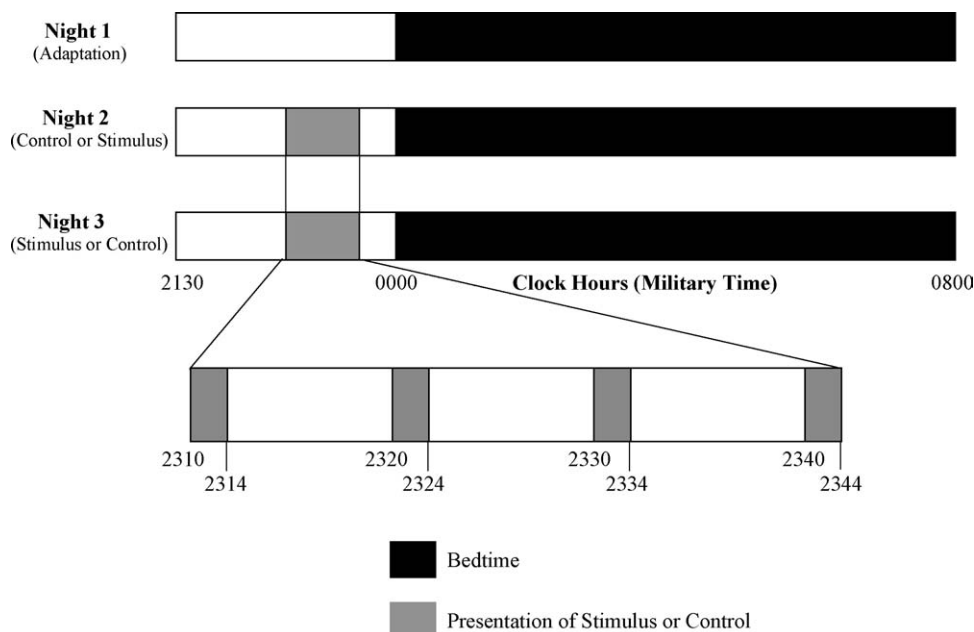


Fig. 1. Schematic representation of the three consecutive night study protocol.

administration technique and use of water as a control have been used previously (Goel and Grasso, 2004; Goel et al., 2005; Ilmberger et al., 2001; Kline et al., 2000). Subjects assessed stimulus perceptual qualities via Likert scales at 23:14 h and 23:44 h during the experimental and control sessions. The SSS was administered at 23:55 h and 08:15 h and the POMS was administered at 23:00 h, 23:14 h, 23:44 h, and 08:15 h. Both instruments are designed for repeated measures using short time intervals, as noted above; moreover, any possible repeated administration effects would be observed in both sessions.

## 2.7. Statistical analyses

Repeated measures analyses of variance (rmANOVAs), with gender and session order as the primary (“core”) comparisons, assessed differences in PSG sleep measures, perceptual ratings, and subjective sleepiness and mood scores between sessions. In addition, each of the four perceptual qualities was added individually to the rmANOVA core, thus maximizing available sample sizes, to assess PSG sleep measures dependency on these qualities. Post hoc tests, corrected for multiple comparisons, examined significant interactions for all measures. Pearson-product correlation coefficient analyses ( $r$ ) analyzed the relationships between PSG and perceptual ratings. The magnitude of between-group differences in scores was expressed as effect size,  $d$ , the standardized difference between means ( $d = 0.3$ , small; 0.5, medium; 0.8, large; Cohen, 1988). Data are presented as mean  $\pm$  S.D.;  $P < 0.05$  was considered significant for all statistical analyses.

## 3. Results

### 3.1. Peppermint perceptual ratings

Peppermint odor was rated as significantly more pleasant ( $5.40 \pm 1.28$  versus  $4.07 \pm 0.62$ ;  $F_{1,17} = 20.66$ ,  $P < 0.001$ ;  $d = 1.32$ ), intense ( $5.57 \pm 0.90$  versus  $2.60 \pm 1.38$ ;  $F_{1,17} = 90.09$ ,  $P < 0.001$ ;  $d = 2.55$ ), elating ( $4.81 \pm 0.90$  versus  $3.98 \pm 0.63$ ;  $F_{1,17} = 15.59$ ,  $P < 0.002$ ;  $d = 1.07$ ), and stimulating ( $4.05 \pm 1.39$  versus  $3.50 \pm 0.87$ ;  $F_{1,17} = 4.83$ ,  $P < 0.05$ ;  $d = 0.47$ ) than water. Furthermore, intensity ratings showed a significant session  $\times$  gender interaction ( $F_{1,17} = 9.56$ ,  $P < 0.008$ ): although both men and women rated peppermint as more intense than water, this difference was greater in women (women,  $6.05 \pm 0.80$  versus  $2.23 \pm 1.49$ ,  $F_{1,9} = 56.41$ ,  $P < 0.001$ ;  $d = 3.19$ ; men,  $5.05 \pm 0.70$  versus  $3.00 \pm 1.17$ ,  $F_{1,8} = 43.91$ ,  $P < 0.001$ ;  $d = 2.13$ ). There also was a significant overall main effect of gender for depressing/elating ratings; women rated both peppermint and water as more elating than men ( $4.70 \pm 0.70$  versus  $4.05 \pm 0.66$ ;  $F_{1,17} = 12.91$ ,  $P < 0.003$ ;  $d = 0.96$ ).

As originally hypothesized, peppermint perceptual ratings also were significantly associated with PSG sleep

measures. Greater intensity correlated with more SWS %SPT ( $r = 0.51$ ,  $P < 0.05$ ) and greater stimulation correlated with less stage 1 %SPT ( $r = -0.49$ ,  $P < 0.05$ ). Higher elating ratings correlated with more wake after sleep onset (WASO) %SPT ( $r = 0.46$ ,  $P < 0.05$ ) and worse sleep maintenance efficiency ( $r = -0.45$ ,  $P < 0.05$ ).

### 3.2. Polysomnographic sleep

#### 3.2.1. Session order differences

There were no significant session order (stimulus–control versus control–stimulus) differences in PSG measures. Furthermore, there were no significant session order  $\times$  gender interactions for any PSG measure.

#### 3.2.2. Session differences: PSG and peppermint perceptual ratings

The peppermint and control sessions did not differ significantly in PSG measures (Table 1). However, the aforementioned significant correlations indicated an association between peppermint’s qualitative ratings and PSG variables. Indeed, intensity and stimulation ratings, but not depressing/elating and pleasantness/unpleasantness ratings, were associated with significant differential effects in PSG measures. These originally hypothesized associations justified further statistical analyses for both intensity and sedating/stimulating ratings.

As such, the 21 subjects were divided into two groups based on their peppermint intensity ratings at 23:44 h: 9 subjects rated peppermint as moderately intense (rating, 4–5; 7 women and 2 men) while 12 subjects rated it as very intense (rating, 6–7; 4 women and 8 men). SWS %SPT showed a significant session  $\times$  intensity rating interaction ( $F_{1,14} = 4.84$ ,  $P < 0.05$ ; Fig. 2A): subjects rating peppermint as very intense spent more time in SWS (deep sleep) in the peppermint than control session ( $F_{1,8} = 7.53$ ,  $P < 0.05$ ;

Table 1  
PSG measures for the stimulus and control nights (mean  $\pm$  S.D.)

PSG measure	Stimulus night	Control night
TST (min)	461.17 $\pm$ 14.42	457.17 $\pm$ 13.70
SPT (min) <sup>a</sup>	467.67 $\pm$ 13.55	466.07 $\pm$ 10.41
TWT (min)	21.12 $\pm$ 13.75	22.74 $\pm$ 13.49
SE (%)	95.62 $\pm$ 2.85	95.22 $\pm$ 2.74
SME (%)	98.55 $\pm$ 1.70	98.11 $\pm$ 2.03
SOL (min)	13.98 $\pm$ 11.61	12.67 $\pm$ 8.18
WASO, %SPT	1.39 $\pm$ 1.68	1.95 $\pm$ 2.04
WASO, latency (min)	195.81 $\pm$ 150.84	171.88 $\pm$ 131.57
Stage 1, %SPT	4.41 $\pm$ 2.40	3.65 $\pm$ 2.19
Stage 1, latency (min)	13.24 $\pm$ 11.81	11.55 $\pm$ 7.90
Stage 2, %SPT	64.23 $\pm$ 5.37	63.76 $\pm$ 7.01
Stage 2, latency (min)	18.93 $\pm$ 12.92	16.02 $\pm$ 7.98
SWS, %SPT	4.35 $\pm$ 3.60	4.61 $\pm$ 4.06
SWS, latency (min)	38.34 $\pm$ 20.59	31.58 $\pm$ 10.84
NREM, %SPT	73.00 $\pm$ 3.91	72.00 $\pm$ 4.31
REM, %SPT	25.60 $\pm$ 4.69	26.03 $\pm$ 3.98
REM, latency (min)	92.74 $\pm$ 34.42	91.71 $\pm$ 33.86

<sup>a</sup> SPT is defined as the duration from sleep onset to the end of sleep.

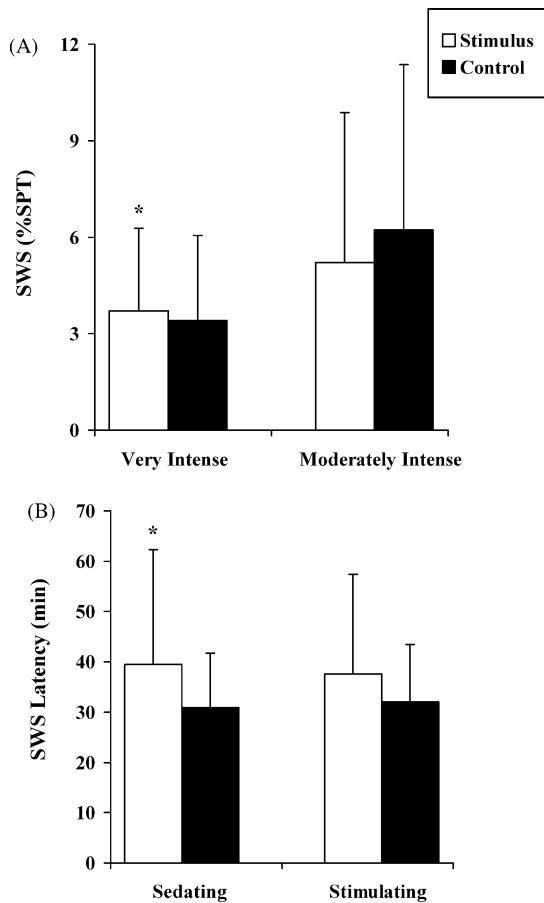


Fig. 2. (A) SWS %SPT for subjects rating peppermint as either very intense or moderately intense (mean  $\pm$  S.D.). (B) SWS latency (min) for subjects rating peppermint as either sedating or stimulating (mean  $\pm$  S.D.). \*Significantly greater than the control session,  $P < 0.05$ .

$d = 0.21$ ) while those rating it as moderately intense showed no significant session differences ( $F_{1,6} = 1.40$ ,  $P > 0.05$ ). Notably, SWS %SPT across both nights did not differ significantly between those who rated peppermint as very versus moderately intense ( $F_{1,14} = 0.16$ ,  $P > 0.05$ ). In addition, subjects rating peppermint as very intense had a longer total sleep time ( $463.94 \pm 10.22$  versus  $452.81 \pm 16.28$ ;  $F_{1,14} = 4.45$ ,  $P < 0.05$ ;  $d = 0.85$ ) and sleep period time ( $471.65 \pm 8.76$  versus  $460.50 \pm 13.14$ ;  $F_{1,14} = 6.23$ ,  $P < 0.05$ ;  $d = 1.03$ ) across both nights than those rating it as moderately intense.

As was done for intensity, the 21 subjects were divided into two groups based on their peppermint sedating/stimulating ratings: 11 subjects rated peppermint as stimulating (rating, 4.5–7; 6 women and 5 men) while 10 subjects rated it as sedating (rating, 1–3.5; 5 women and 5 men). SWS latency showed a significant session  $\times$  stimulation interaction ( $F_{1,11} = 4.64$ ,  $P < 0.05$ ; Fig. 2B), such that subjects rating peppermint as sedating took longer to reach SWS during the peppermint session ( $F_{1,4} = 34.92$ ,  $P < 0.005$ ;  $d = 0.47$ ), while subjects rating it as stimulating showed no significant session differences ( $F_{1,7} = 0.96$ ,  $P > 0.05$ ). In addition, subjects who found peppermint

stimulating had a higher NREM %SPT ( $73.54\% \pm 3.91\%$  versus  $71.36\% \pm 4.15\%$ ;  $F_{1,13} = 5.05$ ,  $P < 0.05$ ;  $d = 0.54$ ) and a shorter REM duration ( $115.48 \pm 19.62$  versus  $126.10 \pm 20.73$ ;  $F_{1,13} = 4.54$ ,  $P < 0.05$ ;  $d = 0.53$ ) across both nights than those who found it sedating. Furthermore, REM latency showed a significant gender  $\times$  stimulation interaction ( $F_{1,13} = 8.05$ ,  $P < 0.05$ ): women rating peppermint as stimulating took longer to reach REM than those rating it as sedating ( $105.04 \pm 37.83$  versus  $67.85 \pm 27.02$ ;  $F_{1,7} = 5.52$ ,  $P < 0.05$ ;  $d = 1.12$ ). By contrast, men rating peppermint as stimulating or sedating did not differ significantly ( $91.30 \pm 27.09$  versus  $102.15 \pm 23.30$ ;  $F_{1,6} = 3.30$ ,  $P > 0.05$ ).

### 3.2.3. Session $\times$ gender effects

There was a significant session  $\times$  gender interaction for NREM duration ( $F_{1,17} = 4.43$ ,  $P < 0.05$ ); women spent significantly more time in NREM sleep during the peppermint than control session ( $343.87 \pm 22.41$  versus  $324.91 \pm 17.97$ ;  $F_{1,9} = 5.42$ ,  $P < 0.05$ ;  $d = 0.93$ ), while men showed no session differences ( $338.60 \pm 19.45$  versus  $347.30 \pm 18.86$ ;  $F_{1,8} = 0.56$ ,  $P > 0.05$ ).

### 3.3. Subjective sleepiness and mood

SSS scores also showed a significant session  $\times$  gender interaction at 08:15 h ( $F_{1,17} = 6.32$ ,  $P < 0.05$ ; Fig. 3): men ( $F_{1,8} = 6.29$ ,  $P < 0.05$ ;  $d = 0.95$ ) but not women ( $F_{1,9} = 0.91$ ,  $P > 0.05$ ) reported feeling more alert the morning after peppermint than control exposure. Similarly, anger ( $F_{1,17} = 4.31$ ,  $P < 0.05$ ) and depression ( $F_{3,17} = 3.21$ ,  $P < 0.05$ ) POMS scores both showed significant session  $\times$  gender interactions, although post hoc tests revealed no further significant differences between the sessions for men or women.

Fatigue scores showed a significant session night  $\times$  time interaction ( $F_{3,51} = 3.39$ ,  $P < 0.05$ ); peppermint significantly reduced fatigue at 23:44 h compared with the control

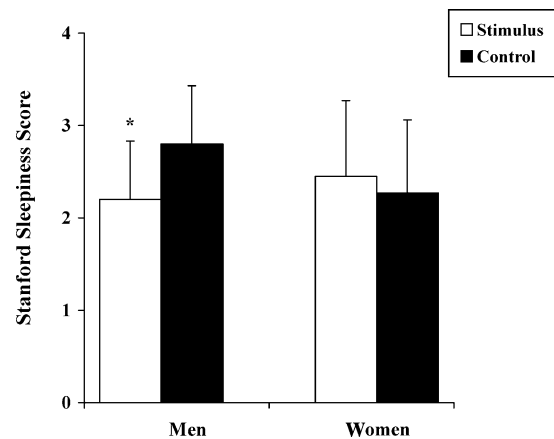


Fig. 3. Stanford Sleepiness Scores at 08:15 h for men and women in the stimulus and control sessions (mean  $\pm$  S.D.). \*Significantly lower than the control session,  $P < 0.05$ .

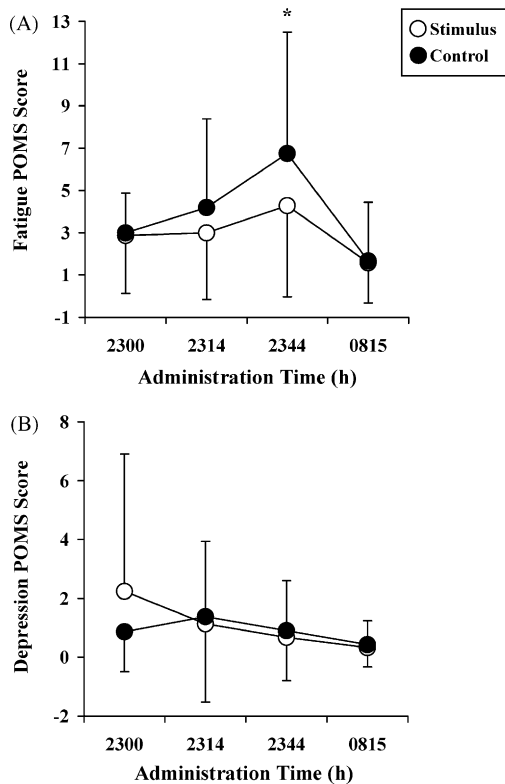


Fig. 4. (A) Fatigue and (B) depression POMS scores in the stimulus and control sessions for all assessment time points (mean  $\pm$  S.D.). \*Significantly higher than the stimulus session,  $P < 0.008$ .

( $t_{20} = 3.01$ ,  $P < 0.008$ , Fig. 4A;  $d = 0.49$ ). Similarly, depression scores showed a significant session night  $\times$  time time interaction ( $F_{3,51} = 2.90$ ,  $P < 0.05$ ; Fig. 4B): peppermint reduced depression scores at 23:14 h, 23:44 h, and 08:15 h compared with the control. Vigor, TMD, anger, confusion, and tension scores did not show significant session differences.

#### 4. Discussion

This study demonstrates that individual differences in the perception of peppermint are associated with physiological changes in sleep. Subjects who found peppermint very intense showed increases in total sleep time and sleep period time compared with those who found it moderately intense, and showed more SWS in the peppermint than control session. Similarly, subjects rating peppermint as stimulating showed more NREM and less REM sleep, while those rating it as sedating had a delayed SWS onset. Moreover, peppermint produced gender-specific effects: it increased NREM sleep in women, but not men, and increased alertness the following morning in men, but not women, compared with the control. In all subjects, peppermint also reduced fatigue and depression immediately after presentation. The psychological interpretation of peppermint, including individual differences in odor

perception plays an important role in physiological sleep changes in young adults.

Contrary to our hypothesis, peppermint odor, when not considering perceptual qualities, did not disrupt sleep. Our data differ from other studies reporting physiological arousal during daytime presentation (Klemm et al., 1992; Norrish and Dwyer, 2005; Torii et al., 1988) and EEG arousals during sleep stages 1, 2, and 4 (Carskadon and Herz, 2004). Because we administered peppermint only before bedtime, this methodological difference may explain our contrasting results. The timing of physiological assessments also may underlie our lack of overall results: some of the aforementioned studies found physiological arousal during, but not after peppermint exposure (Klemm et al., 1992; Torii et al., 1988). Since we did not assess physiological arousal during administration, we may have missed immediate changes occurring across the entire sample. Moreover, since lavender produces physiological sleep changes (Goel et al., 2005), peppermint's particular chemical composition may underlie our lack of sleep effects. Peppermint's components can produce both sedating and stimulating effects on ambulatory activity in mice (Kovar et al., 1987; Ortiz de Urbina et al., 1989; Umezu et al., 2001); if these results extend to human sleep, overall changes may have been negated across subjects.

Peppermint was rated as more pleasant, intense, stimulating, and elating than water, consistent with previous findings (Ilmberger et al., 2001; Klemm et al., 1992; Warm et al., 1991). These ratings significantly correlated with sleep variables, including SWS and WASO, highlighting an important relationship between sleep changes and odor perception. Indeed, intensity was associated with PSG sleep: in subjects rating peppermint as very intense, SWS, total sleep time, and sleep period time all increased. Other studies also have found that intensity relates to various physiological changes (Bensafi et al., 2002a; Carskadon and Herz, 2004; Wang et al., 2002); thus, intensity is an important variable warranting further consideration.

Peppermint increased SWS in those perceiving it as very intense, in contrast with our predictions and other findings reporting stimulating effects of peppermint (Badia et al., 1990; Carskadon and Herz, 2004; Klemm et al., 1992; Norrish and Dwyer, 2005; Stampi et al., 1996; Sullivan et al., 1998; Torii et al., 1988; Warm et al., 1991). This SWS increase in subjects perceiving peppermint as intense, however, corroborates other reports of improved sleep following odor exposure (Connell et al., 2001; Goel et al., 2005; Hardy, 1991; Henry et al., 1994; Hudson, 1996; Raudenbush et al., 2003; Sano et al., 1998; Svoboda et al., 2002; Wolfe and Herzberg, 1996). Therefore, peppermint has sleep-promoting effects in a subset of subjects, underscoring the importance of perceptual odor interpretation.

Peppermint's perceived stimulating properties also were associated with PSG sleep. Subjects rating peppermint as stimulating had more NREM and less REM sleep, while

those who found it sedating took longer to reach SWS. Other studies, including those also using peppermint have shown that the stimulatory quality of odors associates with differential changes in physiological measures (Badia et al., 1990; Bensafi et al., 2002a,b; Klemm et al., 1992; Lorig and Schwartz, 1988; Romine et al., 1999). By contrast, there were no significant PSG differences between groups varying on pleasantness/unpleasantness ratings. Our results agree with some studies that did not find a hedonic-physiological relationship (Levy et al., 1997; Millot et al., 2002; Möller and Dijksterhuis, 2003), but contrast with others (Bensafi et al., 2002a,b,c; Brauchli et al., 1995; Ehrlichman and Bastone, 1992; Henkin and Levy, 2001; Kline et al., 2000; Millot and Brand, 2001; Miltner et al., 1994). Differences across study findings may result from the odors and administration methods used or measures collected.

Our study showed that different perceptual odor components such as intensity and stimulation relate to distinctive physiological effects. Similarly, other studies have found that intensity and hedonics show differential activation of neural substrates, indicating that the emotional and physiological experience of some odors (including peppermint's components) may result from such separate neural activation (Anderson et al., 2003; Rolls et al., 2003; Zatorre et al., 2000). Moreover, and in concurrence with our data, other studies have found that the subjective or psychological evaluations of odors (Heuberger et al., 2001; Knasko, 1992; Lorig and Roberts, 1990) or the situational or environmental context in which odors are presented (Bensafi et al., 2004; Carskadon and Herz, 2004) relate to physiological and mood changes. Future studies comparing peppermint with odors matched on hedonics and intensity, but producing different physiological responses, such as chamomile or lavender (Connell et al., 2001; Goel et al., 2005; Hardy, 1991; Henry et al., 1994; Hudson, 1996; Wolfe and Herzberg, 1996), would separate the psychological from the physiological influences on sleep.

Beyond perceptual differences, peppermint also produced gender differences in odor perception, mood and sleep. Women rated peppermint as more elating and intense than men, contrasting another study that did not find gender differences (Levy et al., 1997). Peppermint also produced gender-differentiated mood effects, with women showing larger anger and depression score changes. Moreover, since only women who found peppermint stimulating took longer to reach REM sleep, odor sensitivity in women associates with subsequent sleep changes. Women, but not men, also showed more NREM sleep in the peppermint than control session, which may reflect gender differences in neural activation. Such activation differences have been found following exposure to odors including peppermint; different structures were activated (Savic et al., 2001) or greater responses were observed in women (Becker et al., 1993; Evans et al., 1995; Henkin and Levy, 2001; Levy et al., 1999; Yousem et al., 1999). Women may have experienced greater

olfactory activation as evidenced by higher intensity and elating ratings, which, in turn, may have activated more NREM-promoting neurons. Similarly, we previously found that lavender increased stage 2 sleep in women only (Goel et al., 2005). Since a nearly equal number of women were in their luteal or follicular menstrual cycle phases, peppermint's gender-differentiated effects are unlikely due to reproductive hormone levels.

Peppermint produced stimulating effects on alertness and mood, by reducing fatigue and decreasing depression scores immediately after presentation, corroborating other studies (Barker et al., 2003; Klemm et al., 1992; Raudenbush et al., 2001, 2002; Stampi et al., 1996; Sullivan et al., 1998; Warm et al., 1991). Our results also complement studies indicating immediate physiological effects, including EEG changes following peppermint exposure (Klemm et al., 1992; Norrish and Dwyer, 2005; Torii et al., 1988). Furthermore, since men were less sleepy the morning after peppermint than control exposure, residual alertness effects remain in some individuals even after a full night's sleep.

Because water served as the control, expectancy effects may underlie the physiological and psychological differences between the peppermint and control conditions, including the aforementioned gender-differentiated responses (see Campenni et al., 2004; Ilmberger et al., 2001; Jellinek, 1997). This possibility seems unlikely, however, since subjects remained uninformed about the specific odors presented (including the fact that one vial contained water) and about the odors' intensity, stimulating/sedating and hedonic properties.

Our study is the first to examine peppermint essential oil's effects on PSG sleep. Stimulus quality is an important variable for assessing such physiological responses, since peppermint's perceived intensity and stimulating ratings were associated with differences in REM and NREM sleep, including SWS. Importantly, peppermint did not affect sleep in the absence of consideration of its perceptual or psychological qualities. In addition, peppermint produced gender-differentiated changes in NREM sleep, reduced fatigue and sleepiness and improved mood. These results point to important clinical applications. Peppermint may be an alternative or adjunctive (Atanassova-Shopova and Roussinov, 1970) to drugs for producing substantial sleep, mood and alertness effects in young adults. Peppermint also may benefit some depressed subjects who show SWS reductions (Benca et al., 1992) and may alter sleep in critically ill or hospitalized patients, groups who both benefit from aromatherapy (Richards et al., 2003; Waldman et al., 1993).

## Acknowledgements

We thank Krystl Giordano, Jessica Jacobsen, and Ann Lee for assistance in data collection. We also are grateful to Dr. Albert Fry for his invaluable assistance in the gas chromatography analysis of the peppermint oil.

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