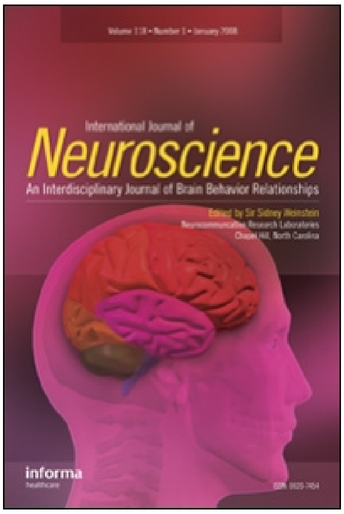

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Aromatherapy Facts and Fictions: A Scientific Analysis of Olfactory Effects on Mood, Physiology and Behavior

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AROMATHERAPY FACTS AND FICTIONS: A SCIENTIFIC ANALYSIS OF OLFACTORY EFFECTS ON MOOD, PHYSIOLOGY AND BEHAVIOR

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A systematic review of scientific experimentation addressing olfactory effects on mood, physiology and behavior was undertaken. From this review, 18 studies meeting stringent empirical criteria were then analyzed in detail and it was found that credible evidence that odors can affect mood, physiology and behavior exists. To explain these effects, pharmacological and psychological mechanisms were explored and a psychological interpretation of the data was found to be more comprehensive. Methodological problems regarding dependent measures and stimuli, which led to inconsistencies in the data were discussed, as were the mediating variables of culture, experience, sex differences, and personality.

Keywords Behavior, mood, odor, pharmacology, physiology, psychology

INTRODUCTION

The aim of this article is to review and analyze the current literature on *aromachology*, the scientifically documented study of olfactory effects in humans, and thus to determine whether and how the inhalation of aromatic chemicals can influence mood, physiology and behavior. The methods,

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mechanisms and theories that produce and explain these effects, as well as cultural, individual and olfactory factors that may influence the outcomes of various manipulations will be discussed.

To begin with, the term "aromatherapy" will be defined and contrasted to "aromachology." Aromatherapy is the use of essential oils extracted from plants for the treatment of physical and psychological health. The concept of aromatherapy is ancient. Aromatic plant-based compounds were used by the Chinese in the form of incense, by the Egyptians in embalming the dead, and by the Romans in their baths. The term "aromatherapy" (originally *aromatherapie*) was coined by the French chemist Rene-Maurice Gattefosse, in the late 1920s, who began the exploration of essential oils for their healing powers after an explosion in his laboratory left his hand badly burned and the accidental soaking of his injury in pure lavender oil produced a rapid and miraculous healing. Contemporary aromatherapy proposes that various plant-based aromas have the ability to influence mood, behavior, and "wellness."

It is true that many plants have therapeutic properties. For example, the use of acetyl salicylic acid, the active ingredient in aspirin, came from the discovery that chewing willow bark alleviated pain, inflammation, and fever. However, aromatherapy is based not on the ingestion of various plant-based products, but rather on inhaling their aromas, which are claimed to have a range of therapeutic and psychological properties. Here are some examples of the purported effects for several commonly "prescribed" essential oils: Sandalwood aroma is sedating and relaxing and is beneficial for treating anxiety, depression, and insomnia. Rosemary clears the mind and stimulates memory. Lavender is uplifting, soothing and helpful for reducing stress, anxiety, depression, and insomnia. Sweet marjoram is calming and sedating and helpful in relieving a variety of negative emotional states, including anxiety, irritability and loneliness. Clary sage is uplifting and relaxing as well as helpful in relieving depression, anxiety, fatigue and calming irritable children. Indeed authors of aromatherapy textbooks make a number of extraordinary and sometimes contradictory assertions in the absence of systemically collected data for a range of cures. For example, juniper oil is claimed to have 17 different properties ranging from aphrodisiac to sedative (Price, 1991).

Aromatherapy today is usually practiced in conjunction with massage, and one of the major claims of aromatherapy is a reduction in anxiety. There is considerable evidence from randomized trials that massage alone reduces anxiety (Field et al., 1992). If massage is effective, then aromatherapy plus massage, unless essential oils are harmful (which seems unlikely), is also effective. So "aromatherapy works, even if it doesn't", as several reviews of the literature have noted, at least for the reduction of anxiety (Cooke & Ernst, 2000; Vickers, 2000).

In contrast to aromatherapy which is not scientifically supported, *aromachology*, a term that was coined by the Sense of Smell Institute in 1982, refers to the scientific analysis of olfactory effects on mood, physiology and behavior. Aromachology research must meet the following empirical criteria: (1) theory guided goals and clear hypothesis testing, (2) fragrances are tested using appropriate experimental methodology, (3) sufficient and representative subject populations and appropriate contrasting control groups are used, (4) data are analyzed using suitable statistical methods, and (5) the results have been vetted by scientific peers and accepted for publication in reputable journals. Note that there are numerous "research" reports that claim to demonstrate the effects of various aromatic compounds on mood, mental state, and behavior, however, most of these studies are vexed with problems that prevent them from being scientifically meaningful.

LITERATURE REVIEW: METHODS AND RESULTS

To determine the current state of aromachology research, the literature on the psychological and physiological effects of "essential oil," "fragrance," "aroma," "scent," and "odor or odorant" was searched using Pubmed (www.pubmed.gov) databases, a service of the National Library of Medicine and the National Institutes of Health. The results of this search yielded several hundred articles. The abstracts of these articles were read and sorted according to whether they were: (1) discountable aromatherapy studies or (2) possibly viable aromachology research. Discountable aromatherapy studies were those not meeting three or more of the five criteria described above. Other reasons for exclusion included: studies of nonspecific odor effects or nonspecific odors, studies where the effects of odors were not pertinent to mood or mental state, studies involving animal subjects, studies that examined the effects of odors on psychiatric or medical conditions or involved clinical trials, and studies that were more than 10-years old. The articles that passed this first level of examination were then reviewed in detail and from this analysis 18 studies were chosen as representative of valid aromachology experimentation, and/or which addressed important conceptual or methodological issues in aromachology research.

Table 1 provides a synopsis of the aromachology studies that were reviewed in detail for this article.

Table 1. Aromachology studies reviewed

Authors	Date	Title and journal	Odor(s) tested and dependent measures	Effects/findings
Diego et al.	1998	*International Journal of Neuroscience*	Essential oil of Lavender and Rosemary. Mood arithmetic computation, EEG.	Pre vs post "aromatherapy" comparison of mood, math computation and EEG. Contrary to predictions, both odors increased speed in math computations, increased relaxation, and decreased anxiety. However, EEG changes were interpreted as consistent with the idea that lavender is sedating and rosemary is alerting. No control group. Sex differences were not assessed.
Lehrner et al.	2000	*Physiology & Behavior*	Essential oil of Orange (citrus sinensis). Subjective emotional states.	Women undergoing a stressful procedure while exposed to ambient orange oil experienced decreased state anxiety, improved mood, and increased calmness. Presence of orange oil had no effect on the well-being of male participants in this situation.
Heuberger et al.	2001	*Chemical Senses*	(+)limonene, (−) limonene, (+) carvone, (−) carvone. Physiological measures, subjective states, odor hedonic ratings.	Inhalation of (+) limonene led to increased systolic BP, subjective alertness and restlessness. (−) limonene increased systolic BP. (+) carvone increased systolic and diastolic BP. (−) carvone increased diastolic BP, pulse and restlessness. Effects were attributable to odor hedonic perception. Sex differences were not assessed.

Ilmberger et al.	2001	*Chemical Senses*	Peppermint, jasmine, ylang-ylang, 1,8-cineole [100 μl], 1,8-cineole [10 μl], menthol. Reaction time and motor time. Subjective odor ratings.	Alertness as a function of odor presence was measured by a reaction time task. Subjects exposed to any odor, except cineole 100 μl, did not differ in reaction time from control groups inhaling water (no- odor). Subjects exposed to cineole 100 μl had faster reaction times than control subjects. Subjective ratings (pleas, intensity, stimulation, relaxation) were obtained for all stimuli and any/all odor effects were seen to be psychological. Sex differences were not assessed.
Raudenbush et al.	2001	*Journal of Sport & Exercise Psychology*	Synthetic peppermint oil. Physical performance.	Both male and female athletic college students exposed to peppermint oil in a patch on their upper lip experienced enhanced physical performance, specifically generating more push-ups and running faster (400m dash), compared to when they were exposed to an un-scented patch. No sex differences.
Motomura et al.	2001	*Perceptual and Motor Skills*	Lavender essential oil HR, BP Subjective mood and arousal.	Lavender decreased negative mood and arousal during a 20 min stressful situation compared to the stressor without lavender. No effects on physiological measures. Sex differences were not assessed.

(Continued on next page)

Table 1. Aromachology studies reviewed

Authors	Date	Title and journal	Odor(s) tested and dependent measures	Effects/findings
Raudenbush et al.	2002	*International Sports Journal*	Synthetic peppermint oil, jasmine oil, dimethyl sulfide (3ppm in water). Physiological measures, subjective athletic performance.	During a 15 treadmill exercise, exposure to any odor had no effect on physiological parameters (BP, pulse, oxygen saturation). However, peppermint odor significantly reduced perceived workload and effort and increased self-evaluated physical performance and energy among athletic college students. No sex differences.
Bensafi et al.	2002	*Chemical Senses*	Isovaleric acid, thiophenol, pyridine, menthol, isoamyl acetate, 1–8 cineole. Physiological measures, Subjective odor ratings.	ANS responses (e.g., heart-rate, skin conductance) were correlated with subjective odor ratings. Odor pleasantness predicted HR changes. The more pleasant the odor was rated, the lower the subject's HR. Odor arousal correlated with skin conductance. Interaction between trigeminal and olfactory odor factors suggested. Sex differences were not assessed.
Moss et al.	2003	*International Journal of Neuroscience*	Essential oil of Lavender and Rosemary. Objective cognition measures, Subjective mood.	Lavender decreased working memory and impaired reaction time on memory and attention tasks compared to control (no odor). Rosemary enhanced performance for memory and secondary memory factors, but also impaired reaction time compared to control. After testing, the rosemary group was more alert than the lavender or control group and both aroma groups were more content than the control group. Subjects did not evaluate odor hedonics. Sex differences were not assessed.

Villemeure et al.	2003	*Pain*	Self-selected pleasant and unpleasant synthetic odors. Subjective measures of mood and pain.	Subjects were exposed to painful heat under various odor conditions. Self-selected pleasant odors improved mood and decreased anxiety and pain unpleasantness, while an unpleasant odor worsened mood, anxiety and pain unpleasantness. Odor condition did not affect the perception of pain intensity. No sex differences.
Campenni et al.	2004	*Psychological Reports*	Synthetic lavender, neroli, placebo (no-odor). Subjective mood, Physiological measures	The *suggestion* that an odor would be "stimulating" increased HR and skin conductance. The *suggestion* that an odor would be "relaxing" decreased HR and skin conductance. Effects were seen regardless of the odor, including the no-odor condition. No self-report mood effects were seen as a function of odor/suggestion condition. However, over time in the experiment mood improved for all subjects. Female subjects only.
Heuberger et al.	2004	*Neuropsych-opharmacology*	(−) Linalool via transdermal absorption. Inhalation of (−) linalool was prevented by a face mask. Physiological measures, subjective measures of mood/mind.	Trandsdermally absorbed (−) linalool induced mild de-activating effects on BP and skin temperature, but did not have any effects on subjective measures of well-being or mood. Sex differences were not assessed.

(Continued on next page)

Table 1. Aromachology studies reviewed *(Continued)*

Authors	Date	Title and journal	Odor(s) tested and dependent measures	Effects/findings
Burnett et al.	2004	*Psychological Reports*	Essential oils of rosemary and lavender Physiological measures, subjective mood	No effects on physiological measures, however some subjective mood changes were observed; e.g., lavender led to higher vigor/activity than rosemary. Rosemary increased anxiety. Sex differences were not assessed.
Lehrner et al.	2005	*Physiology & Behavior*	Essential oil of Orange (citrus sinensis) and lavender. Subjective emotional states.	Both men and women undergoing a stressful procedure experienced decreased state anxiety, more positive mood and greater calmness when exposed to either orange or lavender oil in ambient air compared to no-odor or music.
Ho & Spence	2005	*Neuroscience Letters*	Synthetic peppermint oil. Cognitive tasks.	Peppermint aroma improved performance on a difficult but not on an easy cognitive task. Female subjects only.
Kuroda et al.	2005	*European Journal of Applied Physiology*	Jasmine tea lavender essential oil (R)-(−) linalool (S)- (+) linalool Physiological measures, Subjective mood.	Jasmine tea, lavender and (R)-(−) linalool decreased HR, increased positive mood and decreased negative mood. (S)- (+) linalool increased negative mood and decreased positive mood. No sex differences.
Goel et al.	2005	*Chronobiology International*	Lavender oil sleep physiology measured by polysomnograpy, subjective sleepiness and mood ratings.	Lavender increased slow-wave-sleep and subjects reported higher vigor upon awakening compared to control. No effects on rated sleepiness. Sex differences on some sleep measures.
Goel & Lao	2006	*Biological Psychology*	Peppermint oil sleep physiology measured by polysomnograpy, subjective sleepiness, mood and odor ratings	No main effects on physiological sleep, but individual perception of peppermint (e.g., stimulating, intensity) correlated with polysomnography measures. Peppermint reduced fatigue and depression for all subjects. Sex differences on some sleep measures.

Studies are listed chronologically. ANS = autonomic nervous system; HR = heart rate; BP = blood pressure.

All experiments used subjective and/or behavioral and/or physiological measures to obtain quantitative data on the effect of odors on mood, mental states, physiology and behavior. In addition, for discussion and comparison, one study was included where odor was delivered via transdermal absorption rather than inhalation (Heuberger, Redhammer, & Buchbauer, 2004).

A careful review of these studies revealed reliable empirical evidence that various inhaled aromas can significantly affect mood, cognition, physiology and behavior/performance. However, inconsistencies were frequently observed both within studies and across laboratories for various dependent measures and specific odors. The remainder of this paper attempts to address the questions of: (1) how and why odors produce the observed effects, (2) how methodology influences outcomes, and (3) what the relevant mediating factors are.

THEORIES AND MECHANISMS

The most important question for the field of aromachology is how and why odors produce the effects that have been observed on various aspects of mood, behavior and physiology. Two primary mechanisms for the psychodynamic and physiological effects of odors have been proposed: (1) a pharmacological hypothesis, and (2) a psychological hypothesis.

Pharmacological Hypothesis

The pharmacological hypothesis proposes that the effects of various aromas on mood, physiology and behavior are due to the odor's direct and intrinsic ability to interact and affect the autonomic nervous system/central nervous system and/or endocrine systems. In support of the proposition that odors could behave pharmacologically, lavender has been shown to act postsynactpically where it is suggested to modulate the activity of cyclic andenosine monophosphate (cAMP) (Lis-Balchin & Hart, 1999). A reduction in cAMP activity is associated with sedation. Linalool, a principal component of lavender, has also been found to inhibit glutatmate binding, which may have sedative effects (Elisabetsky, Marschener, & Souza, 1995). It is therefore possible that lavender produces sedative effects via these neuropharmacological mechanisms.

In order for a volatile compound to act pharmacologically it must enter the bloodstream by way of the nasal or lung mucosa, or diffuse directly into the olfactory nerves and the limbic system of the brain. Although the level of active compounds that can be absorbed by these routes is low compared to more typical modes of administration, such as ingestion or injection, aromatic compounds have been detected in the bloodstream of rodents exposed to the vapors of essential oils (Jirovitz, Buchbauer, Jager, Raverdino, & Nikiforov, 1990; Jirovitz, Buchbauer, Jager, Woiiieh, & Nikiforov, 1992; Kovar, Gropper, Friess, & Ammon, 1987). It has also been shown in rats that after surgically reducing olfactory function, inhalation of cedrol, a major component of cedarwood oil, marked sedative effects were still seen, suggesting that the mechanism of action is via a pathway other than the olfactory system (Kagawa, Jokura, Ochiai, Tokimisu, & Tsubone, 2003).

The pharmacological hypothesis has some compelling components, however, there are a number of problems as applied to human olfactory responses. For one, there is no data in humans suggesting that inhaled volatiles become present in bloodstream or any other physiological system. This may be because the concentration of odors that one is normally exposed to is much lower than would be required for their presence to be detected in bloodstream. Nevertheless, this means that in the normal context of "aromatherapy," or odor experimental manipulations, odor levels do not reach the appropriate doses to be pharmacologically active/detectable. Extrapolating data from rodents and expecting similar outcomes in humans is confounded by the relative body-size to chemical concentration ratio between rats and humans, the rat's much greater olfactory sensitivity and number of functioning olfactory receptors as well as experimental conditions that are neither practical nor ethical for humans. Moreover, the mode of chemical administration in animal studies where pharmacological effects have been demonstrated has involved direct physiological infusion, not inhalation (e.g., Elisabetsky et al., 1995; Lis-Balchin & Hart, 1999).

Another issue is that the emotional and behavioral effects of aromatic compounds that are reported in the studies reviewed here indicate that responses to odors are immediate. If the mechanism of action is via bloodstream then the effects would require at least 20 min to be seen, as this is the time necessary for chemically active substances to be circulated through blood and then cross the blood-brain barrier.

One study that allows evaluation of this point in humans was conducted by Heuberger and colleagues at the University of Vienna who investigated the effects of (−) linalool a primary chemical in lavender scent, via transdermal absorption (Heuberger et al., 2004). Although the presence of volatiles in internal systems was not measured in this study, when (−) linalool in peanut oil, as compared to peanut oil alone, was applied to the ventral skin of participants, mild central nervous system effects were seen. Inhalation of the odorant was prevented by having participants wear a surgical facemask throughout the procedures. Subjective mood and mental measurements were taken when (−) linalool or pure peanut oil was first applied to the participant's abdominal skin surface and then at the end of a 20-min trial. Physiological ratings were acquired throughout the 20-min trial. No subjective emotional, mental, or mood changes were observed at any time. However, after application of (−) linalool systolic blood pressure was significantly reduced, which may be due to its deactivating effect on the autonomic nervous system (ANS). However, this effect was not seen until the end of the trial. That is, 20 min postapplication, consistent with the time required for physiological action.

Transdermal absorption of linalool is comparable to the experience of aromatherapeutic massage. Thus, through skin massage and hence absorption, as opposed to inhalation, an aromatic oil may have the possibility of producing deactivating central nervous system effects. It was noted earlier that massage alone has been validated to be physically and emotionally relaxing (Cooke & Ernst 2000). Therefore, massage coupled with transdermal absorption of certain compounds may have some real physiological and psychological benefits.

Proponents of the pharmacological hypothesis also suggest that odorants could exert their effects through direct, immediate, nonconscious interactions with neural substrates. The most critical issue for the pharmacological hypothesis in this respect is receptor-ligand binding. That is, the specific chemical structure of the aromatic compound is critical to the effects produced, and a structure-function relationship must exist between odorant and response. In order to test the structure-function relationship aromatic compounds with different structural properties need to be directly compared, as do molecules that smell identical but which have different chemical/structural composition.

The critical test of whether molecules that smell the same but are chemically different produce the same effects (or not) has not been directly tested. However, as will be further discussed, the fact that many different variants of the same "odors" have been used across laboratories with similar results suggests that it is the psychological perception of the odorant not the chemical structure of the molecule that is important. The structure-function issue has, however, been examined by testing chemically identical molecules with minor differences in molecular orientation. Chirality refers to the fact that subtly different aspects of a molecule's orientation (e.g., mirror images) exist. If odor molecules act pharmacologically then odor chirality will influence the outcomes because the different orientations of chiral molecules means that they will bind differently to the system's receptors.

Olfactory receptors are especially geared towards shape-fit interactions, which is why chiral forms of odor molecules smell different from one another. For example, (+) carvone smells like caraway and (−) carvone smells like spearmint.

Heuberger and colleagues (Heuberger, Hongratanaworakit, Bohm, Weber, & Buchbauer, 2001) examined the structure-function issue by testing how odor chirality for limonene and carvone influenced autonomic and self-evaluation measures of arousal and mood in healthy young adults. Autonomic measures were: skin temperature, pulse rate, breathing rate, and blood pressure. Subjective mental and emotional states were: mood (cheerful-bad tempered), calmness (calm-restless), and alertness (alert-tired). The participants also rated the two chiral forms (enantiomers) for pleasantness (pleasant-unpleasant), intensity (weak-strong), and stimulation (stimulating-tiring) on visual analog scales.

The physiological results showed that (+) limonene led to increased systolic blood pressure, subjective alertness, and restlessness, while (−) limonene caused increases in pulse rate, diastolic blood pressure, and restlessness. Note that the hedonic qualities of (+) and (−) limonene are rather different; (+) limonene is characterized as a fresh citrus orange note, and (−) limonene as a harsh turpentine lemon note. Inhalation of (+) carvone (caraway scent) led to increases in systolic and diastolic blood pressure but had no effects on any of the emotional/mental measures. Inhalation of (−) carvone (spearmint scent) led to increases in pulse rate, diastolic blood pressure, and subjective restlessness. In terms of mental or emotional effects, none of the enantiomers led to distinctive effects on mood or mental states, though individuals responded differently to the various odorants on the hedonic rating scales. Most importantly, correlation analyses showed that both the psychological and physiological effects produced by the odorants could be explained simply by the subjective hedonic evaluations that each odorant received. For example, in the (+) limonene condition, subjective ratings of the fragrance's <u>pleasantness</u> were positively correlated with how <u>alert</u> it made the participants feel, and how much <u>blood oxygen saturation</u> increased during the trial. <u>Intensity</u> ratings to (+) limonene were positively correlated with <u>skin conductance</u> and <u>systolic blood pressure</u> changes (Heuberger et al., 2001). Note too that because enantiomers smell different, perceptual-psychological and structural-chemical factors are confounded, and thus a pure test of structures-function relationships is not achieved.

To this end, Kuroda and colleagues (Kuroda et al., 2005) examined the enantiomeric components of lavender essential oil, (−) linalool and (+)

linalool, and also found different results; (+) linalool is perceived as a sweet floral and (−) linalool is a woody lavender note. Jasmine tea, lavender essential oil, and (−) linalool (a component of both jasmine tea and lavender oil) decreased heart-rate and improved subjective mood, whereas (+) linalool was found to increase heart-rate and negative mood. Notably, the authors stated that the concentrations of (+) linalool and (−) linalool tested were below detection threshold, and therefore subjects could not smell the difference between them, though subjects could smell the odors of jasmine tea and lavender oil.

The Kuroda et al. (2005) results are the most compelling for a structure-function relationship and hence the pharmacological hypothesis because subjects could not smell the different enantiomers of linalool yet physiological and psychological differences were observed. However, in all other studies reviewed the scent of the compounds was perceived and variations of natural and synthetic compounds were used. In addition to confounding the question of structure-function relationships, the issue of chemical inconsistencies across laboratories may also explain why inconsistencies for particular odors were observed across laboratories. For example, although lavender has been generally shown to have relaxing and positive effects on mood, physiological and psychological indices have not been consistent. Goel, Kim, and Lau (2005) found that lavender produced some sleep enhancing physiological effects but had no concomitant mood effects. In contrast, Motomura, Sakurai, and Yotsuya (2001) found that lavender positively influenced mood but had no physiological influences.

The use of certain experimental techniques such as electroencephelograms (EEG) has been interpreted by some (e.g., Diego et al., 1998) as indicating direct neurological responding and hence pharmacological effects. However, this measure is also influenced by psychological factors. Contingent negative variation (CNV) is a central metric used in EEG research. Changes in the participants' CNV magnitude after presentation of an odor as compared to a blank indicate whether the odor has a stimulatory or sedative effect on the brain. Decreases in CNV amplitude indicate a sedative effect and increases in CNV amplitude indicate a stimulatory effect. Torii and colleagues (Torii et al., 1988) examined odor-induced alternation in CNV as a measure of aromatic effects on mood and well-being. Twenty different essential oils were tested by this procedure and most of them produced changes in CNV magnitude that corresponded to their attributed aromatherapeutic effects. For example, jasmine which is said to have stimulatory properties significantly increased CNV magnitude, while lavender which is believed to be sedating led to a decrease in CNV magnitude.

The value of CNV as an indicator of the stimulatory or sedative properties of essential oils has, however, been seriously questioned by Lorig and Roberts (1990) who replicated the study of Torii and colleagues but introduced an additional odor condition. As in the experiments of Torii et al. (1988), changes in CNV after inhalation of jasmine and lavender were measured. Additionally, responses to a mixture of the two fragrances were recorded. Subjects were led to believe that they would be exposed to high or low concentrations of the odors. In the high concentration condition, pure fragrances were administered, while in the low concentration condition, the mixture was used. For the high concentration conditions changes in CNV replicated the findings of Torii et al. (1988), however, in the low concentration condition changes in CNV reflected the subjects *expectation* of odor effects rather than the chemicals that were present; indicating that beliefs and expectation about an odor can crucially influence changes in CNV independent of the odor that is present.

Psychological Hypothesis

The psychological hypothesis proposes that odors exert their effects through emotional learning, conscious perception, and belief/expectation. The central claim of the psychological hypothesis is that responses to odors are learned through association with emotional experiences, and that odors consequently take on the properties of the associated emotions and exert the concordant emotional, cognitive, behavioral, and physiological effects themselves (Herz, 2001, 2004a). Evidence to support the associative learning hypothesis for olfactory emotional and behavioral effects comes from a multitude of studies and has been reviewed in detail elsewhere (see Herz, Beland, & Hellerstein, 2004a; Mennella & Beauchamp, 2005). It has also been shown that the emotions elicited by pleasant and unpleasant odors affect physiological correlates of emotion as expected (Alaoui-Ismaili, Robin, Rada, Dittmar, & Vernet-Maury, 1997; Ehrlichman, Kuhl, Zhu, & Warrenburg, 1997; Miltner, Matjak, Braun, Diekmann, & Brody, 1994). For example, an odor that triggered anxiety elicited electrodermal changes that were consistent with fear but only among participants who had a fearful association to the specific smell (Robin, Alaoui-Ismaili, Dittmar, & Vernet-Mauri, 1998). Physiological effects produced by odors are therefore simply the physiological sequelae of the psychological-emotional responses elicited by the odor, and are expected due to mind-body interactions.

That odors are highly associable and emotionally evocative is consistent with the neuroanatomy of the limbic system. Olfactory efferents have a uniquely direct connection with the neural substrates of emotional and memory processing (Cahill, Babinsky, Markowitsch, & McGaugh, 1995). Only two synapses separate the olfactory nerve from the amygdala, a structure critical for the expression and experience of emotion and human emotional memory; and only three synapses separate the olfactory nerve from the hippocampus, involved in the selection and transmission of information in working memory, short-term and long-term memory transfer, and in various declarative memory functions (Eichenbaum, 2001). Classical conditioning of specific cues to emotion is also mediated by the amygdala (Otto, Cousens, & Herzog, 2000). Moreover, olfactory processing is primarily localized to the orbitofrontal cortex and the orbitofrontal cortex and amygdala have been shown to play a major role in stimulus reinforcement association learning.

A large body of literature indicates that mood can influence behavior. In general, positive mood is linked to an increase in productivity and the tendency to help others (Clark, 1991; Isen, 1984; Wright & Staw, 1999); while negative mood reduces prosocial behavior (Underwood, Froming, & Moore, 1997). Notably, prosocial behavior and productivity are also enhanced in the presence of positive ambient odors. For example, people exposed to pleasant ambient odors in a shopping mall (baking cookies, roasting coffee) were more inclined to help a stranger than people not exposed to an odor manipulation (Baron, 1997). Baron (1990) also found that participants who worked in the presence of a pleasant ambient odor reported higher self-efficacy, set higher goals and were more likely to employ efficient work strategies than participants who worked in a no-odor condition. Conversely, Rotton (1983) found that the presence of a malodor reduced participants' subjective judgments and lowered their tolerance for frustration. Participants in these studies also reported concordant mood changes.

The observed behavioral responses in the presence of pleasant and unpleasant odors are due to the effect that various ambient odors have on an individual's mood. In the research reviewed here, participants who did not show the expected hedonic response did not experience the mood or behavioral change (e.g., Burnett, Solterbeck, & Strapp, 2004). Personal liking or disliking of an odor is directly related to the mood change that occurs. For example, Villemeure and colleagues (Villemure, Slotnick, & Bushnell, 2003) found that only odors that participants self-selected as pleasant were able to improve mood, decrease anxiety and pain unpleasantness, whereas a disliked odor worsened mood and the emotional effects of pain.

Several studies in my laboratory have directly shown how an odor that has been associated to a specific emotional state can later influence behavior in an emotionally consistent manner. Both children and adults who were exposed to a novel odor while engaged in a frustrating experience later showed less motivation to complete an unrelated task when re-exposed to that odor (Epple & Herz, 1999; Herz, Schankler, & Beland, 2004b). These data indicate that emotional experiences associated to odors can in turn influence behavior in a mood congruent way. In sum, through associative learning odors can elicit emotional, behavioral and physiological responses that are equivalent to the responses that an emotionally involving event itself would produce.

Other psychological factors, such as belief and expectation, have significant influences on aromatherapeutic outcomes as well. To illustrate the power of belief and expectation in the creation of aromatic effects, Campenni and colleagues (Campenni, Crawley, & Meier, 2004) conducted a very clever study. Lavender, neroli and placebo (no-odor) and the "suggested" effects of these odors (relaxing, stimulating, none) were examined in 90 female college students. Mood was assessed by the physiological measurements of heart rate (HR) and skin conductance and by a self-report mood questionnaire. Results revealed that regardless of what odor was present, or even whether an odor was there, the suggestion that an ambient odor was "relaxing" decreased HR and skin conductance, and the suggestion that an ambient odor was "stimulating" increased HR and skin conductance. Notably, no self-report changes in mood were seen as a function of odor presence. However over the one-hour course of the experiment, all subjects rated their mood as having improved. It should be underscored that the placebo no-odor condition was able to produce the predicted physiological changes associated with relaxation or stimulation simply by "suggestion," and that lavender which is a culturally denoted "relaxing" odor was able to elicit stimulatory effects when so designated. Knasko (1995) also found that the suggestion of a pleasant odor in a room (when none was there) had positive effects on mood. These findings illustrate that the chemical nature of the odorant itself plays a secondary role in the emotional and subjective changes that occur in the presence of an odor, and that it is the *meaning* of the aroma that induces the consequent psychological and/or physiological responses.

Associative learning, perceptual experience, and expectation can account for the emotional, behavioral, and physiological effects produced by odor inhalation that are reported in Table 1. Thus the psychological hypothesis is currently the best explanatory model for how odors produce emotional, cognitive, behavioral, and physiological responses.

ANALYSIS OF AROMACHOLOGY METHODOLOGY

This section reviews the main methodological issues that need to be considered for the future of aromachology research and discusses problems with the data reviewed here. Although all the studies selected for review met a basic level of scientific legitimacy, there are still methodological problems endemic to this area of research, particularly if one wants to compare results across different laboratories. Statistical issues are also a major factor that must be considered when assessing the validity of aromachology data; the central problem in this area being statistical power (1-ß); the probability of correctly rejecting H_o, the null hypothesis. Cooke and Ernst (2000) analyzed the extant aromatherapy literature and focused on the problem of statistical power in detail, as such the present paper does not do so and the reader is referred to Cooke and Ernst (2000) for further review.

Dependent Measures

The most common dependent measures obtained in the studies reviewed were those involving subjective self-report of mood and mental state. Physiological recordings of autonomic nervous system (e.g., heart rate) or central nervous system (e.g., skin conductance) reactivity were often recorded in addition to, or independently of, subjective emotional states. Less frequently, actual physical, or cognitive performance was behaviorally measured. Rarely was EEG used and neuroimaging has not yet been employed.

The most meaningful data are those where both physiological and psychological measures are taken and correlated with one another. However this was rarely observed in the studies reviewed. For example, Raudenbush, Corley, and Eppich (2001) found that athletic young adults ran faster and did more push-ups in the presence of peppermint aroma, and in a similar study found that peppermint aroma enhanced self-evaluations of vigor and perceived performance on a tread-mill running task (Raudenbush, Meyer, & Eppich, 2002). Regrettably subjective measurements of energy and strength were not obtained in Raudenbush et al. (2001) and in Raudenbush et al. (2002) subjective changes in response to odor exposure occurred but no physiological changes were observed. Motomura et al. (2001) found emotional changes in the presence of lavender odor but no physiological effects, whereas Campenni et al. (2004) observed physiological changes in the presence of lavender and neroli odors but no concomitant changes in reported mood. Diego et al. (1998) found effects on EEG and mood in the presence of lavender and rosemary but they were inconsistent. Both lavender and rosemary increased subjective relaxation among subjects, but EEG evaluation were interpreted as rosemary being stimulating. Kuroda et al. (2005) and Goel et al. (2005) are the only studies reviewed here where both objective and subjective measures of aromatic chemicals were found to correlate as expected.

Physiological recordings are useful for demonstrating changes in physiological reactivity in the presence of odors, but they are only meaningful once they have been correlated with subjective evaluations. There are many different emotional situations that can lead to very similar nervous system changes and only by asking someone what they are feeling do you know whether the person showing heightened heart-rate is *ecstatic, anxious,* or *angry*. The lack of correlation between physiological responses and subjective responses makes the meaningfulness of the physiological recordings alone questionable. Subjective measures alone have more validity because behavioral changes in response to aromas have been shown to be dependent upon subjectively altered mood (Herz et al., 2004b), and unless one has reasons to suspect that participants are lying, subjective reports are a valid measure of internal state (Vincent & Furedy, 1992).

Odorant Characteristics

Aromatherapy makes much of the superior properties of natural versus synthetic chemicals, yet no studies compared natural and synthetic versions of odors to address this claim. Moreover, the studies reviewed here varied widely with respect to whether synthetic or natural chemicals were used and where the odorants were derived from. The lack of consistency with respect to chemical stimuli makes designating effects to specific odorants less achievable.

The perceived hedonic value of the odors tested was, however, found to be important. Burnett et al. (2004) specifically controlled for subjective differences in pleasantness evaluations to the aromatic conditions in their study; lavender, rosemary, and water, without which they would not have seen any effects. Notably, while the majority of participants in the lavender and rosemary groups rated their scent as pleasant, 20% of subjects in the water condition also rated water as somewhat or very pleasant. Bensafi, Rouby, Farget, Bertrand, Vigouroux, and Holley (2002) showed that odor pleasantness predicted HR changes. The more pleasant the odor was rated, the lower the subject's HR. Indeed, odors need to be *liked* in order to produce positive effects on mental states. Villemeure et al. (2003) showed how the subjective evaluation of an odor's pleasantness was directly related to the emotional experience of pain. In their study, subjects experienced painful heat while exposed to various odors. Odors that were self-selected by participants as pleasant improved mood, decreased anxiety and pain unpleasantness, but an odor that the participant disliked worsened mood and the emotional effects of pain. Similarly, Heuberger et al. (2001) examined chemical chirality in relation to subjective and physiological responses and found that odor hedonics could explain most of the results. For example, the more pleasant (−) limonene was judged to be the less calm participants felt, and the more stimulating it was judged to be the more skin temperature decreased. Note, however, that the effects are not predictable as one would assume that the more pleasant an odor was the more calming it would be, and the more stimulating it was the more it would increase ANS responses.

Other subjective aspects of odor perception were also shown to be relevant to the effects that odors can produce. For example, Goel and Lau (2006) found that half of their participants evaluated peppermint as a sedating aroma and the effects of peppermint on sleep were different than among participants who evaluated peppermint as stimulating. Notably, those who rated peppermint as sedating took *longer* to achieve deep sleep, than those who rated it stimulating. Moreover, participants who rated peppermint as very intense had more total sleep time than those who rated it as only moderately intense. Importantly, the authors note that peppermint odor had no effect on sleep physiology when these subjective factors were not considered. Bensafi et al. (2002) found that the more arousing an odor was rated the more skin conductance increased. Ilmberger et al. (2001) who studied the effects of various aromas on reaction time, and included water as a no-odor control, found that the subjective evaluations given to the odors were largely responsible for their effects. A striking illustration of this point is that the more stimulating water was judged to be, the faster participants' reaction times were on a task that measured alertness. How participants interpret the terms "intense," "arousing," and "stimulating" and whether there are any real differences between them is, however, a further concern for this area of research, particularly when comparing data across laboratories.

In the studies reviewed here, there was no analysis of the trigeminal versus non-trigeminal quality (cranial nerve 5, that gives the tactile quality to an odor, e.g., cooling, burning) of the odors tested and how this may influence outcomes. It is highly likely, particularly in the case of stimulating effects such as peppermint, that trigeminal activation is involved. Raudenbush et al. (2002), tested jasmine, peppermint, and dimethyl sulfide for physiological and subjective effects and found that only peppermint enhanced vigor and feelings of enhanced performance. Peppermint is a pleasant odor that also produces a strong trigeminal cooling sensation. Jasmine, a pleasant but nontrigeminal odor, produced effects that trended towards the positive consequences of peppermint but did not reach it. Dimethyl sulfide, an unpleasant and nontrigeminal odor, had neutral effects on subjective and objective measures of mood and energy. In another study, Ilmberger et al. (2001) found that 100 μL cineole, the aromatic chemical responsible for cinnamon scent and a warming trigeminal stimulant, increased reaction time on a test task relevant to alertness, whereas the other odorants in the study did not. Together these findings suggest that the complementary effect of trigeminal activation with certain odors (e.g., peppermint cooling, cinnamon warming) may enhance the associative responses elicited by them, which then augments that odorant's emotional and behavioral output. At present this hypothesis is purely speculative. In order to establish the role of trigeminal activation in the enhancement of various emotional-behavioral effects a variety of odors and test tasks now need to be assessed.

INDIVIDUAL DIFFERENCE FACTORS

Culture

It has already been discussed that odor perception is mediated by learned associations and culture provides a substantial framework upon which this learning takes place. A striking example is the difference between people in Britain and North America for their hedonic responses to the odorant methyl salicylate (wintergreen mint). A comparison of two studies illustrates this point. In the mid-1960s in Britain, Moncrieff (1966) asked adult respondents to provide hedonic ratings to a battery of common odors. A similar study was conducted in the United States in the late 1970s (Cain & Johnson, 1978). Included in both studies was the odorant methyl salicylate (wintergreen). Notably, in the British study, wintergreen was given one of the lowest pleasantness ratings, whereas, in the US study it was given the highest pleasantness rating. The reason for this difference can be explained by history. In Britain, the smell of wintergreen is associated with medicine and particularly for the participants in the 1966 study, with analgesics that were popular during WWII, a time that these individuals would not remember fondly. Conversely, in the US, the smell of wintergreen is exclusively a candy mint smell and one that has very positive connotations.

To this end, the predictive effects of an aroma are limited to the culture(s) in which the acquired associations fit the aromatherapeutic response. Lehrner and colleagues (Lehrner, Eckersberger, Walla, Potsch, & Deecke, 2000; Lehrner, Marwinski, Lehr, Johren, & Deecke, 2005), who conducted their studies in Vienna, found that orange and lavender essential oil produced significant increases in positive mood among people undergoing a stressful situation. Similarly, Kuroda et al. (2005) found that aroma of jasmine tea had relaxing effects on Japanese participants. As a function of the cultural associations that have been learned to orange and jasmine tea among European and Asian populations, respectively, one cannot assume that these effects would necessarily be seen cross-culturally. It has already been shown that there are widely differing hedonic responses to "everyday" odors across cultures (Ayabe-Kanamura et al., 1998). Further research investigating and defining cultural differences in response to specific aromas is now needed.

Experience

Idiosyncratic experiences with odors are a primary cause for unexpected aromatic reactions. Any given individual within a specific culture may not have the predicted response to an odor due to their own personal associations. For example, if one's first association with the scent of rose were at a funeral, one's hedonic and emotional associative responses to that aroma would be negative and the expected positive effects on mood and physiology would not be observed (Herz, 2005). The issue of individualistic hedonic responses to odors was addressed by Villemeure et al. (2003), and as discussed previously only aromas that were self-selected as pleasant had positive effects. The findings of Goel and Lau (2006) also underscore this issue, as subjective differences in the perception of peppermint aroma led to physiological outcomes for sleep only when individual differences were taken into consideration. Thus, if an individual does not like the scent of lavender she will not find it relaxing, regardless of how well and widely lavender aroma has been marketed as "relaxing."

The problem of individual differences is not restricted to psychological effects. Idiosyncratic responses are also a serious mitigating factor for the effectiveness of drugs. Up to 30% of the population, for example, does not respond to the current pharmacopoeia of SSRI's (selective serotonin reuptake inhibitors) used to treat depression. To this end, it is possible that individuals differ genetically in olfactory receptor expression and that this may also have some influence on odor hedonic perception, particularly as it relates to odor intensity. That is, individual differences in odor receptor expression may predispose some individuals to be more or less sensitive to specific chemicals and accordingly may affect susceptibility to learning particular emotional associations to certain odors. When more is learned about how much and what genetic variation in the expression of olfactory receptors exists within the population or within specific ethnic or racial groups (Gilad & Lancet, 2003), better determination of the role of genetics can be made.

Sex Differences

Women are more sensitive than men to odors at certain times during the menstrual cycle (Doty, Snyder, Huggins, & Lowry, 1981), and this varying sensitivity may modulate the effectiveness of aromas on physical and emotional states. Women have also been shown to be more emotionally reactive to odors (Chen & Dalton, 2005), and more susceptible to emotional conditioning with odors (Bell, Miller, & Schwartz, 1992; Dalton, 1999; Kirk-Smith, Van Toller, & Dodd, 1983). To this end, Lehrner et al. (2000) found that women, but not men, experienced less anxiety and a calmer and more positive mood when they were exposed to orange essential oil while waiting for an anxiety provoking dental appointment.

In most of the studies reviewed in this report sex differences were not considered, so an analysis of this issue is limited. However, in an extended replication of Lehrner et al. (2000), Lehrner et al. (2005) tested both orange and lavender essential oil in contrast to a music or no-odor condition and found that both odors were able to improve mood and reduce anxiety equally among men and women. It is unclear why this inconsistency in sex differences occurred or what it means; the authors themselves do not offer any explanation. Goel et al. (2005) and Goel and Lau (2006) also found differences in the way that men and women's sleep was affected by the scents of lavender and peppermint, respectively. However, here too, the effects could not be predicted across experiments. It is most likely that when sex differences are observed they are due to an interaction between psychological and physiological factors. At this time the basis for these differences has not been well elucidated. The degree to which one is susceptible to the emotional connotation of an odor and forming associations to it will modulate the effectiveness of an aroma to influence mood, physiology and behavior. Further aromachology studies now need to explicitly address whether different responses are elicited by men and women, and if they occur, to what aromas and under what conditions.

Personality

There is evidence to suggest that personality can modulate the degree to which odors elicit emotional states. Devriese and colleagues (Devriese et al., 2000) found that neurotic individuals (individuals with high negative affectivity) were more likely to generalize acquired somatic symptoms in response to odors. For example, neurotic participants were more likely to hyperventilate in response to an odor that had not been previously paired with hyperventilation. There is also some evidence that emotionally labile (unstable and emotionally changeable) individuals have greater absolute sensitivity to some smells (Pause, Ferstl, & Fehm-Wolfsdorf, 1998). Most recently, Chen and Dalton (2005) showed that women high in trait anxiety perceived hedonically polarized odors (odors rated as distinctly pleasant or unpleasant) as more intense than a neutral odor, and that men who were high in neuroticism or anxiety detected hedonically polarized odors faster than a neutral odor. In sum, neurotic, labile and anxious individuals may respond more intensely and selectively to emotionally meaningful odors than individuals without these personality traits. Note, however, that the intensified responses of these individuals tends to be toward negative reactivity rather than augmented positivity responses. The issue of neurotic, labile and anxious personality traits also has implications for the disorder of multiple chemical sensitivities. More research is needed to determine whether it is a significant mediating factor in applied aromachology.

SUMMARY

Aromatherapy is a folkloric tradition espousing the beneficial properties of various plant-based aromas on mood, behavior, and “wellness.” Aromachology is a term that was coined by the Sense of Smell Institute and designates only olfactory effects that have been scientifically demonstrated to affect mood, physiology and behavior. For the purposes of the present review valid aromachology research was defined by the following five criteria: (1) theory guided goals and clear hypothesis testing, (2) fragrances are tested using appropriate experimental methodology, (3) sufficient and representative participant populations and appropriate contrasting control groups are used, (4) data are analyzed using suitable statistical methods and indicate adequate statistical power, and (5) the results have been vetted by scientific peers and accepted for publication in reputable journals. Eighteen studies that met the criteria for aromachology were reviewed in detail for this report. The results indicated that various odors can significantly affect mood, cognition, physiology and behavior, though inconsistencies between dependent measure and laboratories were observed. An analysis of the two theoretical mechanisms that have been proposed to explain these effects (pharmacology or psychology), concluded that a psychological explanation could best account for the data obtained in the studies reviewed here. The *perceived* quality of the odor was the most relevant factor for determining how an individual would respond to it both emotionally and physiologically. The methods that were used in the various aromachology studies were analyzed to explore the problems and inconsistencies that were observed. A central finding was a lack of consistency in the specific chemicals used to evaluate the effects of a particular odor (e.g., natural, synthetic, isomeric molecules). As such, validation and generalization of the effects of odors is currently limited. Several factors were also found to mitigate and modulate the responses elicited to an odor including culture, experience, gender, and personality. At present more consistent methodological practice and further research is needed to fully elucidate how, under what conditions, and to whom, specific aromatic chemicals can alter mood, physiology and behavior.

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