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AROMAS OF ROSEMARY AND LAVENDER ESSENTIAL OILS DIFFERENTIALLY AFFECT COGNITION AND MOOD IN HEALTHY ADULTS

MARK MOSS
JENNY COOK

Human Cognitive Neuroscience Unit
Division of Psychology
University of Northumbria
Newcastle upon Tyne, UK

KEITH WESNES

Human Cognitive Neuroscience Unit
Division of Psychology
University of Northumbria
Newcastle upon Tyne, UK

Cognitive Drug Research
CDR House
Portman Road
Reading, UK

PAUL DUCKETT

Human Cognitive Neuroscience Unit
Division of Psychology
University of Northumbria
Newcastle upon Tyne, UK

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Address correspondence to Dr. Mark Moss, Human Cognitive Neuroscience Unit, Division of Psychology, Northumberland Building, University of Northumbria, Newcastle upon Tyne, NE1 8ST, UK. E-mail: mark.moss@unn.ac.uk

This study was designed to assess the olfactory impact of the essential oils of lavender (Lavandula angustifolia) *and rosemary* (Rosmarlnus officinalis) *on cognitive performance and mood in healthy volunteers. One hundred and forty-four participants were randomly assigned to one of three independent groups, and subsequently performed the Cognitive Drug Research (CDR) computerized cognitive assessment battery in a cubicle containing either one of the two odors or no odor (control). Visual analogue mood questionnaires were completed prior to exposure to the odor, and subsequently after completion of the test battery. The participants were deceived as to the genuine aim of the study until the completion of testing to prevent expectancy effects from possibly influencing the data. The outcome variables from the nine tasks that constitute the CDR core battery feed into six factors that represent different aspects of cognitive functioning. Analysis of performance revealed that lavender produced a significant decrement in performance of working memory, and impaired reaction times for both memory and attention based tasks compared to controls. In contrast, rosemary produced a significant enhancement of performance for overall quality of memory and secondary memory factors, but also produced an impairment of speed of memory compared to controls. With regard to mood, comparisons of the change in ratings from baseline to post-test revealed that following the completion of the cognitive assessment battery, both the control and lavender groups were significantly less alert than the rosemary condition; however, the control group was significantly less content than both rosemary and lavender conditions. These findings indicate that the olfactory properties of these essential oils can produce objective effects on cognitive performance, as well as subjective effects on mood.*

Keywords aromatherapy, attention, lavender, memory, odor, rosemary

Despite the prevailing wisdom that the sense of olfaction may be a vestige of our evolutionary past, the use of aromas to modulate affect and mood has been reported since the beginnings of written language, and is a widely continued practice today. The use of artificially introduced ambient odors in public places such as offices, retail outlets, and hotel lobbies is widespread, as are the purported subjective psychological benefits of the odors themselves (Jellinek, 1997). The use of aromatherapy as a therapeutic treatment for affective disorders has also widely reported in historical anecdotal literature (Valnet, 2000), and referred to in herbal medical texts (Bartram, 1995). Though due to the lack of a suitable placebo, until recently little or no clear empirical evidence was available to support such claims (Diego et al., 1998). However, it is interesting to note that

Ballard and colleagues (Ballard et al., in press) reported the first double-blind clinical trial to demonstrate improvements in agitation levels in severe dementia patients following aromatherapy with Melissa (lemon balm).

The essential oils used in aromatherapy are highly concentrated essences extracted from plants through the process of distillation. Although synthetic analogues of a number of the components of these essential oils are commercially available, they are considered inferior to the natural products by herbal medicine practitioners (Price, 1995). Each essential oil is believed to produce reliable and predictable effects on psychological state when inhaled (Sanderson & Ruddle, 1992), and a number of studies have investigated this possibility. The reputed sedative nature of lavender has consistently been demonstrated through the relief of anxiety and tension, and improvements of mood (Lorig & Schwartz, 1987b; Ludvigson & Rottman, 1989; Buchbauer et al., 1991). Similar subjective relaxing effects have been found for spiced apple (Schwartz et al., 1986b) and sandalwood (Steiner, 1994). The presence of such effects has further been established by physiological and electrophysiological measurements. Diego and colleagues (Diego et al., 1998) studied electroencephalograms (EEGs) and found lavender inhalation to be associated with increased beta power, which is acknowledged as being associated with sedation. In addition, the contingent negative variation (CNV) variable of EEG has been shown to be diminished by both lavender and sandalwood oils, a finding consistent with decreased arousal (Torii & Fukuda, 1985; Torii et al., 1988). By comparison, peppermint, jasmine, and rosemary have been demonstrated to possess subjectively stimulating or arousing properties (Warm & Dember, 1990; Kovar et al., 1987; Diego et al., 1998). These effects, as well as being in line with reputation, have also subsequently been supported by results from physiological and electrophysiological measurements that contrast those outlined above for sedating oils (Kubota et al., 1992; Parasuraman et al., 1992; Sugano, 1992).

It is a possibility that changes in subjective state brought about by aroma inhalation, and in particular changes in arousal and alertness, may impact upon cognitive performance. Indeed arousal has been demonstrated to interact with task demands, producing an inverted-U performance versus arousal curve (Yerkes & Dodson, 1908).

A small number of studies that have attempted to investigate any possible influence of aromas on cognition have produced equivocal results, however. Diego et al. (1998) found the subjective mood and EEG effects for both lavender (sedating) and rosemary (arousing) as predicted. While both aromas improved the speed of maths computations, only lavender increased accuracy. Similarly, Warm and colleagues (Warm et al., 1991) reported that both arousing (peppermint) and relaxing (muguet) aromas produced significant increases in sensitivity on a visual sustained attention task compared to no odor controls. Why these two aromas did not produce contrasting effects on performance is not clear, but neither odor led to a subjective experience of the task being less taxing than in the control condition. It may be that the impact of the aromas on task performance was independent of subjective feelings. Degel and Köster (1999) reported fewer errors on both letter counting and mathematical tasks following inhalation of lavender compared to jasmine. Furthermore, both odors led to significantly poorer performance on a creativity task compared to no odor controls. By comparison, Ludvigson and Rottman (1989) found lavender to impair arithmetic reasoning, but not memory, when compared to cloves, with no concomitant effect on mood for either odor. Ilmberger and colleagues (Ilmberger et al., 2001) reported no clear influence of either peppermint, jasmine, ylang-ylang, or 1,8-cineole (the major constituent of rosemary oil) on speed on a psychomotor task. Rather, they reported complex correlations between subjective evaluations and objective performance, and suggested that the influences of odor on the basic forms of attention are mainly psychological.

Interestingly, studies have also investigated situations where the expectation of an ambient odor is produced in participants but when none is actually presented (Knasko et al., 1990; Gilbert et al., 1997). Furthermore, the participants were misled into believing that the feigned odor would affect cognitive performance. However, the objective test data demonstrated no differences to exist between the conditions, indicating that expectancies may be secondary to the effect of any actual odor presented.

Previous research has therefore produced mixed findings regarding the possible influence of aromas on cognitive performance. Differences in methodology and the types of tasks employed have also made it difficult to compare results across studies. The current study therefore aimed to definitively assess performance on a wide range of tasks relating to a number of established cognitive domains. To this end, the Cognitive Drug Research (CDR) battery was employed. The CDR battery has been used in over 200 phase 1 and phase 2 clinical trials world-wide, and has been demonstrated to be reliable, valid, and sensitive to changes in cognitive function (Wesnes et al., 1999; Moss et al., 1998; Scholey et al., 1999). Participants performance on the test battery was compared across conditions of ambient rosemary aroma, ambient lavender aroma, or no odor (control). Subjective mood state was also assessed príor to and after the experimental session to investigate the possible interaction of cognitive task performance and odor inhalation on ratings of calmness, contentedness, and alertness.

MATERIALS AND METHODS

Participants

One hundred and forty-four undergraduates and members of the general public volunteered to take part in this study. The composition of the three experimental groups consisted of the following: rosemary condition: 28 females (mean age 25.3 years, SD 6.9), 20 males (mean age 24.5 years, SD 7.8); lavender condition: 27 females (mean age 23.8, SD 6.3); 21 males (mean age 24.7, SD 6.7); control condition: 30 females (mean age 24.9, SD 5.6), 18 males (mean age 26.2 SD 8.1). Prior to participation each volunteer completed a health questionnaire. All participants self-reported that they were in good health and none were excluded from the study.

Aromas

"Tisserand" pure essential oils (Tisserand Aromatherapy, Newtown Road, Hove, Sussex, UK) of lavender and rosemary were used to produce the ambient aromas. Four drops of the appropriate oil (or water in the control condition) were applied to a diffuser pad for a

"Tisserand Aroma-stream." The Aroma-stream was placed under the bench in the testing cubicles so as to be out of sight, and switched on for 5 min prior to the testing of each participant. Each aroma was above detection threshold and of approximately equivalent strength for each testing session as assessed by an independent party.

Testing Cubicles

Each testing cubicle measured 2.4 m long × 1.8 m wide × 2.4 m high and were maintained at a temperature between 18 and 22 degrees Celsius throughout the testing sessions.

Cognitive Measures

A tailored version of the Cognitive Drug Research (CDR) computerized assessment system (installed on Viglen genie computers) was employed to evaluate cognitive performance. The CDR system includes a number of measures that are specific to particular aspects of attention, working memory, and long-term memory. Stimuli are presented on a color monitor, and (with the exception of word recall) responses are made using a simple response module containing two buttons labeled "Yes" and "No," respectively. A suite of programs controls all aspects of testing, including selection of appropriate sets of stimuli for presentation and recording all responses.

The tests employed in this study were presented in the following order:

Word presentation. A series of 15 words were presented sequentially for 1 s, each with an interstimulus interval of 1 s. The words were a mix of one, two, and three syllables.

Immediate Word Recall. The computer display counted down 60 s, during which time participants wrote down as many of the words from the list as possible. Recall was scored for number of correct words and errors (words not presented in the list).

Picture Presentation. Twenty photographs were presented, with a stimulus duration of 2 s each, and interstimuli interval of 1 s.

Simple Reaction Time. The word Yes was presented in the center of the screen. The participant had to press the Yes button as quickly as possible. There were 50 trials, and the intertrial interval varied randomly between 1 and 2.5 s. The reaction time was recorded in ms.

Digit Vigilance. A number was displayed constantly to the right of the screen. A series of 240 digits was presented one at a time in the center at a rate of 80 per min; 45 matched the constantly displayed digit. The participant had to press the Yes button as quickly as possible every time the digit in the center matched the one constantly displayed. Accuracy of response (%), reaction time (ms), and number of false alarms were recorded.

Choice Reaction Time. Either the word Yes or No was presented in the center of the screen. The participant had to press the Yes or No button as appropriate and as quickly as possible. There are 50 trials (25 "Yes" and 25 "No"), and the intertrial interval varied randomly between 1 and 2.5 s. Accuracy (%) and reaction time (ms) were recorded.

Spatial Working Memory. A schematic picture of a house was presented for 5 s. The house had nine windows in a 3 × 3 pattern, four of which were illuminated. A series of 36 presentations of the same house in which just one window was illuminated followed, and the participant had to respond Yes if the window was one of the four lit in the original presentation, or No if it was not. Sixteen of the stimuli required a Yes response and 20 a No response. Reaction time and accuracy were recorded and a sensitivity index was calculated.

Memory Scanning. Five digits were presented singly at the rate of 1 every s for the participant to remember. A series of 30 digits was then presented. For each, the participant must press Yes or No according to whether the digit was thought to be one of the five presented initially. Fifteen stimuli required a Yes response and 15 a No response. This was repeated three times using a different *5* digits on each occasion. Reaction time was recorded and a sensitivity index calculated.

Delayed Word Recall. The computer counted down 60 s, during which time participants free-recalled as many of the words from the list as possible. Recall was scored as the number of correct words, and errors (words not presented in the list).

Word Recognition. The 15 words initially presented for the word recall were presented again in random order, interspersed with 15 new words. The participant pressed Yes or No each time to signal whether or not the word was from the original list. Reaction time and accuracy were recorded and a sensitivity index was calculated.

Picture Recognition. The 20 pictures presented earlier were shown again in random order, interspersed with 20 similar new ones. The participant signaled recognition by pressing the appropriate Yes or No button. Reaction time and accuracy were recorded, and a sensitivity index calculated.

"*Pencil and Paper" Visual Analogue Scales.* Subjective levels of alertness, calmness, and contentedness were presented prior to and following the computerized tests. Participants were required to indicate their current state by marking a line drawn between two bipolar adjectives. The entire battery took approximately 25 min to administer.

Primary Cognitive Outcome Measures

The above measures were collapsed into four global outcome factors, and two subfactors derived from the battery by factor analysis, as previously utilized (Kennedy et al., 2000, 2001; Wesnes et al., 1997, 2000).

Quality of memory. This was derived by combining the percentage accuracy scores (adjusted for proportions of novel and new stimuli where appropriate) from all of the working and secondary memory tests: spatial working memory, numeric working memory, word recognition, picture recognition, immediate word recall, and delayed word recall (with adjustments to the total percentage correct for errors on the latter two tasks). A 100% accuracy across the six tasks generated a maximum score of 600 on this index.

Examination of the factor pattern suggests that this global "quality of memory" factor can usefully be further divided into two subfactors: "working memory" and "secondary memory"

Working memory subfactor. This was derived by combining the percentage accuracy scores from the two working memory tests: spatial working memory and numeric working memory. One hun-dred percent accuracy across the two tasks generated a maximum score of 200 on this index.

Secondary memory subfactor. This was derived by combining the percentage accuracy scores (adjusted for proportions of novel and new stimuli where appropriate) from all of the secondary memory tests: word recognition, picture recognition, immediate word recall, and delayed word recall (with adjustments to the total percentage correct for errors on the latter two tasks). One hundred percent accuracy across the four tasks generated a maximum score of 400 on this index.

Speed of memory. This was derived by combining the reaction times of the four computerized memory tasks: numeric working memory, spatial memory, delayed word recognition, and delayed picture recognition (units are summed ms for the four tasks).

Speed of attention. This was derived by combining the reaction times of the three attentional tasks: simple reaction time, choice reaction time, and digit vigilance (units are summed ms for the three tasks).

Accuracy of attention. This was derived by calculating the combined percentage accuracy across the choice reaction time and digit vigilance tasks with adjustment for false alarms from the latter test. One hundred percent accuracy across the two tasks would generate a maximum score of 100.

The contribution of individual task measures to each of these factors and subfactors is illustrated schematically in Figure 1.

Subjective Mood Measure

The Bond-Lader visual analogue scales (Bond & Lader, 1974). The 16 visual analogue scales of Bond-Lader were combined as recommended by the authors to form three mood factors: "alert," "calm," and "content."

Procedure

Participants were approached individually and asked if they would help in the validation of a new cognitive test battery. No mention of aromatherapy or essential oils was made. This deception was carried

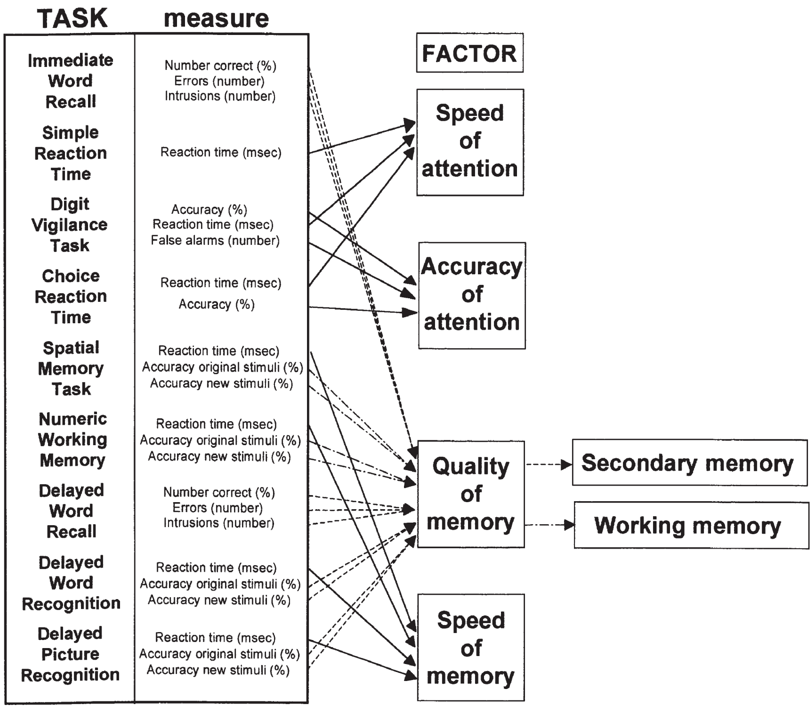


FIGURE 1. Schematic representation of the CDR battery showing (from left to right) running order of tasks, individual task outcome measures, and the composition of the four factors derived by factor analysis. Arrows indicate that a task outcome measure contributes to the given factor "Speed of Attention," "Accuracy of Attention," "Quality of Memory," or "Speed of Memory." Dotted lines indicate contribution to both "Quality of Memory" and to either "Working Memory" (-.-) or "Secondary Memory" (- - -), respectively.

out in order to avoid the possibility of expectancy effects contaminating the data. Recruitment took place one week prior to testing, and participants were randomly and unknowingly allocated to one of the three conditions: lavender, rosemary, or no odor (control). They were then given a time and day on which to attend the laboratory. Testing took place in three different cubicles, and on three different days of the week (Monday, Wednesday, and Friday) to avoid cross contamination of odors. On arrival at the lab, each participant was once again reminded that he or she was there to assist in the validation of the new test battery and to try his or her best on all the tasks. Participants were then asked to complete the mood scales, supposedly to assess if the tasks affected mood. Participants were then taken into the cubicle where they completed the CDR battery followed by a second mood scale. Finally, they were debriefed regarding the true nature of the experiment, and any questions answered. If any of the participants commented on the presence of an odor prior to or during the testing session, the researcher dismissed it with responses of the kind: "nothing to do with me" and "don't know where it came from." No participants indicated at any time that they felt the odor had affected them at all, or that they thought the study was investigating the effect of odor on performance or mood.

Statistics

Scores from the individual task outcome measures were combined to form the four global outcome measure factor scores, as well as the secondary memory and working memory factor scores. These and the individual task outcome measures making up the factors were analyzed using the statistical package Minitab 12 for Windows. The one-way analysis of variance (ANOVA) followed by Tukey pairwise comparisons were employed to identify where any differences between the three conditions may have existed. Analysis of subjective mood was made in a similar manner on the pre- to post-testing difference scores, reflecting any changes in mood state due to exposure to the aromas and/or as a result of completing the assessment battery.

RESULTS

The analyses of the individual task outcome measures that make up the factors are presented in Table 1. The results described here concentrate on the primary cognitive outcome measures described above.

Quality of Memory Factor

An independent groups ANOVA revealed a significant difference between groups, $F(2,141) = 4.80$; $p = .010$. Tukey post-hoc

TABLE 1. Effects of rosemary and lavender essential oils on individual task outcome measures from the CDR battery

Outcome variable	*1) Control Mean ± SD*	*2) Rosemary Mean ± SD*	*3) Lavender Mean ± SD*	*Significant comparisons*
Immediate Word Recall Correct	5.47 ± 1.82	6.18 ± 2.03	5.54 ± 2.16	
Immediate Word Recall Errors	0.42 ± 0.65	0.30 ± 0.58	0.64 ± 1.02	
Simple Reaction Time	245.97 ± 14.12	249.43 ± 31.32	259.36 ± 36.35	
Number Vigilance Accuracy	94.17 ± 9.79	90.69 ± 12.05	91.94 ± 9.12	
Number Vigilance False Alarms	1.04 ± 0.94	1.04 ± 1.52	0.92 ± 1.16	
Number Vigilance Reaction Time	372.62 ± 32.34	375.87 ± 39.73	380.11 ± 46.05	
Choice Reaction Time	393.34 ± 49.39	402.52 ± 62.70	431.62 ± 83.61	1 vs 3*
Spatial Memory Sensitivity Index	0.91 ± 0.10	0.89 ± 0.18	0.79 ± 0.26	1 vs 3*, 2 vs 3*
Spatial Memory Reaction Time	824.5 ± 166.9	1043.8 ± 405.8	964.4 ± 326.5	1 vs 2**
Numerical Working Memory Sensitivity Index	0.83 ± 0.13	0.82 ± 0.16	0.75 ± 0.28	
Numerical Working Memory Reaction Time	705.5 ± 137.5	782.4 ± 170.8	762.6 ± 161.3	1 vs 2*
Delayed Word Recall Correct	3.67 ± 2.03	4.28 ± 2.80	3.21 ± 2.70	
Delayed Word Recall Errors	0.42 ± 0.77	0.52 ± 1.05	0.69 ± 0.97	
Word Recognition Sensitivity Index	0.57 ± 0.16	0.65 ± 0.17	0.53 ± 0.31	2 vs 3*
Word Recognition Reaction Time	772.8 ± 209.5	802.8 ± 173.5	929.3 ± 298.5	1 vs 3*, 2 vs 3*
Picture Recognition Sensitivity Index	0.62 ± 0.23	0.69 ± 0.17	0.69 ± 0.16	
Picture Recognition Reaction Time	826.7 ± 128.5	875.8 ± 186.9	909.3 ± 177.3	

Note. The units are number of correctly recalled items for the word recall tasks, ms for the reaction times. The sensitivity indices are calculated using the nonparametric signal theory index (SI) presented by Frey and Colliver (1973). $*p < .05$; $**p < .01$.

comparisons identified that the rosemary condition (mean = 363.91) produced significantly higher scores than the lavender condition (mean = 326.61), $p < .05$ (Figure 2a). No other significant differences were found.

Secondary Memory Subfactor

An independent groups ANOVA revealed a significant difference between groups, $F(2,141) = 4.44$; $p = .014$. Tukey post-hoc comparisons identified that the rosemary condition (mean = 200.03) produced significantly higher scores than the lavender condition (mean = 174.24), and the control condition (mean = 176.60), $p < .05$ in each case (Figure 2b). No other significant differences were found.

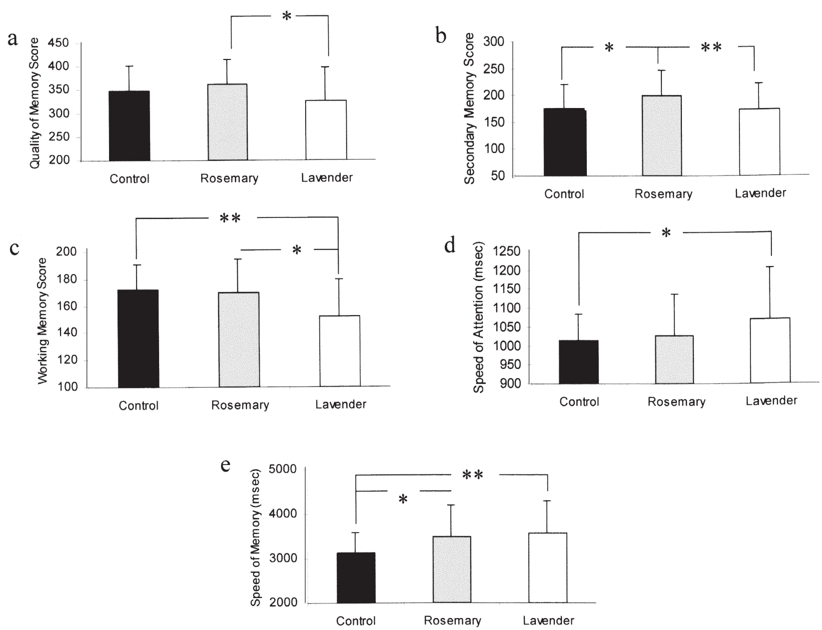


FIGURE 2. Effects of rosemary and lavender on the cognitive factors derived from the CDR test battery: (a) "Quality of Memory," (b) "Secondary Memory," (c) "Working Memory," (d) "Speed of Attention," and (e) "Speed of Memory" (see text for details). Figures depict mean values. Error bars represent standard deviations. *$p < .05$; **$p < .01$.

Working Memory Subfactor

An independent groups ANOVA revealed a significant difference between groups, $F(2,141) = 5.40$; $p = .006$. Tukey post-hoe comparisons identified that both the rosemary condition (mean = 169.92) and the control condition (mean = 172.74) produced significantly higher scores than the lavender condition (mean = 152.37), $p < .05$ and <.01, respectively (Figure 2c). No other significant differences were found.

Speed of Memory Factor

An independent groups ANOVA revealed a significant difference between groups, $F(2,141) = 6.38$; $p = .002$. Tukey post-hoc comparisons identified that the control condition (mean = 3129.5 ms) produced significantly quicker responses than both the lavender condition (mean = 3565.5 ms) and the rosemary condition (mean = 3504.7 ms), $p < .0l$ and <.05, respectively (Figure 2d). No other significant differences were found.

Speed of Attention Factor

An independent groups ANOVA revealed a significant difference between groups, $F(2,141) = 3.57$; $p = 031$. Tukey post-hoc comparisons identified that the control condition (mean = 1013.9 ms) produced significantly quicker responses than the lavender condition (mean = 1071.1 ms), $p < .05$ (Figure 2e). No other significant differences were found.

Accuracy of Attention Factor

An independent groups ANOVA revealed no significant differences between groups, $F(2,141) = 1.20$; $p = .305$.

Subjective Mood Measures

Analysis of the pre-test ratings indicated no differences between the three conditions on any of the mood variables prior to the experimental session: Alertness, $F(2,141) = 0.87$; $p = .422$. Contentedness, $F(2,141) = 1.18$; $p = .311$. Calmness, $F(2,141) = 0.52$; $p = .594$. Subsequent analyses compared post-test minus pre-test change in mood scores.

Alertness

An independent groups ANOVA revealed a significant difference between groups, $F(2,141) = 5.43$; $p = .005$. Tukey post-hoc comparisons identified that the rosemary condition produced an increase in alertness (mean change = 5.51), compared to decreases for both the control condition (mean change = –3.06), $p < .05$, and the lavender condition (mean change = –7.49), $p < .01$ (Figure 3a). No other significant differences were found.

Contentedness

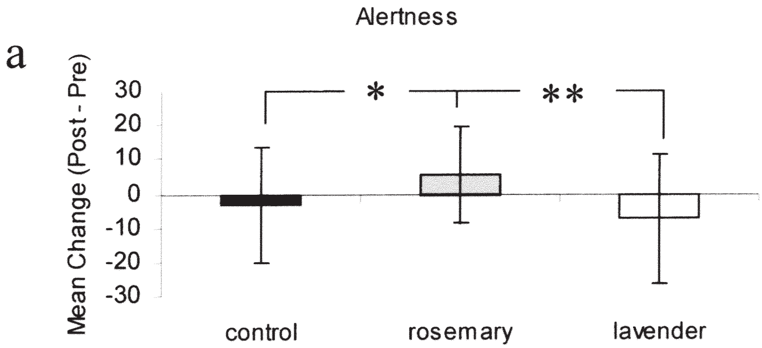
An independent groups ANOVA revealed a significant difference between groups, $F(2,141) = 9.72$; $p = .0001$. Tukey post-hoc comparisons identified that the rosemary condition produced an increase in contentedness (mean change = 2.39) compared to controls (mean change = –9.58), $p < .01$. In addition, the lavender condition produced a decrease in contentedness (mean change = –2.79) that was significantly less than that for the control condition (mean change = –9.58), $p < .05$ (Figure 3b). No other significant differences were found.

Calmness

An independent groups ANOVA revealed no significant differences between groups, $F(2,141) = 0.73$; $p = .481$.

DISCUSSION

The results of this study clearly support previous work indicating that essential oils can influence mood (Roberts & Williams, 1992; Buchbauer et al., 1991; van Toller & Dodd, 1988). More important, we have demonstrated that the inhalation of ambient aromas of



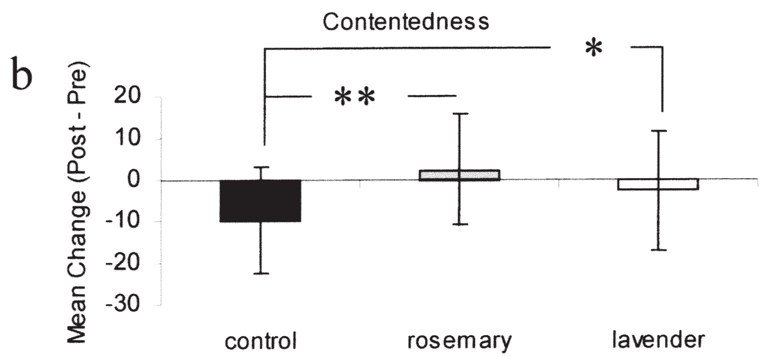


FIGURE 3. Effects of rosemary and lavender on change in self-rated mood as measured using the Bond-Lader Visual Analogue Scales: (a) "Alertness" and (b) "Contentedness." Figures depict mean change (post-test minus pre-test ratings), such that a positive change represents an increase on that dimension over the test session. Error bars represent standard deviations. *$p < .05$; **$p < .01$.

essential oils can significantly affect aspects of cognitive performance. Further, due to the design employed in this study and the deliberate diversion of participants attention away from the odors, these effects are considered to be irrespective of participants expectations or beliefs.

The changes in mood recorded over the period of the cognitive testing can, to some extent, be matched to the objective test outcomes. Lavender essential oil is widely considered to possess sedating properties, and rosemary is believed to be arousing and has been linked to memory at least as far back as the writings of Shakespeare (Hamlet Act4, scene5). These facets are broadly reflected in the effects on cognitive performance observed here.

The quality of memory factor was found to be impaired by lavender when compared to rosemary, but not when compared to controls. Consideration of the memory subfactors indicates that secondary memory possessed the same odor-performance relationship, although on this subfactor performance in the lavender condition was on a par with controls, indicating enhancement for the rosemary condition rather than a decrement for lavender. For the working memory subfactor, however, lavender was significantly impaired compared to both the rosemary and control conditions. A clear dissociation of the aroma effects on these two memory systems is apparent here, with rosemary enhancing secondary memory and lavender having no effect, in contrast to lavender which impaired working memory and rosemary which had no effect. A similar profile of results to those obtained here for rosemary has been reported previously for the influence of oxygen administration on cognition (Moss et al., 1998) and for the acute administration of Ginseng (Kennedy et al., 2000). It is interesting to note that the distinction between secondary and working memory appears to be more than theoretical on the basis of the results reported here and elsewhere. It may be the case that the two systems are served to some degree by distinct neuropsychological and neurochemical pathways that are differentially available for enhancement, although some natural interventions (most notably, chewing gum) appear capable of impinging on both in a positive manner (Wilkinson et al., 2002).

With reference to the speed of memory factor, both aromas significantly slowed performance as compared to controls. As this factor encompasses reaction times from both working memory and secondary memory tasks, this may indicate a speed accuracy tradeoff in both the enhancement found for rosemary, and the impairment found for lavender reported here. However, consideration of the individual task outcome measures that make up these factors indicates an interesting pattern. Reaction times were not significantly slowed by rosemary compared to the other conditions on the word and picture recognition tasks, which constitute the secondary memory tasks, which have a speed component associated with them. However, both tasks did show improvements in accuracy, and, as such, a clear speed accuracy trade-off can be discounted for rosemary. In contrast, lavender did not produce significantly faster performance compared to controls on the spatial and numerical working tasks on which accuracy was impaired. Indeed, participants were both slower and less accurate on these tasks. However, lavender did produce a slowing of reaction times on the secondary memory tasks that were not impaired in terms of accuracy. The reduction in speed here possibly facilitates a level of accuracy that may otherwise have been lost. The relationship between speed and accuracy may be important in the effects of lavender then, but not rosemary.

The speed of attention factor displayed a significant impairment for the lavender condition compared to controls, but not to rosemary. This may have, in part, been predicted on the basis of lavender's putative sedating properties. Rosemary, however, would reasonably have been predicted to enhance attentional speed as a consequence of its arousing properties. Certainly the mood data indicated that the participants in the rosemary condition felt more alert than those in the lavender or control conditions. Performance for the rosemary condition, however, was numerically slower than the controls, and faster than the lavender group though neither comparison was significant. In spite of increased subjective alertness, however, objective performance did not improve, which suggests that the enhancements observed for memory may be independent of subjective state.

Another possible explanation may be found in the inverted-U relationship between arousal and performance described in the Yerkes-Dodson law. Attentional tasks require the directing of psychological resources to events in the environment, and arousal levels (as monitored by changes in physiological parameters such as blood pressure and heart rate) are low (or even reduced compared to resting) for such tasks compared to tasks with a higher cognitive load (Lacey & Lacey, 1970, 1974; Turner & Carroll, 1985a, 1985b). It may well be the case that rosemary inhalation raises arousal levels to such an extent that enhancement is not possible for attentional tasks (due to overarousal). At the same time performance on the more cognitively demanding tasks relating to memory consolidation and retrieval is enhanced (due to optimal arousal being attained for these tasks).

Performance on the accuracy of attention factor was effectively equal across conditions, and consideration of the mean levels of accuracy in the tasks that combine to create this factor suggests that ceiling levels were being achieved. Accuracy levels of greater than 90% in the control condition indicates that there is very little room for enhancement in the participant group employed here, and the nature of the tasks is such that only serious cognitive deficits produce large impairments in accuracy of performance compared to controls (Simpson et al., 1991). It is therefore perhaps not surprising that no effect of condition was observed on this factor.

Returning to the mood data, as well as the effect of rosemary on levels of alertness, a significant effect was found for both lavender and rosemary compared to controls for degree of contentedness. Rosemary led to participants reporting higher levels of contentedness after completion of the test battery than before the start. In addition, although lavender was associated with a small decrease in levels of contentedness from pre- to post-testing, this change was still significantly less than the decrease in contentedness observed in the control condition. It would appear therefore that the aromas employed here are capable of elevating mood, or at least maintaining good mood during the completion of a challenging test battery under laboratory conditions. These positive effects on mood are consistent with those identified in the aromatherapy literature under resting conditions (Buchbauer et al., 1991; van Toller & Dodd, 1988). In contrast, no significant effect was revealed for the calmness mood dimension, which may have been predicted to show an increase for lavender based on its reported sedative properties. It may be that the experimental situation experienced by the participants was such that although feeling content, they did not find themselves able to relax (i.e., increase calmness). This may also have been reflected in the finding that lavender did not significantly decrease feelings of alertness below those of controls. It may be possible that central or conscious mechanisms were able to override the effects of the aroma during testing at least for aspects of subjective mood, if not for the objective measures of cognitive functioning as described above.

In considering how essential oils may influence mood and cognition, such as that recorded here, a number of possibilities have been proposed, but again little hard evidence exists. Jellinek (1997) outlined four mechanisms by which odors may exert effects. Two of these can be rejected with regard to the current study. The “semantic mechanism” describes contextual effects on memory and experience that were not investigated in this study. The “placebo mechanism” describes the influence of expectancies on behavior and is discounted here because the experiment explicitly set out not to produce expectancies, and no participant indicated that he or she had any during the testing procedure. The “hedonic valence mechanism” asserts that the degree of pleasure/displeasure that is gained from an experience defines the moods that emerge from it, and that mood state affects cognitive and behavioral responses. Evidence suggests that hedonic valence is affected by aromas (Baron & Thomley, 1994; Ehrlichman & Bastone, 1992) and that aromas may therefore influence cognition via this route. Certainly, pleasant-smelling commercially produced air-fresheners have been shown to improve mood and task performance (Baron, 1990). In the current study, however, differential cognitive effects were found for two essential oils, both of which are considered to be pleasant smelling, and both of which increased contentedness in participants compared to controls. As such, a direct link to hedonic valence would appear too simple to explain these results.

Finally, the “pharmacological mechanism” describes how constituents of the essential oils may influence behavior through the central nervous or endocrine systems. Volatile compounds may enter the bloodstream by way of the nasal or lung mucosa, or may diffuse directly into the olfactory nerve and pass up to the limbic system in the brain—a region closely associated with arousal. Although the level of active compounds that may be absorbed by these routes is low compared to other modes of administration, essential oils have been detected in the blood of rodents exposed to the vapors of essential oils (Jirovitz et al., 1990, 1992; Kovar et al., 1987). A pharmacological mechanism would imply substance-specificity—a concept that would fit well with results described here, with each aroma producing a unique pattern of influence on the cognitive domains assessed. In addition, neuropharmacological research has provided insights into the possible modes of influence of different plant-based substances that may be relevant here. Specifically, Wake and colleagues (Wake et al., 2000) found that varieties of sage and melissa possessed nicotinic and muscarmnie acetylcholine activity in homogenate preparations of human cortical cell membranes. The link between the cholinergic system and memory is well established, and it may be that rosemary also possesses such cholinergic activity—the results presented here suggest that it might. This possibility remains to be investigated. Lavender has also been demonstrated to act postsynaptically, and it is suggested that it modulates the activity of cyclic adenosine monophosphate (cAMP) (Lis-Balchin & Hart, 1999). A reduction in cAMP activity is associated with sedation, a causal relationship that has been established for the effects of cannabis. It is possible that lavender produces sedative effects via the same route albeit with less intensity.

In summary, the cognitive effects recorded here are clear, specific, and dependent upon ambient aroma. Furthermore, these effects only mirror to some degree the changes in subjective mood state reported by the participants, and a simple change in levels of arousal is not entirely satisfactory as an explanation of these findings either. Recent work suggests that some of the essential oils employed in aromatherapy possess pharmacological properties that may be responsible for both the effects on mood and cognition attributed to them. However, the information is currently limited and further research is required if such properties and relationships are to be identified clearly. At the same time, research in our lab shall continue in an attempt to provide clear cognitive and mood profiles for the effects of a wide range of essential oils.

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