Aroma Effects on Physiologic and Cognitive Function Following Acute Stress: A Mechanism Investigation

Irina Chamine, PhD,¹ and Barry S. Oken, MD, PhD^{1,2}

Abstract

Objective: Aromas may improve physiologic and cognitive function after stress, but associated mechanisms remain unknown. This study evaluated the effects of lavender aroma, which is commonly used for stress reduction, on physiologic and cognitive functions. The contribution of pharmacologic, hedonic, and expectancy-related mechanisms of the aromatherapy effects was evaluated.

Methods: Ninety-two healthy adults (mean age, 58.0 years; 79.3% women) were randomly assigned to three aroma groups (lavender, perceptible placebo [coconut], and nonperceptible placebo [water]) and to two prime subgroups (primed, with a suggestion of inhaling a powerful stress-reducing aroma, or no prime). Participants' performance on a battery of cognitive tests, physiologic responses, and subjective stress were evaluated at baseline and after exposure to a stress battery during which aromatherapy was present. Participants also rated the intensity and pleasantness of their assigned aroma.

Results: Pharmacologic effects of lavender but not placebo aromas significantly benefited post-stress performance on the working memory task ($F_{(2,86)}=5.41$; $p=0.006$). Increased expectancy due to positive prime, regardless of aroma type, facilitated post-stress performance on the processing speed task ($F_{(1,87)}=8.31$; $p=0.005$). Aroma hedonics (pleasantness and intensity) played a role in the beneficial lavender effect on working memory and physiologic function.

Conclusions: The observable aroma effects were produced by a combination of mechanisms involving aroma-specific pharmacologic properties, aroma hedonic properties, and participant expectations. In the future, each of these mechanisms could be manipulated to produce optimal functioning.

Introduction

A COMMON RECOMMENDATION FOR REDUCING stress is to inhale a stress-reducing aroma, such as the aroma from English lavender (*Lavandula angustifolia*).¹ Despite its popularity for stress reduction,² and despite growing evidence of beneficial aromatherapy effects on cognitive function and stress biomarkers,^{3–5} specific mechanisms producing the stress-reducing effects of lavender and general mechanisms of aromatherapy actions remain unclear.^{6,7}

Four mechanisms underlying odor effects on functioning have been previously suggested: pharmacologic, hedonic, psychological, and contextual.^{8,9} *Pharmacologic* mechanism is unique to specific aromas and is produced by major aroma constituents affecting neural activity by activating specific olfactory receptors. This mechanism has been of most interest in previous studies. For lavender aroma, the major constituents

are linalool and linalyl acetate.² In animals, linalool produces effects on glutamate receptors similar to those of an anxiolytic and sedative drug phenobarbital;¹⁰ it also produces effects on γ -aminobutyric acid A receptor binding similar to those of anxiolytic drugs and benzodiazepines.¹¹ Linalyl acetate produces narcotic effects.¹¹ Such effects are consistent with the analgesic,¹² soporific,^{13–15} and particularly anxiolytic^{16,17} properties of lavender linked to relaxation and stress reduction.^{2,18} However, human pharmacokinetic data for lavender essential oil metabolites are scarce, and little information is available regarding biological pathways associated with stress-reducing lavender effects.² *Hedonically driven* mechanism produces mood changes stemming from the odor's hedonic qualities (e.g., pleasantness) with secondary effects on other functions. *Psychological* mechanism creates odor-related benefits resulting from expectancies about odor qualities. *Contextual/associative* mechanism generates

¹Department of Neurology, Oregon Health & Science University, Portland, OR.

²Departments of Behavioral Neuroscience and Biomedical Engineering, Oregon Health & Science University, Portland, OR.

effects linked to previous odor associations with particular stimuli. The relative contribution of these mechanisms to aromatherapy effects has not been defined.

This study assessed the contribution of these potential mechanisms in the stress-reducing effects of aromas by evaluating the effects of English lavender on cognition and physiology after stress exposure. The pharmacologic effects of lavender were compared with those of two placebo aromas (odorless water and pleasant-smelling coconut). Expectancy was experimentally manipulated by introducing a positive or neutral *prime* about aroma stress-reducing effects. Aroma hedonics was also assessed. The contextual/associative mechanism that might interact with the other three mechanisms was not experimentally tested.

In addition to clarifying the role of these mechanisms, this study investigated the pathways associated with stress-reducing aroma effects. Stress response involves activation of the autonomic nervous system (ANS) and subsequent activation of the hypothalamic-pituitary-adrenal (HPA) axis.¹⁹ Physiologic markers of these branches of stress response systems were assessed.

The hypotheses stated that (1) lavender would be more protective against stress effects than placebos and (2) several mechanisms would contribute to aroma effects.

Materials and Methods

Participants

The study flowchart appears in Figure 1. The participants were recruited via announcements for a study evaluating stress-reducing aromatherapy properties (clinical trial ID NCT01307748). Eligibility criteria assessed by phone included age 50–85 years, good physical and cognitive health (score ≥ 31 on the Modified Telephone Interview for Cognitive Status²⁰), moderate stress (score ≥ 9 on the Perceived Stress Scale²¹), no medications affecting study measures, and nonsmoking. The Oregon Health & Science University Institutional Review Board approved the study. Before the study visit, participants were randomly assigned to aroma groups and prime subgroups with covariate adaptive randomization²² that accounted for sex, age median split, and baseline stress.

Laboratory evaluation

The laboratory visit started at noon to minimize circadian effects. Participants avoided scented products and had a meal 30 minutes before the visit. After participants consented, their eligibility was confirmed by using anosmia

FIG. 1. Consolidated Standards of Reporting Trials diagram.

FIG. 2. Study activities.

screening with a 3-item Quick Smell Identification Test (Sensonics Inc., Haddon Heights, NJ).²³ The procedures included a baseline assessment, stress battery, and post-stress assessment (Fig. 2). During the baseline the recording equipment was fitted, the initial salivary sample collected, and self-report and cognitive tasks completed. After the baseline, participants received a card with “prime” or “no prime” statement²⁴ and began inhaling the aroma (described below). Five minutes after the initial exposure, participants underwent a stress battery. The stress battery included physical, emotional, and mental stressors described previously²⁴ and was followed by the post-stress assessment similar to the baseline assessment. The visit lasted 4 hours. Afterward, the participants were debriefed about the study purpose and received a payment of \$10.00 per hour.

Self-rated measures

Previous aromatherapy use (frequency and purpose) was assessed at baseline with a custom questionnaire. Expectancy of aromatherapy effect was assessed at baseline with a 0- to 100-mm visual analog scale (VAS). Participants rated expected effect of aromatherapy on stress (from decreased to increased stress) and overall effect of aromatherapy (from negative to positive). Affect and stress were assessed with the Positive and Negative Affect Schedule,²⁵ Perceived Stress Scale,²¹ and a subjective stress VAS ranging from 0 (no stress) to 100 (extremely stressed). Participants rated aroma hedonics by using a VAS with ratings of pleasantness (0=extremely unpleasant to 100=extremely pleasant), and intensity (0=barely noticeable to 100=extremely intense).

Cognitive measures

The cognitive measures were selected on the basis of brevity and previous evidence of sensitivity to stress or expectancy effects.^{26,27} Executive functions were assessed with the color-word interference score of the Stroop Color-Word Test.²⁸ Working memory was assessed with the overall score of the Wechsler Adult Intelligence Scale (WAIS)-III Digit Span Backward.²⁷ Attention and working memory were assessed with the summary score of the WAIS-III Letter-Number Sequencing.²⁷ Processing speed was evaluated with the median reaction time on the simple reaction time test.²⁶

Physiologic measures

Respiration rate (RR) was recorded during a 5-minute restful awake state with an intermittent auditory vigilance task presented in EPrime 2.0 (Psychology Software Tools Inc., Pittsburgh, PA). Participants pushed the right button on a two-button box if they heard a high-pitch tone (2000 Hz) and the left button if they heard a low-pitch tone (1000 Hz). The auditory stimuli were presented for 1 second, with a random 4- to 14-second inter-trial interval. RR was recorded while the participants were sitting with eyes closed at baseline, during the stress battery, and post-stress, in a light- and sound-attenuated laboratory. The respiratory signal was acquired by using a piezo-electric strap placed around the upper chest (Ambu Sleepmate, Glen Burnie, MD) and a BioSemi Active Two electroencephalography recording system (BioSemi BV, Amsterdam, the Netherlands).

Saliva samples, collected by using Salivettes (Sarstedt AG & Co, Numbrecht, Germany), were centrifuged, refrigerated, and stored at -80°F before processing. Individual participant's samples were run in the same assay batch. Commercial enzyme-linked immunosorbent assay kits were used for chromogranin A (CgA) (Kamiya Biomedical Company, Seattle, WA) and cortisol (Salimetrics, State College, PA).

Study groups and blinding

Each participant experienced one aroma during the study. For the stress-reducing aroma, one drop of lavender (*L. angustifolia*) essential oil (Mountain Rose Herbs, Eugene, OR) was diluted in 15 mL of grapeseed oil (Now Foods, Bloomingdale, IL). For the detectable placebo aroma, 1 teaspoon of virgin coconut (*Cocos nucifera*) oil (The Annanda Apothecary, Boulder, CO) was diluted in 15 mL of grapeseed oil (Now Foods). Distilled water was the undetectable placebo aroma. Three drops of the assigned aroma solution were placed on a 5×5-mm cotton pad attached to the participant's nose with transparent odor-free tape. The aroma-infused pad came between the nose and upper lip and stayed throughout the visit.

Additionally, 50% of participants in each aroma group were randomly assigned to prime and 50% to no-prime subgroups. Just before aroma exposure, the prime subgroup received a written suggestion about experiencing a powerful stress-reducing aroma. The no-prime subgroup received a suggestion that their aroma may or may not reduce their stress. Both groups were informed that the aroma is faint and possibly imperceptible but still effective, as previously described.²⁴

An assessor conducting assessments was blinded to the randomization assignment and wore an active carbon nose filter (Breathe-Ezy Nasal Filters, Henderson, NV) to avoid perceiving odors. A nonblinded investigator conducted randomization and participants' debriefing.

Statistical analysis

IBM SPSS Statistics software, version 19, was used for analyses. Excessively non-normal data were transformed by using natural log, square root, or box Cox. Baseline characteristics were assessed with analyses of variance (ANOVAs) with group and subgroup as between-subject variables. All outcome variables represented percentage of baseline value.

Primary analyses. The primary analyses for post-stress cognitive measures used multivariate analysis of covariance with the prestress measure as covariate and aroma (lavender, coconut, water) as between-group factor. For physiologic measures, repeated-measures ANOVAs with time (stress, post-stress) as a within-group factor and aroma (lavender, coconut, water) as a between-group factor was used. Post hoc independent *t*-tests compared lavender and placebo groups' results if significant group differences were observed. Family-wise adjustments for multiple comparisons were made for each outcomes set (cognitive, HPA-related, and ANS-related) by using false discovery rate.²⁹

Secondary analyses

The secondary analyses included ANOVAs with aroma group and prime subgroup to compare post-stress self-report measures. A *p*-value less than 0.005 was considered to represent statistically significant differences for secondary analyses.

Expectancy effects. The approach paralleled that of the primary analyses, but prime subgroup (prime, no prime) was the between-group factor instead of aroma group to explore expectancy effects. Potential confounders were included as covariates in the model to assess their effect on the primary outcomes.

Correlational analyses. Relationships among cognitive, aroma hedonic, expectancy, and stress variables were assessed by using Pearson correlations.

Results

Ninety-two adults (mean age, 58.0 years; 79.3% female) participated. Study groups/subgroups were similar with regard to baseline demographic, physiologic, and cognitive measures (Tables 1 and 2).

Stress-related measures

The stress battery affected self-reported stress measures: Post-stress stress ($p \leq 0.001$) and anxiety ($p = 0.002$) were increased, and positive affect was decreased ($p = 0.013$). Group/subgroup patterns of change were similar.

Aroma hedonics

Lavender and coconut were similar with regard to pleasantness ($p = 0.107$); both were higher than water ($p < 0.001$). Intensity ratings were greater for lavender than for coconut ($p < 0.001$) and water ($p = 0.004$) (Supplementary Fig. S1; Supplementary Data are available online at www.liebertpub.com/acm).

Aroma perception differed between the groups ($p < 0.001$) (Supplementary Fig. S2). The majority (94%) of the lavender group perceived the aroma, and 52% recognized it. In the coconut group, 43% participants perceived the aroma and described it as food-related (e.g., "cookie" or "cinnamon"). In the water group, 30% participants perceived the aroma and described it as "linen" and "fresh laundry."

Because of differences in hedonics, analyses were performed with and without aroma hedonics as covariates to probe whether variance related to aroma hedonics was a significant factor.

Cognitive measures

Aroma effects. The significant multivariate analysis of covariance omnibus test ($F_{(8, 168)} = 2.16$; $p = 0.033$) suggested an aroma effect on cognition. Performance on the working memory task was affected ($F_{(2, 86)} = 5.41$; $p = 0.006$); specifically, the lavender group demonstrated a 15% increase (1-point overall score increase) in post-stress working memory performance compared with a 1% or less change in the coconut group ($p = 0.008$) and water group ($p = 0.021$). No effects were evident for the other cognitive tests (Fig. 3A).

TABLE 1. BASELINE PARTICIPANT CHARACTERISTICS

Characteristic	Aroma groups			Prime subgroups	
	Lavender (n=31)	Coconut (n=31)	Water (n=30)	Prime (n=47)	No prime (n=45)
Age (yr)	58.9±6.6	57.9±6.0	57.3±5.9	59.1±6.2	56.9±6.0
Female (%)	77.4	83.9	75.9	85.1	72.7
Education (yr)	16.1±0.4	16.2±0.4	15.8±0.4	15.4±0.4	16.6±0.4
PSS score	16.6±5.3	18.4±5.7	16.2±5.9	17.9±5.0	16.2±6.2
mTICS score	39.0±0.7	38.5±0.7	37.2±0.7	38.1±0.5	38.3±0.6
VAS stress	19.8±16.6	18.9±17.4	21.5±19.2	23.9±18.6	16.0±15.7
STAI score	33.9±6.7	34.5±7.6	33.3±9.4	33.6±8.2	34.3±7.9
PANAS negative	13.6±4.0	12.8±3.0	13.2±5.6	12.6±4.2	13.8±4.4
PANAS positive	30.5±9.1	32.5±5.7	34.4±6.4	32.5±7.0	32.3±7.7
Aroma use (%)	51.6	38.7	46.4	42.6	48.8
Expected effect	70.3±2.3	71.2±2.3	71.7±2.4	71.6±1.9	70.6±2.0
Expected stress	33.8±3.3	32.9±3.3	34.5±3.4	33.1±2.6	34.4±2.8

Values expressed with a plus/minus sign are the mean±standard deviation. Expected effect refers to expected effectiveness of aromatherapy; expected stress refers to expected stress level due to aromatherapy (from neutral of 50; less than 50 indicates reduction in stress).

PSS, Perceived Stress Scale; mTICS, modified Telephone Interview for Cognitive Status; VAS stress, visual analog scale stress rating; STAI, State and Trait Anxiety Inventory; PANAS, Positive and Negative Affect Schedule.

TABLE 2. BASELINE PHYSIOLOGIC AND COGNITIVE FUNCTIONING

Variable	Aroma groups			Prime groups	
	Lavender (n=31)	Coconut (n=31)	Water (n=30)	Prime (n=47)	No prime (n=45)
RR (breaths/min)	15.9±3.4	15.8±3.2	14.6±3.7	15.4±3.6	15.5±3.4
CgA (pmol/mL)	5.08±3.4	4.52±2.8	7.32±8.8	4.98±3.5	6.29±7.4
Cortisol (µg/dL)	0.13±0.08	0.14±0.07	0.11±0.08	0.13±0.07	0.13±0.08
SRT mRT (ms)	275.3±12.2	242.8±12.4	282.2±12.6	267.7±10.0	265.8±10.2
DSB score	8.5±0.4	8.4±0.4	8.3±0.4	8.3±0.3	8.4±0.3
LNS score	20.2±0.5	20.2±0.5	19.5±0.5	20.1±0.4	19.8±0.4
GS interference	59.4±2.0	54.5±2.0	54.6±2.0	55.4±1.6	57.0±1.6

Values are expressed as the mean ± standard deviation.

RR, respiration rate; CgA, chromogranin A; SRT mRT, simple reaction time task median reaction time; DSB, Digit Span Backward; LNS, Letter Number Sequencing; GS, Golden Stroop.

Expectancy effects. Expectancy effects on cognition were indicated by the omnibus test ($F_{(4, 84)} = 2.28$; $p = 0.043$). Specifically, the prime status affected post-stress performance on the processing speed task ($F_{(1, 87)} = 8.31$; $p = 0.005$). Although post-stress participants' slowing was expected because of fatigue, those receiving a prime displayed less slowing (8-millisecond reaction time [RT] increase) than those receiving no prime (35-millisecond RT increase) (Fig. 3B).

Contribution: aroma hedonics. To evaluate the role of factors contributing to the change in post-stress performance on the working memory and processing speed tasks, simple mediation analyses were conducted (Table 3). Each variable that related to the performance on the tasks or differed between the groups was entered individually as a factor into the regression equation, which contained a cognitive variable as an outcome and a group variable as a predictor. Only inclusion of aroma intensity rating caused the p -value for the

aroma effect to become nonsignificant, suggesting that aroma intensity might mediate relationships between changes in the working memory task performance and aroma group.

Physiologic measures

HPA marker. Cortisol increased in all groups following the stress battery ($p < .001$), with no significant group differences (Fig. 4). Adding aroma intensity or pleasantness as covariates in the main model did not change the results.

ANS markers. As expected, participants' RR increased during stress battery compared with baseline ($F_{(1, 87)} = 87.99$; $p < 0.001$). Repeated-measures ANOVA indicated a significant time × aroma interaction ($F_{(2, 84)} = 4.15$; $p = 0.019$), and post hoc analyses revealed that, while RR in the water group remained stable over time, there were within-group decreases in RR in the lavender ($p = 0.036$) and coconut ($p = 0.047$)

FIG. 3. Post-stress cognitive performance: aroma groups (A) and prime subgroups (B). The data are presented as mean percentage difference from baseline performance, with the untransformed mean values presented for easier interpretation. Error bars represent standard errors of the mean (SEM). Positive difference on Digit Span Backward (DSB) and Letter-Number Sequencing (LNS) tasks indicates improvement, and on simple reaction time (SRT) and Golden Stroop (GS) task indicates deterioration in performance. ** $p \leq 0.01$ for the between-group differences.

TABLE 3. POTENTIAL MEDIATION OF AROMA EFFECT ON DSB AND PRIME EFFECT ON SRT

Possible mediator	Standardized β (p-Value)	
	Aroma effect on DSB performance ^a	Prime effect on SRT performance ^b
Post-stress alertness level	-0.289 0 (0.009)	NA
Post-stress stress level	-0.231 (0.025)	NA
Aroma intensity rating	-0.222 (0.071) ^c	NA
Aroma pleasantness rating	-0.253 (0.033)	NA
Expected stress change	NA	0.310 (0.004)
Expected aroma effectiveness	NA	0.329 (0.003)

^aEffect on cognitive function without mediator: standardized $\beta = -0.255$; $p = 0.014$.

^bEffect on cognitive function without mediator: standardized $\beta = 0.304$; $p = 0.005$.

^cAroma intensity rating was the only variable that significantly affected the p -value of the aroma effect on the DSB performance. NA, not applicable.

groups. The between-group differences at any time point were not significant.

After aroma intensity or pleasantness was added as a covariate in the model, the aroma $\times$ time interaction became nonsignificant for intensity ($p = 0.052$) and pleasantness ($p = 0.059$), indicating that some of the variance in RR patterns was explained by aroma hedonics.

A significant aroma effect was observed for CgA ($F_{(2, 87)} = 4.03$; $p = 0.021$). The effect was driven by lower average CgA

levels in the water group than in the lavender ($p = 0.037$) and coconut ($p = 0.045$) groups. Similarities in CgA patterns between two perceptible aromas, lavender and coconut, suggest that CgA might be affected by mere aroma presence. Including aroma intensity or pleasantness ratings as covariates in the model did not affect the results, with one exception: With pleasantness included in the model, the time $\times$ aroma interaction became significant ($p = 0.019$).

There were no differences in RR, cortisol, or CgA patterns across time points between prime and no-prime subgroups. Correlation analyses indicated few significant correlations between stress biomarkers and subjective variables (Table 4).

Discussion

The study evaluated the effects of stress-reducing aroma on physiology and cognitive function after stress exposure and assessed mechanisms underlying aroma effects. A stress response, indicated by changes in stress-related measures following the stress battery, was successfully elicited in participants.

One notable study finding was that lavender aroma benefited post-stress working memory; in contrast, placebo aromas did not affect post-stress cognitive performance. The 1-point improvement in score on the working memory task in the presence of lavender was a clinically meaningful change. The link between stress and cognitive performance has been supported in several studies and is especially relevant for higher-order cognitive functions because of the detrimental effects of acute stress on the prefrontal cortex.^{30,31} Similar to previous research reporting beneficial changes in cognition after aroma exposure,^{4,5} the current findings of protective lavender effects on working memory add to the increasing evidence that some aromas may protect cognitive functions after acute stress.

FIG. 4. Post-stress physiologic functioning by aroma group: Cortisol (A), Respiration (B), and Chromogranin A (C). The data are presented as percentage change from baseline value in an untransformed form to allow for easier interpretation. All physiologic measures were significantly different from baseline at stress time point. $**p < 0.01$ for the time differences (change from baseline).

TABLE 4. ZERO-ORDER BIVARIATE CORRELATIONS AMONG POST-STRESS PHYSIOLOGIC AND COGNITIVE FUNCTION AND SUBJECTIVE MEASURES OF EXPECTANCY, AROMA HEDONICS, AND STRESS

Variable	1	2	3	4	5	6	7	8	9	10	11	12
1. Cortisol level	1	-0.287	-0.042	-0.123	0.098	-0.308	-0.086	-0.051	-0.136	-0.073	0.045	-0.057
2. Respiration rate		1	-0.242	-0.014	0.118	0.329	-0.188	-0.051	0.190	-0.022	-0.005	-0.018
3. Chromogranin A level			1	0.040	-0.023	-0.029	0.206	-0.022	-0.021	0.111	0.046	0.158
4. DSB score (% change)				1	-0.147	-0.075	0.010	0.074	-0.107	0.243	0.189	-0.291
5. SRT (% change)					1	-0.014	-0.063	-0.012	0.111	-0.036	-0.031	0.110
6. LNS score (% change)						1	0.233	0.207	0.130	0.129	-0.041	-0.074
7. GS interference (% change)							1	-0.008	-0.118	0.049	0.037	-0.127
8. Expectancy of stress change								1	-0.392	0.130	0.087	0.050
9. Expectancy of aroma effect									1	0.027	-0.190	0.122
10. Aroma intensity rating										1	0.472	0.045
11. Aroma pleasantness rating											1	-0.156
12. Subjective stress rating (post-stress battery)												1

Italicized font, $p \leq 0.05$; bold font, $p < 0.01$.

One hypothesis for how aroma may benefit cognitive functions is via interruption of HPA axis activation, resulting in inhibition of frontal brain regions. However, the evidence from the current study and several previous studies^{32,33} did not indicate that lavender aromatherapy interfered with HPA axis activation and cortisol release because no lavender-specific effects on post-stress cortisol levels were observed. On the basis of lavender effects on ANS evident from changes in respiration and CgA, lavender may affect some ANS aspects.

Another interesting study result was that priming people with a suggestion aimed at increasing their expectations of powerful aroma effects benefited their processing speed regardless of the aroma they experienced. Previous research indicated that some aromatherapy effects arise solely from expectancy.^{32,34} The finding that expectancy of improvement affected processing speed agrees with previous studies showing benefits of expectancy on reaction time tasks.^{24,26} Because of the inherently low error rate on the easy task used in the current study, it was impossible to assess whether better reaction times are linked to increased probability of errors. This question can be answered by using a more challenging processing speed task.

Many previous studies aimed at pinpointing one specific mechanism responsible for observed aroma effects, but the current results indicate that all of the assessed mechanisms (i.e., pharmacologic, psychological, and hedonic)⁹ contributed to aroma effects on physiologic and cognitive functions. Interestingly, different mechanisms were associated with distinct changes. For example, benefits in working memory observed as improved post-stress working memory performance were attributable to a pharmacologic, lavender-specific effect. However, benefits in post-stress performance on the processing speed task arose primarily from a psychological mechanism (expectancy-increasing prime). Furthermore, the observed changes in physiology (respiration and CgA levels) and cognition (working memory performance) were influenced by aroma hedonics, indicating the critical role of hedonically driven odor effects. The fourth contextual/associative mechanism of aroma effect was not experimentally evaluated. However, it may have played a role in lavender action because of the popularity of this aroma. Lavender was recognized and identified by more than 50% of participants and produced different changes than the placebo aromas, which were not as well recognized and identified. Overall, this study demonstrates that stress-reducing aroma effects are complex and arise from different mechanisms.

The results are limited in several aspects. First, they are restricted to the assessed aromas, and different aromas might have different modes of action. Second, the study assessed a limited number of biomarkers and cognitive functions, and future research may benefit from different outcome measures. Third, the study used highly diluted aromas. The amounts used in research and practice vary and might produce different effects.² Although this study demonstrated an effect of lavender on cognitive function, lack of other lavender-specific effects may have been due to low lavender concentration. Additionally, because the study sought to elucidate hedonics effects, participants were not blinded; many perceived and recognized the assigned aroma. Furthermore, the perceptible aromas in the current

study differed in intensity, thus making it impossible to dissociate aroma intensity effects from the aroma pharmacologic effects. Matching experimental and placebo aromas on aroma intensity would be important for assessing the role of aroma intensity in aromatherapy actions. Next, larger and more representative samples that include more men and different clinical conditions and that span a wider age range will help improve understanding of stress-reducing aroma effects and associated mechanisms.

Conclusions

This study indicated that cognitive performance on a working memory task following acute stress was facilitated by exposure to lavender but not placebo aromas, while a verbal suggestion of aroma effectiveness for stress reduction regardless of aroma type improved performance on a speed of processing task. The observable effects were produced by a combination of mechanisms that involve aroma-specific pharmacologic properties and aroma hedonic properties, as well as participants' expectations. Thus, overall consequences of aromatherapy exposure are produced by different mechanisms, each of which could be manipulated to produce the optimal effect on functioning. Given that aromatherapy is a fast and easy intervention with a low side effect profile, future studies are warranted because of aromatherapy's potential utility for enhancing cognitive function in the face of stress.

Acknowledgments

The authors thank Elena Goodrich and Meghan Miller for help with blinding the participants, Helané Wahbeh for help with study design and conduct, Roger Ellingson for engineering support, Michael Demidenko for data management, and Andy Fish for administrative support.

This research was supported by the American Psychological Association Dissertation Award and National Institutes of Health grants U19AT002656, UL1TR000128, T32AT002688, K24AT005121, and F31AT006647. The authors have not entered into any agreements with the funding organization that has limited their ability to complete experiments, analyze data, and publish this work.

Author Disclosure Statement

No competing financial interests exist.

References

1. Wildwood C. *The Encyclopedia of Aromatherapy* Rochester: Healing Arts Press, 1996.
2. Woronuk G, Demissie Z, Rheault M, Mahmoud S. Biosynthesis and therapeutic properties of *Lavandula* essential oil constituents. *Planta Medica* 2011;77:7–15.
3. Atsumi T, Tonosaki K. Smelling lavender and rosemary increases free radical scavenging activity and decreases cortisol level in saliva. *Psychiatry Res* 2007;150:89–96.
4. Diego MA, Jones NA, Field T, et al. Aromatherapy positively affects mood, EEG patterns of alertness and math computations. *Int J Neurosci* 1998;96:217–224.
5. Moss M, Cook J, Wesnes K, Duckett P. Aromas of rosemary and lavender essential oils differentially affect cognition and mood in healthy adults. *Int J Neurosci* 2003;113:15–38.
6. Herz RS. Aromatherapy facts and fictions: a scientific analysis of olfactory effects on mood, physiology and behavior. *Int J Neurosci* 2009;119:263–290.
7. Lee MS, Choi J, Posadzki P, Ernst E. Aromatherapy for health care: an overview of systematic reviews. *Maturitas* 2012;71:257–260.
8. Johnson AJ. Cognitive facilitation following intentional odor exposure. *Sensors (Basel)* 2011;11:5469–5488.
9. Jellinek JS. Psychodynamic odour effects and their mechanisms. *Cosmet Toilettries* 1997;112:61–71.
10. Elisabetsky E, Marschner J, Souza DO. Effects of Linalool on glutamatergic system in the rat cerebral cortex. *Neurochem Res* 1995;20:461–465.
11. Cavanagh HM, Wilkinson JM. Biological activities of lavender essential oil. *Phytother Res* 2002;16:301–308.
12. Irmak Sapmaz H, Uysal M, Tas U, et al. The effect of lavender oil in patients with renal colic: a prospective controlled study using objective and subjective outcome measurements. *J Altern Complement Med* 2015;21:617–622.
13. Lewith GT, Godfrey AD, Prescott P. A single-blinded, randomized pilot study evaluating the aroma of *Lavandula angustifolia* as a treatment for mild insomnia. *J Altern Complement Med* 2005;11:631–637.
14. Lillehei AS, Halcon LL. A systematic review of the effect of inhaled essential oils on sleep. *J Altern Complement Med* 2014;20:441–451.
15. Lillehei AS, Halcon LL, Savik K, Reis R. Effect of inhaled lavender and sleep hygiene on self-reported sleep issues: a randomized controlled trial. *J Altern Complement Med* 2015;21:430–438.
16. Karadag E, Samancioglu S, Ozden D, Bakir E. Effects of aromatherapy on sleep quality and anxiety of patients. *Nurs Crit Care* 2015 Jul 27 [Epub ahead of print].
17. Kianpour M, Mansouri A, Mehrabi T, Asghari G. Effect of lavender scent inhalation on prevention of stress, anxiety and depression in the postpartum period. *Iran J Nurs Midwife Res* 2016;21:197–201.
18. Kim S, Kim HJ, Yeo JS, et al. The effect of lavender oil on stress, bispectral index values, and needle insertion pain in volunteers. *J Altern Complement Med* 2011;17:823–826.
19. Oken BS, Chamine I, Wakeland W. A systems approach to stress, stressors and resilience in humans. *Behav Brain Res* 2015;282:144–154.
20. Welsh KA, Breitner JCS, Magruder-Habib KM. Detection of dementia in the elderly using telephone screening of cognitive status. *Neuropsychiatry Neuropsychol Behav Neurol* 1993;6:103–110.
21. Cohen S, Kamarck T, Mermelstein R. A global measure of perceived stress. *J Health Soc Behav* 1983;24:385–396.
22. Pocock SJ, Simon R. Sequential treatment assignment with balancing for prognostic factors in the controlled clinical trial. *Biometrics*. 1975;31:103–115.
23. Jackman AH, Doty RL. Utility of a three-item smell identification test in detecting olfactory dysfunction. *Laryngoscope* 2005;115:2209–2212.
24. Chamine I, Oken BS. Expectancy of stress-reducing aromatherapy effect and performance on a stress-sensitive cognitive task. *Evidence Based Complement Altern Med* 2015;2015:419812.
25. Watson D, Clark LA, Tellegen A. Development and validation of brief measures of positive and negative affect: the PANAS scales. *J Personal Soc Psychol* 1988;54:1063–1070.

26. Oken BS, Flegal K, Zajdel D, et al. Expectancy effect: impact of pill administration on cognitive performance in healthy seniors. *J Clin Exp Neuropsychol* 2008;30:7–17.
27. Wechsler D. WAIS-III Administration and Scoring Manual. San Antonio, TX: Psychological Corp., 1997.
28. Golden CJ. Stroop Color and Word Test: A Manual for Clinical and Experimental Uses. Chicago, IL: Skoeltin, 1978:1–32.
29. Benjamini Y, Hochberg Y. Controlling the false discovery rate: a practical and powerful approach to multiple testing. *J R Stat Soc B* 1995;57:289–300.
30. Arnsten AF. Stress signalling pathways that impair prefrontal cortex structure and function. *Nat Rev Neurosci* 2009;10:410–422.
31. Lupien SJ, Maheu F, Tu M, et al. The effects of stress and stress hormones on human cognition: implications for the field of brain and cognition. *Brain Cogn* 2007;65:209–237.
32. Kiecolt-Glaser JK, Graham JE, Malarkey WB, et al. Olfactory influences on mood and autonomic, endocrine, and immune function. *Psychoneuroendocrinology* 2008;33:328–339.
33. Toda M, Morimoto K. Effect of lavender aroma on salivary endocrinological stress markers. *Arch Oral Biol* 2008;53:964–968.
34. Howard S, Hughes BM. Expectancies, not aroma, explain impact of lavender aromatherapy on psychophysiological indices of relaxation in young healthy women. *Br J Health Psychol* 2008;13(Pt 4):603–617.

Address correspondence to:

Irina Chamine, PhD

Department of Neurology

Oregon Health & Science University

Mail Code CR120

3181 SW Sam Jackson Park Road

Portland, OR 97239

E-mail: fonareva@ohsu.edu