

Gender moderates the effects of ambient bergamot scent on stress restoration in offices

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ABSTRACT

We investigated the physiological (heart rate variability) and psychological (state of anxiety, pleasantness, and comfort) effects of ambient bergamot scent on the stress levels of office workers by exposing them to the scent while stressors persisted as the workers continued to work on the office tasks. Forty-eight young adults were randomly assigned to either a control or scent group. Our results show that the stress restoration effect of bergamot scent depends on gender. The change in heart rate variability revealed that bergamot scent increased stress among males but not for females. The reported pleasantness and comfort followed the same trend. Compared to the control groups, females in the scent group thought the office smelled pleasant and felt more comfortable, but males in the scent group reported the opposite. However, no gender effect was found in the level of state anxiety. Specifically, compared to the control groups, both males and females exposed to the bergamot scent self-reported decreasing stress levels. This inconsistency between self-reported stress and physiological measurements is not uncommon, especially among males who are socialized to downplay emotional experiences. Our data suggest that there is indeed a gender difference in the effectiveness of the bergamot scent for reducing stress in office workers.

1. Introduction

Psychological disorders have been recognized as a leading occupational health concern by the National Institute for Occupational Safety and Health (Sauter et al., 1990); in particular, many people suffer from work-related stress with dire consequences. A national survey by the American Psychological Association in 2017 reported that work is one of the most common sources of stress identified by 61% of Americans (American Psychological Association, 2017). Per the latest report in 2022 by Gallup on employees around the world, employees are getting more stressed compared to previous years, and 44% of workers experience stress at work daily (Gallup Inc., 2022). Stress has adverse effects on the human immune function, which may influence the occurrence of severe diseases, such as cancer (O'Leary, 1990).

Specifically, chronic stress increases the risk for health conditions like metabolic syndrome and coronary heart disease by producing certain physiological responses repeatedly over time. When exposed to stress, the human body activates the sympathoadrenal medullary system to prepare the body for the encountered stress (Turner et al., 2020). The

release of catecholamines and cortisol causes cardiovascular responses such as an increase in heart rate and vasoconstriction (Chrousos, 2009). Over time, the persistence of these physiological responses will result in high blood pressure, which can lead to diseases like metabolic syndrome and coronary heart disease.

As a common source of stress for American adults, job stress not only increases health risks, but also hurts productivity. Reducing work-related stress is therefore essential for a healthy and productive workforce. Compared to people exposed to no work-related stress, stress at work has been found to double the risk of metabolic syndrome (Chandola et al., 2006) and increase the risk of coronary heart disease by 50% (Kivimäki et al., 2006). Among employees in North America, 34% report losing at least 1 h per day in productivity due to stress (Boyd, 2022). Around one million American workers take a leave of absence every day due to stress (Mazur, 2022).

Stress also increases the risk of mental health problems (Baker, 1985). Because encountering stressors, like conflict on the job site, produces physiological responses, the emotional experience of stress (e.g., distress, anxiety) is often closely coupled with such physiological

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responses (Campbell & Ehler, 2012). However, self-reports of experiences such as stress do *not always* correspond with the physiological responses. For example, studies also found variability between self-reported stress and physiological responses, where the two measures were sometimes not significantly associated, especially among male participants (Campbell & Ehler, 2012; Vaessen et al., 2021). Females are socialized to be more comfortable expressing negative emotions (except anger) than males, and thus males might not report experiencing distress or anxiety after encountering stressors; however, their physiological response could still reveal the stress, thereby creating a disconnect between self-report and physiological response.

Because of these negative impacts of job stress, there have been movements to help people reduce and recover from such stress. Since changing the nature of work tasks or preventing interpersonal conflicts at work is challenging, the emphasis has been on reducing stress by modifying the office environment itself (Becerik-Gerber et al., 2022). One major approach to this problem is biophilic design, which “emphasizes the necessity of maintaining, enhancing, and restoring the beneficial experience of nature in the built environment” (Kellert et al., 2011). Indeed, many studies have demonstrated the stress-relieving effect of a connection with nature at the workplace by implementing biophilic designs (Colenberg & Jylhä, 2021; Gillis & Gatersleben, 2015). The Stress Reduction Theory sets the theoretical foundation for this approach, stating that being in an unthreatening natural environment assists in stress restoration, as explained by evolutionary theories. Humans inherently feel pleasure and calm toward nature elements (e.g., water and plants) because these items ensured the survival of their ancestors. For example, the sound of running water is found to be soothing because of its association with nearby freshwater resources. The Stress Reduction Theory has been used to explain this association between positive human responses and the presence of nature that biophilic design leverages.

The majority of previous studies have focused on the visual aspect of biophilic design (Aristizabal et al., 2021; Colenberg & Jylhä, 2021; Gillis & Gatersleben, 2015), such as integrating plants in an office space or adding nature views either artificially or through windows (Bjørnstad et al., 2015; Craig et al., 2021; Sop Shin, 2007). Second to visualizations, many studies have examined auditory features, finding a relaxing effect associated with nature sounds (e.g., wind, birds) (Jahncke et al., 2015; Largo-Wight et al., 2016; Ratcliffe et al., 2013). Despite some benefits, both visual and auditory interventions may interrupt office workers’ tasks. Indeed, the evaluation of biophilic designs within the realm of stress restoration has primarily been studied in ways that interrupt office workers’ tasks by requiring participants to take a break away from their work. For example, the effectiveness of nature sounds was studied by letting participants take a 15-min micro-break while listening to nature sounds (Largo-Wight et al., 2016). Another study tested the effect of auditory and visual stimuli by presenting participants with pictures and sounds of urban nature and an open-plan office for 20 min, which would also take office workers away from their work (Jahncke et al., 2015).

Fewer studies have focused on olfactory sensations relative to work-related stress (Aristizabal et al., 2021; Awada et al., 2023; Colenberg & Jylhä, 2021), instead focusing primarily on the effects of olfactory sensation on human behavior (Wilson et al., 2006) and emotions (Douce et al., 2014; Soudry et al., 2011). Olfactory stimuli have significant potential in creating a restorative workspace without requiring office workers’ attention on the treatment. However, to our knowledge, only two studies designed their experiment to maintain the stressor during the restoration treatment by exposing participants to scents while they stayed in a psychologically stressful condition (Lehrner et al., 2000; Motomura et al., 2001). The first study was conducted with female participants who visited a dental office and had stress arousal due to waiting for dental treatment that persisted throughout the experiment. The study found a relaxing effect of the orange scent by adding an ambient scent in the waiting room and comparing it with the control group, where no scent was in the air (Lehrner et al., 2000). The second

study simulated the stress by letting participants wait 20 min in an empty soundproof room for the experimenter to introduce the experimental procedure. By comparing stress among three conditions: stress with scent, stress with no scent, and no stress, the study demonstrated the stress restoration effect of lavender scent (Motomura et al., 2001).

The objective of this research was to investigate the potential stress restoration effect of bergamot, a commonly used essential oil in aromatherapy, on office workers. Bergamot has been widely used to alleviate symptoms of stress-induced conditions such as anxiety and mild mood disorders, and previous studies have provided a neuropharmacological explanation for its effectiveness (Bagetta et al., 2010; I. Lee, 2016). Inhaling bergamot essential oil has been shown to have a calming effect on mental state and may reduce work-related stress (Sowndharajan & Kim, 2016). For instance, research conducted on school teachers found that the use of bergamot aromatherapy spray led to significant changes in autonomic nervous system parameters, supporting the effectiveness of bergamot scent in reducing stress (Chang & Shen, 2011; Liu et al., 2013). Additionally, given the limited research on non-intrusive interventions and the potential drawbacks of interruptions in office work, we tested the scent during a stressful task of preparing for an oral presentation (Merz et al., 2019). We observed participants’ physiological and psychological changes during the task after exposure to the scent without causing any work interruptions.

2. Methodology

2.1. Experimental design

The study was approved by the Institutional Review Board (IRB) of the University of Southern California. Participation in this study was voluntary, and participants provided informed consent before enrolling. Deception was used to minimize response bias: Participants were informed that the study focused on the work productivity of office workers and were not told that the study’s actual purpose was to evaluate the use of ambient scent for stress restoration. Participants were also informed that receiving the allocated compensation for their participation depended on their performance during the experiment. The study ended with a debriefing session where experimenters explained the real purpose of the experiment and provided full compensation to the participants irrespective of their performance.

To mimic a stressful office-based work task, participants were given 30 min to create a presentation on the scientific and philosophical achievements of two major Greek philosophers and to discuss how their achievements still shape our modern life. The topic was chosen as a task most people felt unfamiliar with among multiple topics explored in pilot testing. The requirements were deliberately chosen to ensure the task was demanding but achievable. To maximize stress responses, a confederate played the role of a university professor who monitored participants through Zoom. Participants were required to turn on their cameras and share their screens as they prepared the presentation. A scoreboard was displayed on the screen, reflecting the professor’s evaluations of their work. The scoreboard was programmed to increase and decrease in a standardized manner across all the participants. Participants were told that their final score would be compared with all the participants, and their monetary compensation for participating in this study would be adjusted based on their performance. For example, the participant with the best score would receive \$50, and the one with the lowest score would receive \$5. During the 30 min, participants reached a stressed state intended to mimic high workloads and time pressure, such as work deadlines which are the common causes of work-related stress in offices (Bhui et al., 2016; Michie, 2002).

The examination of olfactory sensations on stress restoration was conducted at the end of the 30-min session (Fig. 1). During this period, participants were told that in 15 min they would use the slides they had just created about Greek philosophers to do an oral presentation to the professor through Zoom. They would use the 15 min to refine the slides

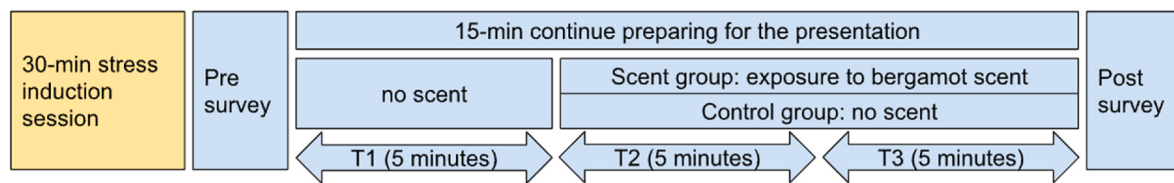


Fig. 1. Olfactory stimuli study procedure.

and prepare for the oral presentation. Participants were randomly assigned to either the control or scent group. Since the same stressor cannot be applied twice to the same person, each participant experienced only one condition. Participants completed a pre-experiment survey (see Section 2.3), the experimenters started a 15-min timer, and the participants were left alone in the office. For analysis purposes, the 15-min session was divided into three 5-min segments. All the participants were exposed to no scent for the first 5-min period (T1). After T1, bergamot essential oil was diffused in an office through an electric diffuser that could be controlled remotely for the scent group, whereas no ambient scent was added for the control group. This process took 10 min; the first 5 min were labeled as T2, and the second 5 min were labeled as T3. Three drops of bergamot essential oil were applied to 100 ml of water in this study. When the time was up, participants completed a post-experiment survey. Participants wore a chest strap with a heart rate monitor throughout the experiment.

2.2. Participants

A total of 48 young adults participated in the study using a between-group design. The participants had a mean age of 22.6 and a standard deviation of 2.1. Screening criteria comprised normal to corrected-to-normal vision, normal sense of smell, self-declared as not pregnant, no rhinitis or hay fever, no allergic reactions to essential oil, and not using prescription medication. Each participant was randomly assigned to the scent group (14 female, 11 male) or the control group (14 female, 9 male). The sample size was based on previous similar studies where the sample size per group typically ranged from 9 to about 35 (Kuroda et al., 2005; Largo-Wight et al., 2016; Lehrner et al., 2000; Motomura et al., 2001). To ensure that the task adequately induced stress, participants rated their stress level on a scale of 0–100 (0 – Not stressed at all, 100 – Extremely stressed) at the beginning and the end of the 30-min presentation preparation session. The 30-min session induced stress in both males and females; ratings of stress were significantly higher at the end of the 30-min session (females: 51.79 ± 28.64 , males: 43.65 ± 28.36) than before it (females: 34.68 ± 23.13 , males: 31.95 ± 24.96); $t(27) = -3.768$, $p < 0.001$ for females and $t(19) = -2.201$, $p = 0.040$ for males.

2.3. Measurements

Cardiovascular response was chosen as the primary objective outcome measure as it is highly related to stress and can consistently differentiate stressors (Andreassi, 2000). Multiple measures of heart rate (HR) and heart rate variability (HRV) were used as psychological stress indicators (see Table 1) (Chang & Shen, 2011; Ikei et al., 2016; Kim et al., 2018; J. Lee et al., 2014; Liu et al., 2013; Motomura et al., 2001; B. J. Park et al., 2010; B.-J. Park et al., 2008, 2009). Heart rate (HR) measures autonomic cardiovascular activity that can be represented as a rate in beats per minute or as the RR interval (i.e., the time elapsed between two successive R-waves) in milliseconds (Goldberger et al., 2014; Lanfranchi & Somers, 2011). The two parameters can be non-linearly transformed to each other where HR increases under stress (Clays et al., 2011; Delaney & Brodie, 2000; Kaegi et al., 1999; Orsila et al., 2008) but the RR interval decreases (Lucini et al., 2002; Orsila et al., 2008; Sloan et al., 1994). HRV can be quantified by many measures, including time-domain and frequency-domain metrics (Shaffer &

Table 1

HRV parameter definitions and their indications for stress.

Parameters	Units	Definitions	Indication for stress
Mean HR	beats/min	Mean number of heart beats per minute	Increase
Mean RR	ms	Mean RR interval	Decrease
Time-domain metrics			
RMSSD	ms	Root mean square of successive normal-to-normal (NN) interval differences	Decrease
NN50	beats	The number of adjacent NN intervals that differ from each other by more than 50 ms	Decrease
pNN50	%	The percentage of adjacent NN intervals that differ from each other by more than 50 ms	Decrease
Frequency-domain metrics			
LF power (LFnu)	nu	The relative power of the low-frequency band (0.04–0.15 Hz) in normal units $LFnu = LF / (\text{total power} - VLF)$ ^a	Increase
HF power (HFnu)	nu	The relative power of the high-frequency band (0.15–0.4 Hz) in normal units $HFnu = HF / (\text{total power} - VLF)$ ^a	Decrease
LF power (% LF)	%	The relative power of the low-frequency band (0.04–0.15 Hz) $\%LF = LF / \text{total power} \times 100\%$ ^a	Increase
HF power (% HF)	%	The relative power of the high-frequency band (0.15–0.4 Hz) $\%HF = HF / \text{total power} \times 100\%$ ^a	Decrease

^a VLF (ms^2) is the absolute power of the very low-frequency band (0.0033–0.04 Hz) and total power (ms^2) is the sum of the energy in the VLF, LF, and HF bands.

Ginsberg, 2017). Considering the high sensitivity of HRV to the length of the recording period, metrics should be compared by the values calculated from durations of the same length (Malik, 1996; Shaffer & Ginsberg, 2017). Therefore, we divided the continuous 15-min data into three 5-min epochs (See T1, T2, T3 in Fig. 1) because 5 min is recognized as a typical length for short-term measurements (Malik, 1996; Shaffer & Ginsberg, 2017). For short-term analysis, RMSSD, NN50, and pNN50 are acknowledged as the most widely used time-domain measures by the Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology (Malik, 1996), all of which are known to decrease in stressful situations (Clays et al., 2011; Delaney & Brodie, 2000; Hintsanen et al., 2007; Orsila et al., 2008). For frequency-domain metrics, the two main components of HRV are the power level of low-frequency (LF: 0.04–0.15 Hz) and high-frequency (HF: 0.15–0.40 Hz). HF power and LF power can be expressed as relative power in percentage (%HF and %LF) or in normalized units (HFnu and LFnu) (Kim et al., 2018; Shaffer et al., 2014; Shaffer & Ginsberg, 2017). Psychological stress is indicated by an increase in LF power and a decrease in HF power (Chang & Shen, 2011; Delaney & Brodie, 2000; Kim et al., 2018; Liu et al., 2013).

In addition to objective physiological measurements, pre- and post-experiment surveys were used for subjective measurements. In the pre-experiment survey, participants were given the State-Trait Anxiety Inventory (STAI) to measure their state anxiety, where a higher score

indicates a higher anxiety level (Julian, 2011). In the post-experiment survey, in addition to the STAI, participants were also asked to select their levels of agreement using a 5-point scale (1 - strongly disagree, 2 - somewhat disagree, 3 - neither agree nor disagree, 4 - somewhat agree, 5 - strongly agree) on two statements about the environment scent: "The office smelled pleasant" and "Overall, the office smelled comfortable."

2.4. Statistical analysis

We used mixed ANOVAs (REMANOVA) to examine the overall effects across time relative to each physiological outcome metric in Table 1. Group (i.e., control and scent) and gender (i.e., male and female) were included in the models as between-subjects variables, and time (i.e., T1, T2, T3 in Fig. 1) was entered as a within-subjects variable. To examine change in self-reported stress across genders and experimental groups, we used mixed ANOVA (REMANOVA), where group (i.e., control and scent) and gender (i.e., male and female) were the between-subjects variable and time (i.e., at pre-experiment and post-experiment) was a within-subjects variable. Finally, to examine perceived pleasantness and comfort, we conducted factorial ANOVAs with gender and group as between-subjects variables. SPSS statistics 27.0 was used for statistical analysis, and a p-value of 0.05 was used as a marker of statistical significance. The $G \times \text{Power}$ 3.1.9.6 software (Faul et al., 2007) was used to calculate the sensitivity of our analysis with an alpha of 0.05. We are powered at 80% to detect large effects for the factorial ANOVA ($d = 0.83$) and moderate effects for the mixed ANOVAs with 2–3 measurements ($d = 0.41$ and 0.37 , respectively).

3. Results

3.1. Physiological measures

Statistical analysis of the HRV metrics across time indicated no main effect of group on HRV metrics ($p > 0.1$). However, we noted significant interactions of time $\times$ group $\times$ gender ($p < 0.05$, $d > 0.5$) on most of the HRV parameters, which are summarized in Table 2. Among these, the strongest interaction effects with Cohen's d greater than 0.7 were noted in measures of mean HR, mean RR, and pNN50. %HF was the only variable that did not achieve statistical significance, yet the results of the analyses on this outcome are highly suggestive ($p < 0.1$, $d > 0.5$). We next describe the pattern of the results for these interaction effects.

The means of all physiological parameters by subgroups (i.e., control male, control female, scent male, and scent female) across the three data collection time points are reported in Table 3.

Within the experimental group that received the bergamot smell, there were no statistically significant effects across time noted in HRV measures among female participants. Alternatively, after smelling the bergamot scent, male participants' mean HR increased significantly ($F(2, 20) = 4.441$, $p = 0.025$, partial Eta squared = 0.308, $d = 1.334$) and mean RR interval decreased significantly ($F(2, 20) = 4.707$, partial Eta squared = 0.320, $p = 0.021$, $d = 1.372$). The increase in mean HR and a decrease in mean RR correspond with increases in stress (Table 1),

Table 2
Time $\times$ group $\times$ gender interactions.

Measure	F	df	p	Cohen's d
Mean HR	5.584	2, 88	0.005	0.714
Mean RR	5.739	2, 88	0.005	0.721
RMSSD	4.386	1.651, 72.651	0.022	0.633
NN50	4.038	2, 88	0.021	0.606
pNN50	5.466	2, 88	0.006	0.707
LFnu	3.429	1.765, 77.674	0.043	0.557
HFnu	3.446	1.764, 77.623	0.042	0.561
%LF	3.930	2, 88	0.023	0.598
%HF	2.745	1.765, 77.662	0.077 ^a	0.501

^a Not statistically significant, only marginal.

Table 3

Means and standard deviations for parameters of heart rate variability.

		T1	T2	T3
Mean HR	Control, Female	75.56 $\pm$ 12.13	75.22 $\pm$ 11.68	76.64 $\pm$ 12.60
	Control, Male	77.39 $\pm$ 9.77	75.88 $\pm$ 9.81	75.09 $\pm$ 10.06
	Scent, Female	80.56 $\pm$ 10.80	79.93 $\pm$ 10.80	80.08 $\pm$ 12.09
	Scent, Male*	73.59 $\pm$ 7.65	73.92 $\pm$ 7.14	75.40 $\pm$ 6.93
Mean RR	Control, Female	813.03 $\pm$	815.83 $\pm$	802.80 $\pm$
	Control, Male	131.20	129.31	135.33
	Control, Male	786.25 $\pm$	802.44 $\pm$	811.81 $\pm$
	98.15	102.21	108.09	
	Scent, Female	757.29 $\pm$	763.80 $\pm$	765.95 $\pm$
	101.76	105.61	120.74	
	Scent, Male*	822.71 $\pm$	818.30 $\pm$	801.42 $\pm$
	78.13	74.99	67.52	
RMSSD	Control, Female	51.08 $\pm$ 29.81	47.92 $\pm$ 25.73	50.12 $\pm$ 28.97
	Control, Male	45.80 $\pm$ 19.32	54.41 $\pm$ 38.07	53.17 $\pm$ 29.00
	Scent, Female	38.35 $\pm$ 20.42	38.07 $\pm$ 20.57	40.68 $\pm$ 23.78
	Scent, Male	49.32 $\pm$ 16.99	46.85 $\pm$ 13.00	46.78 $\pm$ 15.66
NN50	Control, Female	92.07 $\pm$ 58.20	86.14 $\pm$ 53.26	86.00 $\pm$ 48.67
	Control, Male	81.00 $\pm$ 40.37	85.56 $\pm$ 51.25	90.33 $\pm$ 49.98
	Scent, Female	62.43 $\pm$ 53.46	65.86 $\pm$ 63.60	70.64 $\pm$ 63.00
	Scent, Male	92.82 $\pm$ 49.33	87.18 $\pm$ 38.91	86.64 $\pm$ 48.67
pNN50	Control, Female	26.59 $\pm$ 20.08	24.69 $\pm$ 18.52	24.699 $\pm$
				17.61
	Control, Male	22.05 $\pm$ 12.08	24.17 $\pm$ 16.42	25.35 $\pm$ 15.25
	Scent, Female	16.97 $\pm$ 15.71	18.18 $\pm$ 18.39	19.68 $\pm$ 18.50
LFnu	Scent, Male	26.09 $\pm$ 14.51	24.07 $\pm$ 10.96	23.60 $\pm$ 13.49
	Control, Female	64.32 $\pm$ 11.83	69.98 $\pm$ 10.26	62.59 $\pm$ 14.28
	Control, Male*	71.10 $\pm$ 7.82	70.83 $\pm$	76.01 $\pm$ 8.19
	11.54			
	Scent, Female	65.97 $\pm$ 12.40	65.62 $\pm$ 11.40	65.792 $\pm$
				11.31
	Scent, Male	60.19 $\pm$ 21.12	67.97 $\pm$ 15.70	65.136 $\pm$
				16.42
HFnu	Control, Female	35.60 $\pm$ 11.76	29.94 $\pm$ 10.23	37.350 $\pm$
				14.22
	Control, Male*	28.88 $\pm$ 7.81	29.14 $\pm$	23.967 $\pm$
	11.54			8.18
	Scent, Female	33.99 $\pm$ 12.38	34.36 $\pm$ 11.38	34.171 $\pm$
				11.30
	Scent, Male	39.79 $\pm$ 21.13	32.01 $\pm$ 15.70	34.836 $\pm$
				16.44
%LF	Control, Female*	59.29 $\pm$	65.59 $\pm$ 9.94	57.291 $\pm$
	11.33			14.06
	Control, Male*	64.84 $\pm$ 5.57	63.94 $\pm$ 8.07	70.174 $\pm$
	7.25			
	Scent, Female	60.42 $\pm$ 9.86	58.56 $\pm$ 11.41	59.441 $\pm$ 8.68
	Scent, Male	55.32 $\pm$ 18.63	61.39 $\pm$ 14.83	61.597 $\pm$
				14.99
	Control, Female	32.87 $\pm$ 11.23	28.12 $\pm$ 9.85	34.202 $\pm$
%HF	Control, Male*	26.70 $\pm$ 8.12	27.02 $\pm$	22.179 $\pm$
	11.18			7.67
	Scent, Female	31.74 $\pm$ 12.81	30.59 $\pm$ 10.24	31.579 $\pm$
				12.02
	Scent, Male	37.32 $\pm$ 20.68	29.07 $\pm$ 15.13	33.323 $\pm$
				16.51

* $p < 0.05$.

which indicates a potential association between the addition of bergamot scent and increased stress among males.

Similar trends were noted in other cardiovascular response measures, with significant gender-based interactions reflecting different effects of the bergamot scent on male and female participants. Female participants in the scent group were relatively stable over time in their LF and HF power measures, indicating a stable stress level unchanged with the scent. In contrast, male participants in the scent group exhibited a trend for an increase in the LF component (LFnu and %LF) and a decrease in the HF component (HFnu and %HF) at T2 (when the scent was introduced). After introducing the bergamot scent, RMSSD, NN50, and pNN50 measures had an increasing trend among female participants compared to a decreasing trend among male participants. These cardiovascular responses (i.e., increase in LF (LFnu and %LF) and

decrease in HF (HFnu and %HF), RMSSD, NN50, and pNN50 correspond with increases in stress (Table 1)) further indicate that the bergamot scent seemed to increase stress among male participants but not among females.

In the control group, where no scent was added, statistically significant effects were noted across multiple HRV measures in both male and female participants. Stress levels of male participants tended to decrease at T2 and increase at T3 (the very end of presentation preparation): both measures of LF power (%LF and LFnu) decreased at T2 and then increased at T3 (LFnu: $F(1.897, 15.173) = 4.481$, $p = 0.031$, partial Eta squared = 0.359, $d = 1.497$; %LF: $F(2, 16) = 4.457$, $p = 0.029$, partial Eta squared = 0.358, $d = 1.494$); likewise, relative HF power had a significant change in the opposite pattern by first increasing at T2 and then decreasing at T3 (LFnu: $F(1.896, 15.169) = 4.486$, $p = 0.031$, partial Eta squared = 0.359, $d = 1.497$; %LF: $F(1.710, 13.681) = 4.343$, $p = 0.039$, partial Eta squared = 0.352, $d = 1.474$).

Unlike males, females in the control group experienced more stress that regressed to the mean over time: there was a significant change in the relative LF power where their %LF increased at T2 and then decreased at T3 ($F(2, 26) = 4.780$, $p = 0.017$, partial Eta squared = 0.269, $d = 1.213$). LFnu displayed the same pattern even though the change was not statistically significant. Accordingly, females' averages of HFnu and %HF decreased at T2 and then increased at T3. Changes in the RMSSD, NN50, and pNN50 measures, in contrast, were not statistically significant for each subgroup.

3.2. Psychological measures

The main effect of group ($F(1, 44) = 15.087$, $p < 0.001$, partial Eta squared = 0.255, $d = 1.170$) was significant for self-reported stress. Specifically, the control group reported increased stress ($M = 2.338 \pm 0.121$ vs. $M = 2.293 \pm 0.125$), and the stress level of the scent group decreased after being exposed to the bergamot scent ($M = 2.120 \pm 0.114$ vs. $M = 2.439 \pm 0.118$). A significant interaction of group $\times$ gender ($F(1, 44) = 12.690$, $p < 0.001$, partial Eta squared = 0.224, $d = 1.075$) revealed that males in the control group thought the office smelled more pleasant ($M = 4.556 \pm 0.238$) than the males in the scent group ($M = 3.636 \pm 0.215$); on the contrary, females in the scent group consider the office smell more pleasant ($M = 4.214 \pm 0.190$) than those in the control group ($M = 3.643 \pm 0.190$). Similarly, a significant interaction of group $\times$ gender ($F(1, 44) = 5.516$, $p = 0.023$, partial Eta squared = 0.111, $d = 0.707$) revealed that females in the scent group thought the office smelled more comfortable ($M = 4.214 \pm 0.227$) compared to females in the control group ($M = 4.071 \pm 0.227$); but males in the scent group felt less comfortable ($M = 3.636 \pm 0.256$) than males in the control group ($M = 4.667 \pm 0.284$). Although we found, in contrast to the pattern for the physiological measures above, that reported stress decreased with the scent for both female and male participants, the patterns for perceived pleasantness and comfort matched the results for the physiological measures.

4. Discussion

The results of this study indicate that exposure to the ambient scent of bergamot influences people's stress levels, but the effect is different by gender. Specifically, the HRV results reveal a potential association between the addition of bergamot scent and increased stress among males. No gender effect was observed in self-reported stress; both male and female participants reported decreased stress after exposure to the bergamot scent. Female participants who smelled the bergamot scent while experiencing office work stressors considered the office more pleasant and comfortable than those in the control group; male participants found the bergamot scent less pleasant and less comfortable than male participants in the control group.

These gender differences may be related to the sex-based differences in olfaction (Spangenberg et al., 2006). Women generally have higher

olfactory sensitivity (Cain, 1982; Doty et al., 1984; Yousem et al., 1999). A recent meta-analysis with a sample size of 8848 participants demonstrated the superiority of women in olfactory abilities including identification, discrimination, and threshold (Sorokowski et al., 2019). This sex-based difference exists consistently across different age groups (Brand & Millot, 2001; Wysocki & Gilbert, 1989) and influences human behaviors in places like retail stores (Doucé et al., 2014; Spangenberg et al., 2006) or a bookstore (Doucé et al., 2013). Our female participants (who were cis-gender, thus biologically women) might have perceived the bergamot sooner or identified it as associated with Earl Grey tea. In the absence of this level of sensitivity, our male participants (who were cis-gender, thus biologically men) did not benefit from the bergamot scent in the same way as their female counterparts. In fact, it had –if anything– the opposite effect.

Some gender-based differences have also been observed in the perceived pleasantness of some specific odors (Wysocki & Gilbert, 1989). For example, males consider androstenone (musky or urine), isoamyl acetate (fruity), and mercaptans (foul) scents to be more pleasant than do females, whereas females rate eugenol (spicy) and rose (floral) scents to be more pleasant than do males (Wysocki & Gilbert, 1989). There are limited studies on gender-based differences in the perception of bergamot scent; our findings of differences in pleasantness add new information to the literature. Despite limited information on perceptions of pleasantness, bergamot is a commonly used scent in aromatherapy, with evidence that supports the psychological and physiological effects of reducing stress (Watanabe et al., 2015). Our data suggest that such an effect on stress reduction could differ between male and female office workers (Chang & Shen, 2011). The gender effect revealed in our study could have been due to the persistence of a stressor while providing the olfactory intervention. Previously, stress restoration was studied mainly with no stressor applied to the participants during the restoration treatment (Chang & Shen, 2011; Hedblom et al., 2019; Ikei et al., 2016; Kuroda et al., 2005; Toda & Morimoto, 2008). However, in the present study, we investigated the restoration effect of bergamot scent under a continuous stressor induced by typical office tasks.

Subjective experiences of pleasantness and comfort generally matched the results for physiological outcomes; however, we identified an inconsistency between the self-reported stress level (i.e., state anxiety score) and physiologic measures. Specifically, both male and female participants reported decreasing stress levels in the scent group, even though HRV measurements indicated that males became more stressed with the ambient scent. This may relate to gender-based differences (Deng et al., 2016); specifically, while female socialization fosters expression of emotions (except anger), male socialization encourages repression of emotion, which can result in a disconnect between self-report and physiological signals of stress. Accordingly, even though physiological measures indicate that males had more stress after exposure to the bergamot scent, their self-reports suggested that their stress levels went down.

Gender differences should, thus, not be neglected when olfactory stimuli are considered to help workers with stress restoration. A scent might be relaxing for one gender but bothers the other gender. In real offices, scents could be applied as a stress restoration strategy in private office spaces, but more factors should be considered before using them in shared spaces.

There are some limitations of this study that should be addressed in future studies. First, this study only tested the bergamot scent. Many natural scents, such as herbs, fruits, and flowers, are effective in a nature-based intervention for stress reduction (Ali et al., 2015; Hedblom et al., 2019; Pálsdóttir et al., 2021; Toda & Morimoto, 2008; Tsunetsugu et al., 2010). More scents could be studied to expand the discussion of applying ambient scents in offices. Second, the study did not consider the impact of scent intensity on stress, where a scent too strong or too weak could lead to different outcomes. Third, while this study demonstrates the moderating effect of gender, future research should consider

other personal factors, such as personality and age. Studies have found that personality factors affect how people experience and regulate stress (Vollrath, 2001), and age moderates the experience of work stress (Hsu, 2019). Such factors thus might also affect how well different scents reduce stress. Fourth, future studies should adopt a larger sample size to investigate other factors, including personal factors and outcomes, such as work performance.

5. Conclusion

Instead of having a separate restoration treatment, this study adopted a nonintrusive intervention by applying ambient scent to an office environment. At the same time, participants were stressed by the office tasks and completing an office task. This study revealed gender as a significant factor for stress restoration where the bergamot scent relaxed one gender, but the same scent stressed the other. Our study supports the conclusion that the bergamot ambient scent's relaxant effect is highly dependent on gender. With the existence of work-related stress, female participants felt relaxed when becoming exposed to the bergamot scent. In contrast, male participants felt more comfortable and pleasant in an office without the ambient scent. The findings of the current experiment extend prior research by incorporating stressors in the stress restoration process. Gender must be considered when employing the ambient scent to relax people in stressful working conditions, which affirms the importance of personal factors in designing workspaces.

CRedit authorship contribution statement

Ruying Liu: Writing – Original Draft, Conceptualization, Methodology, Investigation, Visualization, Formal analysis, Data curation, Mohamad Awada: Writing – review & editing, Conceptualization, Methodology, Investigation, Burcin Becerik-Gerber: Writing – review & editing, Conceptualization, Methodology, Resources, Supervision, Project administration, Funding acquisition, Gale M. Lucas: Writing – review & editing, Conceptualization, Methodology, Formal analysis, Shawn C. Roll: Writing – review & editing, Conceptualization, Methodology, Formal analysis.

Declarations of interests

None.

Data availability statement

The data that support the findings of this study are available from the corresponding author, Burcin Becerik-Gerber, upon reasonable request.

Ethics approval statement

The study was approved by the University of Southern California's Institutional Review Board (IRB; UP-21-00484).

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