EXAMINING THE DIFFERENTIAL EFFECTS OF NATURAL AND SYNTHETIC AROMAS OF LAVENDER AND PEPPERMINT ON COGNITION, MOOD, AND SUBJECTIVE WORKLOAD

by

JAMIE LYNN CAVANAUGH

B.A., University of Wisconsin-Milwaukee, 2007

A thesis submitted to the Faculty of the Graduate School of the University of Colorado in partial fulfillment of the requirements for the degree of Master of Arts Clinical Psychology 2013
This thesis for the Master of Arts degree by

Jamie Lynn Cavanaugh

has been approved for the

Clinical Psychology Program

by

James P. Grigsby, Chair

Sondra Bland

Mary Coussons-Read

July 22nd, 2013
ABSTRACT

There is reliable, empirical evidence that various inhaled aromas can significantly affect mood, cognition, physiology and behavior (Herz, 2009). However, the literature often does not document whether natural or synthetic fragrances were used when evaluating these factors. Also, no studies to date have compared natural and synthetic versions of the same odors. The current study attempted to determine whether the natural aromas of lavender and peppermint were superior to their synthetic counterparts in terms of measurable differences in cognition, mood, and subjective workload among 180 college students. Specific Aim 1 compared the inhalation of natural fragrances to the inhalation of synthetic fragrances on measures of cognitive function. Specific Aim 2 addressed whether the inhalation of natural fragrances, as opposed to synthetic fragrances, was associated with greater group differences on a measure of self-reported mood. Finally, Specific Aim 3 compared the inhalation of natural fragrances to synthetic fragrances with respect to their ability to decrease subjective workload and increase subjective performance. This Aim also assessed whether subjective workload was a mediator of cognition and mood. The initial results from this study reinforced the assertion that fragrances are capable of altering cognition, with further evidence revealing that the natural aroma of peppermint is superior to its synthetic counterpart in bringing about these changes. However, after performing a statistical correction for conducting multiple comparisons, these results largely do not remain significant. Combined with small effect
sizes, this study was unable to provide conclusive evidence to support the statement that natural aromas are superior to their synthetic counterparts in terms of their ability to alter cognition, mood, and subjective workload.

The form and content of this abstract are approved. I recommend its publication.

Approved: James P. Grigsby
# TABLE OF CONTENTS

## CHAPTER

I. INTRODUCTION .................................................................................................................. 2  
   Literature Review .................................................................................................................. 2  
   Purpose of the Present Study .............................................................................................. 15  

II. METHODS ........................................................................................................................... 17  
   Subjects ................................................................................................................................ 17  
   Materials ............................................................................................................................... 18  
   Procedure .............................................................................................................................. 22  
   Statistics ................................................................................................................................ 23  

III. RESULTS ............................................................................................................................ 25  
   Cognition ............................................................................................................................... 25  
   Mood .................................................................................................................................... 30  
   Subjective Workload ............................................................................................................ 31  

IV. DISCUSSION ....................................................................................................................... 34  
   Conclusions ........................................................................................................................... 34  
   Limitations ............................................................................................................................ 38  
   Future Directions .................................................................................................................. 39  

REFERENCES .......................................................................................................................... 41
CHAPTER I

INTRODUCTION

Aromatic herbs have been used for centuries for their mind-altering properties. The ancient Egyptians, Greeks, and Romans also employed various plant oils for religious and cosmetic purposes (Burnett, Solterbeck, & Strapp, 2004; Moss, Hewitt, Moss, & Wesnes, 2008). Aromatherapy, the utilization of these aromatic, plant-based compounds for their purported effects on an individual's mind, mood, cognitive function and health, has been recognized as one of the most popular forms of alternative medicine since the 1920's (Herz, 2009; Moss et al., 2008). Aromatherapists use highly concentrated essential oils that have been extracted from different parts of plants (e.g. leaves, flowers, roots), depending on which component is believed to contain the beneficial property. Each oil is believed to produce reliable and predictable effects on psychological states when inhaled (Moss, Cook, Wesnes, & Duckett, 2003; Moss et al., 2008; Diego et al., 1998). Until recently, however, there has been little empirical support for the use of plant essences as a therapeutic modality (Diego et al., 1998; Moss et al., 2008).

Literature Review

Over the past few decades, scientists have begun studying the olfactory effects of aromas. The Sense of Smell Institute coined this field of research “aromachology” in 1982 (Herz, 2009), in which the goal is to evaluate whether and how the inhalation of aromatic chemicals can influence mood, physiology, and behavior. Aromachology research must meet the following empirical criteria: (1) theory-guided goals and clear hypothesis testing are employed, (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 accepted for publication in reputable, peer-reviewed journals (Herz, 2009). A recent metaanalysis of 18 studies that fit the above criteria revealed reliable, empirical evidence that various inhaled aromas can significantly affect mood, cognition, physiology, and behavior (Herz, 2009).

According to the National Association for Holistic Aromatherapy, sales of aromatherapy-related products in the United States in the year 2000 exceeded $1 billion dollars (Burnett et al., 2004). There has been a concurrent rise in the number of products containing synthetic aromas in the cosmetic, fragrance, and food industries. These products, including air fresheners, perfumes, oils, and lotions, often state that they are ‘infused with an essential oil’ or are ‘scented’ like a natural plant fragrance. However, these statements do not equate to containing completely pure ingredients. The fragrance industry uses synthetic aromas that are developed in a laboratory to mimic the aromatic and chemical constituents of natural, plant-based oils. Although, according to Moss, Howarth, Wilkinson, and Wesnes (2006), “The unique combinations of hundreds of constituents ensure that synthetic alternatives are a near impossibility to create” (p. 64).

Some recent evidence suggests that the inhalation of certain synthetic fragrances may be harmful to humans. A recent analysis of six top selling laundry products and air fresheners that utilized synthetic fragrances found “nearly 100 volatile organic compounds were emitted from the products and five of the six products emitted one or more carcinogenic hazardous air pollutants which the Environmental Protection Agency considers to have no safe exposure level,” (De Vader, 2010, p. 3). Unfortunately, these
synthetic fragrances are difficult to identify, as the Food and Drug Administration currently only requires the word ‘fragrance’ to be listed in the ingredients label to comply with regulations. The fragrance industry has begun manufacturing products that are ‘non-scented’ due to increasing numbers of people with allergies to synthetic chemicals. Lyral, an artificial odor used in many cosmetic and toiletry products, is now being included in routine European allergy patch tests due to the large number of people who have developed contact dermatitis after using products containing the chemical (Bruze, Anderson, & Goossens, 2008). This is concerning, considering corporate offices, shopping malls, and some doctors’ offices have begun using artificial fragrances to influence employees’, shoppers’, and patients’ behavior. Synthetic aroma diffusion systems have been developed for the Mirage, Treasure Island, Monte Carlo and Bally’s Resort Hotels in Las Vegas under the assumption that certain aromas could influence gamblers’ behavior (Chebat, 2003).

Thus, synthetic fragrances may not contain the beneficial aspects of natural plant-based essential oils and could even be unsafe for human consumption. Unfortunately, many studies in the literature do not document whether natural or synthetic fragrances were used when evaluating cognition, mood, physiology, etc., making it difficult to compare results. Since natural oils are more expensive to manufacture than their synthetic counterparts, the artificial aromas are more likely to be used. Herz (2009) states that, “Aromatherapy makes much of the superior properties of natural versus synthetic chemicals, yet no studies have compared natural and synthetic versions of odors to address this claim” (p. 280).
Lavender is one of the most popular fragrances used in commercial aromatherapy (Burnett et al., 2004). The plant is a floral, sweet-smelling, aromatic herb that has been used for centuries for its many beneficial functions including anti-microbial, anti-bacterial, anti-fungal, anti-colic, and anti-inflammatory properties, as well as being a smooth muscle relaxant (Cavanagh & Wilkinson, 2002). The use of lavender oil as a healing agent against burns was discovered by the French chemist Rene-Maurice Gattefosse in the late 1920’s. He burned his hand in a laboratory explosion and immediately soaked the burn in pure lavender oil. He noticed that his hand healed rapidly. This incident lead to his long-term study of various essential oils, as well as his coining of the term “aromatherapie” (Herz, 2009). However, lavender is most commonly known for its reputation as a calming aroma that alleviates anxiety, stress, insomnia and depression (Diego et al., 1998; Buchbauer, et al., 1991; Moss et al., 2003; Kuroda et al., 2005; Cavanagh & Wilkinson, 2002).

Lavender essential oil has been studied extensively regarding its effects on cognition, mood, and to a lesser extent, subjective workload. Moss et al. (2003) evaluated cognition and mood in 144 college students who inhaled lavender essential oil. Subjects completed a pre-aroma exposure mood questionnaire to obtain baseline indices of alertness, calmness, and contentedness using the Bond-Lader visual analogue scales (VAS). The subjects then entered a lavender-scented room to complete a computerized test battery often used in pharmacological trials to detect minimal cognitive changes. Following completion of the battery, subjects remained in the scented room to complete the post-aroma mood scales. The authors report that the lavender group scored significantly lower than the control group on composite measures of working memory,
speed of memory, and speed of attention. Participants in the lavender group also reported feeling significantly more content than the control group. Subjects were deceived regarding the purpose of the aromas present in the testing room to eliminate potential expectancy effects. Another study in which subjects were again unaware that a lavender aroma was present found that the lavender group had a significantly lower error rate on a letter counting task than controls, but no difference was found on a mathematical test. It is not stated whether natural or synthetic fragrances were used in this study (Degel & Köster, 1999). Very few studies have evaluated lavender’s effect on subjective workload. One study by Neale, Moss, and Moss (2008) found that subjects who completed a multi-tasking activity did not differ significantly on measures of cognition, mood (via the Bond-Lader VAS), or subjective workload (via the NASA-Task Load Index (TLX)) while exposed to either pure lavender or air. However, the study sample was small (11 subjects) and was composed primarily of women.

The cognitive and mood effects of lavender aroma have also been studied in real-world settings. Sakamoto, Minoura, Usui, Ishizuka and Kanba (2005) aimed to discover the effects of inhaling lavender on work performance. Thirty-six male subjects were exposed to either natural lavender or jasmine aromas or no aroma during 30-minute recesses from five one-hour blocks of performing a tedious task requiring constant concentration. As hypothesized, the time of least concentration (measured by the highest rates of error and longest reaction times) was in the afternoon session (2:30-3:30 pm). During this block, reaction times and tracking errors were significantly lower for the lavender group compared to the control group. Another study by Lehrner, Marwinski, Lehr, Johren and Deecke (2005) compared a natural lavender odor, natural orange odor
(another aroma thought to act as a sedative), music, and control group to determine whether any of the conditions could reduce anxiety and improve mood among patients awaiting various dental procedures. Two hundred consecutive patients completed the State-Trait Anxiety Inventory (STAI) and a VAS to evaluate current mood, alertness, and calmness. Exposure to diffused lavender or orange aromas significantly reduced state anxiety, increased calmness, and improved mood compared to the music and control groups. Finally, Holmes et al. (2002) conducted a placebo-controlled study evaluating the effect of inhaled natural lavender on 15 patients meeting the criteria for severe dementia with agitated behavior. Ten days of alternation between diffused lavender and water placebo resulted in 60% of the patients showing a decrease in agitated behavior as measured by a blind observer on the Pittsburgh Agitation Scale. These results are substantial, considering 20% of individuals over age 80 are diagnosed with dementia, and of those, 18-65% have agitated behavior (Holmes et al., 2002).

Lavender inhalation has also been found to produce physiological changes that correlate with cognitive and mood alterations. Diego et al. (1998) evaluated electroencephalogram (EEG) measures in 40 adults after the inhalation of natural lavender for three minutes and found increased frontal alpha and beta 2 power compared to their pre-inhalation levels. The authors suggest that these findings can be interpreted as evidence of drowsiness, since decreases in cortical arousal often lead to sedation or relaxation. Consistent with the EEG findings, subjects in the lavender group reported feeling more relaxed and less depressed on the Profile of Mood States (POMS) questionnaire and less state anxiety on the STAI compared to their pre-aroma scores. These same subjects also performed faster and more accurately on a simple math
computation test after the inhalation of lavender. The authors suggest that the increased performance on the math test may have been due to lavender’s ability to induce relaxation, and thus potentially increase concentration. A similar study (Field et al., 2005) using a small sample of 11 subjects found that the inhalation of a lavender-based shower gel induced similar cognitive, mood and physiological results as Diego et al. (1998).

These findings are consistent with animal models, which have shown that inhalation of lavender oil acts postsynaptically, where it is suggested to modulate the activity of cyclic adenosine monophosphate (cAMP), a neurotransmitter associated with sedation (Lis-Balchin & Hart, 1999; Lehrner et al., 2005). Also, lavender is thought to enhance gamma-aminobutyric acid (GABA) activity in brain regions (specifically the amygdala), similar to the mechanism of benzodiazepines (Cavanagh & Wilkinson, 2002). In addition, (±)-linalool, one of the main chemical components of lavender, has been shown to inhibit glutamate binding in the rat cortex, which is the main excitatory neurotransmitter in the central nervous system (Elisabetsky, Marschner, & Souza, 1995). Other studies have found that acetylcholine release is inhibited by altering ion channel function at neuromuscular joints after the inhalation of lavender, while others have found both lavender and its major constituents (linalool and linalyl acetate) act as local anesthetics (Cavanagh & Wilkinson, 2002).

Peppermint is another aroma that has been shown to possess cognitive, mood, and subjective workload effects. Moss et al. (2008) compared the natural odors of peppermint and ylang ylang to a no-odor control group. Using the same methods and measures as their 2003 study, the authors found that the peppermint group scored
significantly higher than the control group on quality of memory, with a trend toward significance on measures of alertness. Another study (Barker et al., 2003) examined the effect of peppermint essential oil on memory, typing, and alphabetizing. Twenty-six participants fulfilled the within-subjects design, in which subjects completed the measures once under the influence of peppermint odor and once under a no-odor condition. The authors found that after inhaling peppermint, subjects were significantly faster on measures of mean gross typing speed, net typing speed, typing accuracy, and alphabetization. No significant results for the memory task were found, however the authors note that the method used to measure memory (Milton Bradley’s Simon® game) may not have been an optimal assessment. Warm, Dember and Parasuraman (1991) found that the inhalation of peppermint essential oil led subjects to correctly identify approximately 20% more target symbols in a visual sustained attention task compared to no-odor controls, indicating greater accuracy and vigilance. One study utilizing synthetic peppermint evaluated performance on a visual sustained attention task as well as a tactile discrimination task in 16 subjects. The combination of the tasks involved both easy and difficult components. The synthetic peppermint improved performance on the difficult combination of tasks, but not the easy tasks. The authors suggest that their results might be due to peppermint’s ability to aid task performance only when tasks are difficult, but it is also possible that the easy task had negative results due to the synthetic nature of the peppermint oil (Ho & Spence, 2005).

Similar to lavender, many real-world applications have been studied after the inhalation of peppermint. Raudenbush, Grayhem, Sears and Wilson (2009) evaluated 36 subjects who inhaled natural peppermint odor, natural cinnamon odor, and no odor to
determine the differential effects on mood and subjective workload while participating in a simulated driving task. Subjects’ scores on the POMS indicated significantly less anxiety and fatigue during the peppermint condition compared to scores in the other two conditions. Temporal demand and frustration, assessed by the NASA-TLX, were significantly lower when inhaling peppermint compared to the no odor condition. While under the peppermint condition, subjects also reported feeling significantly more alert on a VAS. These results confirm those from an earlier study by the same authors which also found that the inhalation of natural peppermint oil compared to no-odor controls led subjects to experience a higher level of vigor and lower level of fatigue on the POMS, as well as reduced subjective physical and temporal workload, effort, and frustration and increased perceived performance on the NASA-TLX (Raudenbush, Meyer & Eppich, 2002).

Physiologically, peppermint has been shown to be an alerting fragrance. Goel and Lao (2006) recruited 21 healthy sleepers to evaluate the effect of the inhalation of peppermint essential oil on polysomnography, alertness, and mood. In comparison to measures taken on a no-odor control night, subjects’ scores on the POMS indicated significantly less fatigue and higher mood levels immediately after inhalation. Sleep measures covaried with subjects’ subjective evaluation of the scent’s intensity, and mood measures covaried with subjects’ gender. The authors suggest that subjects’ perception of the fragrance may have led to differential activation of neural substrates. Similar to lavender, peppermint appears to affect cAMP modulation (Lis-Balchin & Hart, 1999; Moss et al., 2008). Inhalation of peppermint has also been shown to decrease theta activity, and increase EEG speed and heart rate during sleep (Goel and Lao, 2006). It is
hypothesized that the mechanism of peppermint’s alerting action works via connections from the olfactory bulb and the midbrain reticular activating system, thought to be responsible for maintaining and regulating vigilance (Warm, Dember, & Parasuraman, 1991; Raudenbush et al., 2009).

One explanation for the similar effects of these two seemingly contradictory aromas on cognition, mood, and subjective workload could be related to their impact on levels of arousal. According to the Yerkes-Dodson law, level of arousal is directly related to performance as an inverted-U function (Yerkes and Dodson, 1908). The law postulates that a moderate level of arousal is the most effective at eliciting an individual’s peak performance (Degel & Köster, 1999). Lower levels of arousal can lead to boredom, whereas extremely high levels of arousal can lead to distracting anxiety. It is hypothesized that alerting fragrances such as peppermint can positively affect performance on tedious tasks requiring high levels of concentration by increasing arousal. On the other hand, relaxing fragrances (i.e., lavender) might attenuate the stress and anxiety felt under conditions that involve high levels of mental activity by decreasing stimulation levels (Warm, Dember & Parasuraman, 1991). Sakamoto et al. (2005) and other investigators mention in their studies the possibility that this mechanism of action is responsible for the observed changes in cognition, mood, and subjective workload after the inhalation of either lavender or peppermint (Moss, 2008).

The literature offers two theories to explain why aromas have certain cognitive, physiological and psychological effects (Herz, 2009; Moss et al., 2003, 2008; Kuroda et al., 2005; Burnett et al., 2004). First, the pharmacological hypothesis states that the effects that various aromas have on mood, physiology and behavior are due to the odor’s
direct ability to interact with and affect the different systems in the body, including the nervous and endocrine systems (Herz, 2009; Burnett et al., 2004). These effects are proposed to act through “direct, immediate, nonconscious interactions with neural substrates,” (Herz, 2009, p. 273). Olfactory receptors are especially geared towards shape-fit interactions (Herz, 2009); there are some 1,000 types of odorant receptor cells in humans, and each receptor has a slightly different structure than the next (Bear, Connors, & Paradiso, 2001). Thus, the exact chemical structure of each aroma is necessary to produce specific effects, and a structure-function relationship must exist between each individual aroma and the associated response (Moss et al., 2008). Upon inhalation, an aroma will activate a specific set of receptors that show a preference for the odorant; the pattern of receptors that is fired is then recognized by the olfactory bulb. From there, the information passes through the cerebral cortex, the thalamus, and finally the neocortex. Due to this path of transduction, information from aromas likely does not reach conscious perception in the orbitofrontal cortex until it has first passed through the cerebral cortex and the thalamus (Bear et al., 2001). Thus, the physiological effects of an odorant are hypothesized to influence cognition and mood due to neural connections rather than conscious perception of the scent (Burnett et al., 2004). This mechanism could explain why different essential oils produce varied somatic and psychological effects.

Supporting the pharmacological hypothesis is the concept of chiral molecules: molecules that contain the same atomic makeup, yet are mirror images of each other (Kuroda et al., 2005). In pharmaceutical drugs, using a molecule’s mirror image (also termed its enantiomer), often leads to less active or inactive drugs, or unwanted side
effects. Kuroda et al. (2005) examined the enantiomeric components of lavender essential oil, (R)-(-) linalool and (S)-(+) linalool. Inhalation of (R)-(-) linalool decreased heart rate and improved subjective mood, whereas (S)-(+) linalool increased heart rate and negative mood in subjects. Since chiral molecules often smell different from each other, both scents were below detection threshold so as to avoid potential subjective responses to each fragrance. In aromachology, the concept of chirality can be likened to using a synthetic fragrance in place of its essential oil counterpart. Steiner (1994) studied the differential effects of natural and synthetic rose and jasmine aromas using skin conductance as an indicator of sympathetic nervous system arousal. Electrodermal activity of the synthetic rose and jasmine aromas was significantly lower than that of the corresponding natural products, indicating a lower physiological response. Thus, the authors suggest that these results provide evidence to support the pharmacological hypothesis.

In contrast to the pharmacological hypothesis, the psychological hypothesis maintains 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,” (Herz, 2009, p. 276). Thus, this hypothesis proposes that odors’ effects are conditioned through emotional learning, conscious perception, and expectations (Herz, 2009). The neuroanatomy of the limbic system lends support to this hypothesis, as it is closely connected to the olfactory system (Diego et al., 1998). Only two synapses separate the olfactory nerve from the amygdala, a structure critical for the expression and experience of emotional memory, including classical conditioning (Lehrner et al., 2005).
Only three synapses separate the olfactory nerve from the hippocampus, which is involved in various types of memory (Herz, 2009).

To test the psychological hypothesis, Campenni, Crawley, and Meier (2004) studied whether expectancy effects would be observed when examining self-reported mood, heart rate, and skin conductance. Ninety female subjects inhaled synthetic lavender, neroli, or no odor, and each group was told that they would experience a relaxing, stimulating, or no effect. An expectancy effect was found for the physiological measurements of heart rate and skin conductance, even for the no odor group, such that being told an odor had arousing properties reliably increased these autonomic measures, and vice versa. No effects were seen across groups and conditions regarding self-reported mood changes. While the authors suggest that these results confirm the psychological hypothesis, it could also be due to the fact that synthetic aromas were used. In contrast to this theory, when other methods of consumption are utilized other than inhalation so that expectancy effects are mitigated, lavender has had the expected sedative effect. Heuberger, Redhammer, and Buchbauer (2004) found that the transdermal application of (-)-linalool decreased systolic blood pressure and showed less of a decrease in skin temperature compared to controls (i.e., less negative mood). A randomized, double blind study compared the ingestion of lavender-filled capsules to a common benzodiazepine (lorazepam) to examine the effects on patients with Generalized Anxiety Disorder (Woelk & Schlafke, 2010). Results showed that the lavender-filled capsules were equally as effective as lorazepam at decreasing scores on the Hamilton Anxiety Rating Scale without any sedative side effects or the potential for abuse.
Purpose of the Present Study

The use of fragrances, both natural and synthetic, has become ubiquitous. It is important to determine whether there are discernable differences between natural and synthetic oils that may impact important outcomes. This study attempted to show that the natural aromas of lavender and peppermint have superior properties compared to their respective synthetic counterparts in terms of cognition, mood, and subjective workload.

Specific aim 1. To compare the effects on cognition after inhalation of natural fragrances compared with the inhalation of synthetic fragrances.

Hypothesis 1. The inhalation of natural peppermint will be associated with higher mean scores on measures of inhibition, accuracy, error detection, implicit learning, verbal learning, and delayed memory than will the inhalation of synthetic peppermint. Similarly, lower mean scores will be found on measures of processing speed and reaction time.

Specific aim 2. To evaluate the effects of inhalation of natural fragrances, compared to synthetic fragrances, on a measure of subjective mood.

Hypothesis 2. Inhalation of natural lavender and peppermint compared to inhalation of synthetic lavender and peppermint will be associated with greater difference scores on the Bond-Lader VAS factors of calmness, contentedness, and alertness.

Specific aim 3. To compare the ability of natural fragrances versus synthetic fragrances to decrease subjective workload, and to assess whether subjective workload is a mediator of cognition and mood.

Hypothesis 3a. Inhalation of natural lavender and peppermint compared to synthetic lavender and peppermint will lead to lower mean scores on the NASA-TLX
sub scales of mental demand, physical demand, temporal demand, effort, and frustration, with higher mean scores on the performance subscale.

_Hypothesis 3b._ Lower scores on the NASA-TLX subscales of mental demand, physical demand, temporal demand, effort, and frustration, as well as higher scores on the performance subscale, will correlate with higher mean scores on cognitive measures of processing speed, inhibition, reaction time, accuracy, error detection, implicit learning, verbal learning, and delayed memory.

_Hypothesis 3c._ Lower scores on the NASA-TLX subscales of mental demand, temporal demand, physical demand, effort, and frustration, as well as higher scores on the performance subscale, will correlate with higher scores on the Bond-Lader VAS factors of calmness, contentedness, and alertness.
CHAPTER II

METHODS

Subjects

A power analysis requiring a medium effect size (.25) and a standard alpha level (.05) found that 40 subjects would be needed in each group to achieve an acceptable power of .8 (G*Power 3.1, Faul, Erdfelder, Lang, & Buchner, 2007). Thus, these calculations suggested that a total sample of 200 volunteers will be adequate to address the Aims and Hypotheses of this study.

Participants were recruited from psychology classes on the University of Colorado Denver campus. Subjects were asked to help determine the effects of environmental stimuli on cognition, mood, and subjective workload. Exclusion criteria included allergies to natural or synthetic fragrances, anosmia (the inability to perceive smells), current or recent cigarette smoking, and current pregnancy.

A total of 183 subjects completed the study over the course of five semesters. Three subjects’ data were not included in the database for the following reasons: two subjects’ participation was discontinued during the study after revelations that they smoked cigarettes, and one subject’s data was not included in the database after discovering they had knowledge of the study aims, including the use of fragrances.

Each scented group was composed of forty subjects, while the control group had twenty participants; thus, the total number of subjects whose data was evaluated was 180. Subject demographics can be found in Table 1. No significant differences between the five groups’ age or gender were found.
Table 1. Subject demographics.

<table>
<thead>
<tr>
<th>Group</th>
<th>Gender (F, M)</th>
<th>Age (M (SD))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural Lavender</td>
<td>25 (15)</td>
<td>22.16 (3.99)</td>
</tr>
<tr>
<td>Synthetic Lavender</td>
<td>31 (9)</td>
<td>22.13 (3.71)</td>
</tr>
<tr>
<td>Natural Peppermint</td>
<td>33 (7)</td>
<td>24.15 (6.38)</td>
</tr>
<tr>
<td>Synthetic Peppermint</td>
<td>33 (7)</td>
<td>21.91 (3.22)</td>
</tr>
<tr>
<td>Control</td>
<td>11 (9)</td>
<td>24.91 (6.22)</td>
</tr>
</tbody>
</table>

Materials

Aromas.

The natural aromas, plug-in oil diffuser, and diffuser pads were purchased from Aura Cacia (www.auracacia.com), a company which sells only natural essential oils. The synthetic aromas were purchased from saveonscents.com. A call was made to a customer service representative at this company to ensure the scents being purchased were entirely synthetic. Four ounces of each fragrance were purchased to mitigate any differences between batches of scents.

Instruments.

Cognition.

*Paper and pencil measure.* The Rey Auditory Verbal Learning Test (RAVLT; Spreen & Strauss, 1998) was used to assess verbal learning and delayed memory. This test consisted of a list of fifteen unrelated concrete nouns repeated five times (the learning trials). An interference trial was then administered, in which a second list of fifteen nouns was read. This was followed by an immediate recall trial of the original list of words. Following a 20-30 minute delay, a delayed recall trial was administered in which
the subject freely recalled as many of the original fifteen words as possible. Outcome measures computed from the RAVLT included the number of words correctly recalled on the final learning trial, across all five learning trials, the interference trial, and the delayed recall trial. One final outcome measure was included: the delayed recall percentage score, calculated by using the number of words recalled after the delay in the numerator and the number of words recalled after the fifth learning trial in the denominator. The RAVLT took approximately five minutes to administer.

*Computerized battery:* The SuperLab battery was devised by Grigsby, Kookan, and Bollwerk in the Neuropsychology Laboratory at the University of Colorado Denver. The computerized battery contained three tests that primarily use visual stimuli to tap into domains of executive function (processing speed, inhibition, accuracy, error detection, implicit learning and reaction time), since studies show these cognitive areas are affected by the inhalation of both lavender and peppermint.

The Sustained Attention to Response Task (SART) was administered as a measure of attention, inhibition, reaction time, and accuracy according to the protocol used by Manly (2003). Two hundred twenty-five digits between one and nine were randomly presented and the subject was required to press the spacebar on the keyboard as quickly as possible in response to each digit, with the exception of threes, on which there should be no response. Subjects were instructed to give equal importance to accuracy and speed of response. Comission (responding to the number nine) and omission (failure to respond to numbers one-eight) errors were computed as outcome measures, as well as the total time to complete the subtest.
A computer-adapted version of the Stroop test was administered that requires participants to quickly and correctly name congruent- and incongruent-colored words. Three trials were administered, and four colored keys were present on the keyboard. In the first trial, color congruent words were presented such that the color of the ink matched the printed word. Subjects pressed the key that matched both the color and text of the word as quickly as possible. The second trial was a presentation of XXXX’s that were in one of the four colors. Subjects again pressed the key that matched the color of the XXXX’s as quickly as possible. The third trial displayed non-congruent colored words: the ink did not match the text. The time and error score on this interference trial were used as a measure of processing speed, inhibition, reaction time, and accuracy, as well as the total time to complete the subtest.

The Serial Reaction Time Task (SRT) was a test of implicit learning via visuospatial attention that also assessed processing speed and reaction time. The four-choice task contained a repeating sequence of responses that subjects unconsciously learned to predict over time, thus decreasing the time required for performance of those sequences compared with randomly distributed stimuli. The Sequence and Random times and errors were the outcome measures, as well as the total time necessary to complete the subtest.

The entire computerized battery took approximately 15-20 minutes to complete. Total time to complete all three subtests was evaluated as an outcome variable.

Mood.

Pre- and post-aroma mood status was evaluated using the Bond-Lader Visual Analogue Scales. The scales were paper and pencil measures originally designed to
assess the mood effects of anxiolytics that have been utilized in numerous psychopharmacological and medical trials; high reliability and validity have been demonstrated (Bond & Lader, 1974). There were 16 100-mm lines anchored at each end by dichotomous mood-related words. Subjects marked their current subjective mood state on each line. Current mood was scored by measuring the number of millimeters from the left-hand side to the subject’s mark. These scores were used to calculate three composite measures derived from factor analysis. Bond and Lader (1974) described these measures as: "calmness" (calm–excited, tense–relaxed), "contentedness" (contented–discontented, troubled–tranquil, happy–sad, antagonistic–friendly, withdrawn–sociable), and "alertness" (alert–drowsy, attentive–dreamy, lethargic–energetic, fuzzy–clearheaded, well-coordinated–clumsy, mentally slow–quick witted, strong–weak, interested–bored, incompetent–proficient). Total scores for each factor were the average sums of the number of millimeters (maximum 100 mm) from each individual scale contributing to the three composite measures. Completing both the pre- and post-aroma mood scales took approximately ten minutes.

**Subjective workload.**

The NASA-Task Load Index (Hart & Stavenland, 1988) is a measure used to assess participants’ subjective workload associated with a variety of demanding tasks. The brief survey included six subscales: mental demand, physical demand, temporal demand, performance, effort, and frustration. The first three subscales assessed how demanding the participant perceived the given task to be. The last three subscales assessed the interaction between the participant and the task. The questionnaire was in VAS format. Subjects indicated their perceived level of mental demand, effort, etc., by
placing a hash mark on a 120mm line between the qualifiers “Very high” and “Very low” (“Very Good” and “Very Bad” on the Performance scale). The distance from the left-hand side to the subjects’ response was taken as the raw score. Completion of this measure took approximately five minutes.

Procedure

Interested participants contacted the Neuropsychology Laboratory to complete an initial screening form regarding demographic information and exclusion criteria. The screening form also included distracting questions so as not to alert subjects to the importance of the aromas, e.g. Do fluorescent lights give you headaches? Are certain sounds overly distracting to you? etc. Qualified subjects were then scheduled to come to the Neuropsychology Laboratory at the University of Colorado Denver for a one-hour appointment.

Before subjects arrived, they were assigned to one of the five groups: natural lavender, synthetic lavender, natural peppermint, synthetic peppermint, or the no-odor control group, with scent condition randomized across day and researcher as much as possible. Different scent conditions were administered on different days of the week to ensure no cross-contamination of aromas occurred. A window was opened after each participant to avoid an accumulation of the scent. For aroma groups, four drops of the fragrance were placed on a diffuser pad, which was then inserted into the plug-in wall diffuser five minutes before the subject’s appointment. Scents were above detection threshold and equivalent in strength according to three independent observers, determined before the beginning of the study.
Upon entering the main, unscented lab room, participants were asked to give informed consent, which was approved by the Colorado Multiple Institution Review Board (protocol #11-1291). A short quiz was administered to ensure comprehension of the informed consent. After finishing the enrollment process, subjects completed the Bond-Lader VAS as a measure of pre-aroma alertness, calmness, and contentedness. Following completion of this brief questionnaire, subjects were led into the scented or unscented testing room. Subjects who commented about the scent were casually told that an air freshener was present in the room.

The cognitive battery was then administered to the subjects. Following completion of the cognitive battery, the Bond-Lader VAS was administered again to obtain post-aroma mood measures. The NASA-TLX was then administered to assess subjects’ subjective evaluations of workload. Finally, after leaving the scented room, subjects were asked a number of questions as a manipulation check to determine whether a fragrance was noticed in the room. Distracting questions were asked regarding lighting, sound, etc.

Statistics

A one-way analysis of variance (ANOVA) was conducted to determine whether significant differences existed between the five groups on all cognitive, mood, and subjective workload outcome measures. Significant differences were further evaluated using Tukey’s HSD pairwise comparison to determine which groups were significantly different from each other. When the assumption of homoscedasticity was violated (via Levene’s test), Welch’s F statistic and significance were reported. In these conditions,
post-hoc analyses were computed using the Games-Howell test, which is robust to unequal variances as well as unequal sample sizes.

Additionally, 2x2 factorial ANOVAs were run to evaluate main effects and interactions between the four aroma groups as follows: one mean score was determined from each outcome measure from the no-odor control subjects' raw scores. These mean control scores served as a baseline (100%). Raw test scores from the other four groups were normalized according to the baseline: each raw score was transformed into a percentage score using the equation = (raw score/baseline mean) x 100. These transformed percentage scores for the four groups were then entered into a 2x2 factorial ANOVA to determine whether any main effects or interactions exist between the two factors of purity (natural vs. synthetic) and scent (lavender vs. peppermint).

Pearson correlation coefficients were run to determine whether the six outcome measures on the NASA-TLX were correlated with both cognitive and mood outcome measures.

Multiple comparisons for each family of tests were controlled for using the Benjamini-Hochberg false discovery rate. All reported values indicate a group size of 40 (aroma groups) or 20 (control group). Unless otherwise stated, P-values < .05 are considered significant, while p-values < .075 are reported as trends. Effect sizes for significant results are reported using partial Eta squared ($\eta_p^2$).
CHAPTER III

RESULTS

Cognition

All significant differences between groups on cognitive tests were no longer significant after performing the correction for multiple comparisons.

Hypothesis 1.

RAVLT.

The natural peppermint group outscored both the synthetic peppermint group and controls on a number of outcome measures from the RAVLT, while no significant differences were found between the lavender groups.

Interference trial.

On the interference trial, a significant difference between groups was found \((F(4, 175) = 2.819, p = .027, \eta_p^2 = .061)\). A Tukey post-hoc comparison revealed that the natural peppermint group \((M = 6.83, SD = 2.159)\) remembered more words from the second list than the synthetic peppermint group \((M = 5.48, SD = 1.59; p = .014)\).

A 2x2 factorial ANOVA also found significant differences between the aroma groups’ mean recall on the interference trial when expressed as a percentage of the control group’s baseline recall score \((F(3, 160) = 3.76, p = .012, \eta_p^2 = .067)\).

Figure 1. Interaction effects on RAVLT, Interference Trial.
A significant interaction between purity and scent was found ($F(1, 160) = 4.45, p = .037, \eta_p^2 = .028$). A Tukey post-hoc analysis found that the natural peppermint group ($M = 1.1, SD = 0.35$) scored significantly higher than the synthetic peppermint group ($M = 0.88, SD = 0.26; p = .008$), with a trend towards significance over the synthetic lavender group ($M = 0.94, SD = 0.33; p = .084$), suggesting that purity was more important in the peppermint condition than the lavender condition.

*Delayed recall trial.*

A trend towards significance was found between groups on the delayed recall trial ($F(1, 175) = 2.132, p = .079, \eta_p^2 = .046$); further analysis using Tukey’s post-hoc test revealed that the natural peppermint group ($M = 11.38, SD = 2.5$) had a higher retention of information than control participants ($M = 9.4, SD = 3.03; p = .041$).

*Delayed recall percentage score.*

Finally, a one-way ANOVA revealed a significant difference between groups on the delayed recall percentage score ($F(4, 175) = 2.55, p = .041, \eta_p^2 = .055$). Further analysis shows that the natural peppermint group ($M = 0.9, SD = 0.15$) had a higher delayed recall percentage score than controls ($M = 0.77; SD = 0.23; p = .017$).
Table 2. Significant results from cognitive outcome measures.

<table>
<thead>
<tr>
<th></th>
<th>( p )-value</th>
<th>( \eta_p^2 )</th>
<th>Significant differences between groups</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>RAVLT</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Interference</td>
<td>.014</td>
<td>.061</td>
<td>NP &gt; SP</td>
</tr>
<tr>
<td>Delayed Recall</td>
<td>.041</td>
<td>.046</td>
<td>NP &gt; C</td>
</tr>
<tr>
<td>Recall %</td>
<td>.017</td>
<td>.055</td>
<td>NP &gt; C</td>
</tr>
<tr>
<td><strong>SART</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Omission</td>
<td>.033*</td>
<td>.048</td>
<td>NP &lt; SL</td>
</tr>
<tr>
<td><strong>Stroop</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Time</td>
<td>.03</td>
<td>.063</td>
<td>NL &lt; C</td>
</tr>
<tr>
<td><strong>SRT</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Time</td>
<td>.063</td>
<td>.063</td>
<td>NP &lt; SP</td>
</tr>
<tr>
<td></td>
<td>.029</td>
<td>.063</td>
<td>NP &lt; C</td>
</tr>
<tr>
<td>Sequence Time</td>
<td>.065</td>
<td>.061</td>
<td>NP &lt; SP</td>
</tr>
<tr>
<td></td>
<td>.063</td>
<td>.063</td>
<td>NP &lt; C</td>
</tr>
<tr>
<td>Random Errors</td>
<td>.029</td>
<td>.051</td>
<td>NL &gt; C</td>
</tr>
</tbody>
</table>

*-Welch’s F statistic reported

**SART.**

A significant difference between groups was found on the number of omission errors made by subjects (Welch’s \( F(4, 71.85), p = 0.014 \)). Follow-up analyses using the Games-Howell post-hoc test revealed that the synthetic lavender group (\( N = 39; M = 15.95, SD = 15.84 \)) committed more errors than the natural peppermint group (\( N = 39, M = 7.72, SD = 6.61; p = .033 \)).

**Stroop.**

A one-way ANOVA was conducted to determine whether any significant differences existed between groups on the total time taken to complete the Stroop test; a significant difference was found \( (F(4, 151) = 2.54, p = .042, \eta_p^2 = .063) \). Tukey’s post-hoc test revealed that the natural lavender group (\( N = 36, M = 314172.28\)ms, SD =
42180.01ms) performed significantly faster than the control group (N = 19, M =
350671.53ms, SD = 66716.44ms; p = .03).

**SRT.**

The natural peppermint group outscored both the synthetic peppermint group and
controls on a number of measures on the SRT. The natural lavender group was found to
commit more errors than controls on one outcome measure from the SRT.

**SRT total time.**

A significant difference between groups on the total time taken to complete the
SRT was revealed by a one-way ANOVA (F(4, 174) = 3.05; p = .018, \( \eta^2_p = 0.066 \)).

Further analysis using Tukey’s post-hoc test revealed that natural peppermint participants
(M = 249686.03ms, SD = 35874.79ms) were significantly faster than control participants
(M = 279628.05ms, SD = 47884.98ms, p = 0.029). A trend towards significance also
existed between the natural peppermint and synthetic peppermint groups (M =
271801.28ms, SD = 30171.2ms; p = .063) on the amount of time taken to complete the
test.

Also, a 2x2 factorial ANOVA demonstrated a significant interaction between
purity and scent when evaluating the time it took to complete the SRT when expressed as
a percentage of the control group’s baseline (F(1, 159) = 4.71, p = .031, \( \eta^2_p = 0.029 \)).

Further analysis using Tukey’s post-hoc test revealed a significant difference in time
between the natural (M = 0.89, SD = 0.13) and synthetic peppermint groups (M = 0.97,
SD = 0.11; p = .03), suggesting that the purity effect was greater in the peppermint
conditions than the lavender conditions.
Figures 2 and 3. Significant interactions between purity and scent on SRT Total Time and SRT Sequence Time.

**SRT Sequence Time.**

Significant results were found when evaluating group differences on the SRT Sequence Time ($F(4, 174) = 2.83; p = .026, \eta_p^2 = 0.061$). Tukey’s post-hoc test revealed that the natural peppermint group ($M = 46213.93ms, SD = 8411.57ms$) was nearly significantly different from both controls ($M = 52214.80ms, SD = 10820.88ms; p = .065$) and participants in the synthetic peppermint group ($M = 51088.55ms, SD = 7227.53ms; p = .065$).

A 2x2 factorial ANOVA also revealed a trend towards significance for the interaction between purity and scent when expressed as a percentage of the control group’s baseline time ($F(1, 159) = 3.83, p = .052, \eta_p^2 = .024$). Tukey’s post-hoc test reveals that the natural peppermint group ($M = 0.89, SD = 0.16$) scored significantly higher than the synthetic peppermint group ($M = 0.98, SD = 0.14; p = .031$), which
suggests that the effect of purity was greater in the peppermint group than the lavender group.

**SRT Random Time.**

While SRT Random Time was found significant by a one-way ANOVA \( (F(4, 174) = 2.59, p = .038, \eta^2 = 0.056) \), further analysis by Tukey’s post-hoc test indicated that significance was lost.

A 2x2 factorial ANOVA found a significant interaction between purity and scent \( (F(1, 159) = 3.92, p = .049, \eta^2 = 0.025) \). Tukey’s post-hoc test revealed that this result also dropped to a trend \( (p = .053) \), suggesting that the purity effect was slightly greater in the peppermint condition than the lavender condition.

**SRT Random Errors.**

A significant difference was found among groups on the number of Random Errors committed (Welch’s \( F(4, 80.99) = 2.96; p = .025 \)). Games-Howell post-hoc test revealed that the natural lavender group (\( N = 39, M = 1.74, SD = 1.37 \)) committed significantly more errors than controls (\( M = 0.85, SD = 0.88; p = .029 \)).

**Mood**

**Hypothesis 2.**

A one-way ANOVA revealed a significant difference in post-aroma content scores \( (F(4, 174) = 2.43, p = .049, \eta^2 = 0.053) \). A Tukey post-hoc comparison showed that participants in the natural peppermint group (\( M = 72.74, SD = 16.84 \)) scored higher than controls (\( M = 59.07, SD = 16.87; p = .024 \)). However, when controlling for subjects’ pre-aroma content scores, this significance disappears \( (p = .253) \).
There were no significant findings regarding the alert, content, or calm difference scores. However, variability within groups tended to be twice the difference scores for each of the three factors (N = 179; alert difference- \( M = -5.51, SD = 16.33, \text{range} = 99.22 \); content difference- \( M = -5.32, SD = 13.96, \text{range} = 96.2 \); calm difference- \( M = -10.04, SD = 21.48, \text{range} = 122.5 \)).

**Subjective Workload**

**Hypothesis 3a.**

A one-way ANOVA found a significant difference between groups on the measure of frustration \( (F(4, 175) = 2.709; p = .032, \eta^2_p = .058) \). However, a Tukey post-hoc analysis revealed that this significance dropped to a trend \( (p = .055) \), with synthetic lavender participants \( (M = 8.68, SD = 5.16) \) reporting less frustration than those in the synthetic peppermint group \( (M = 11.63, SD = 4.47) \).

**Hypothesis 3b.** Pearson Correlation Coefficients were calculated to determine whether scores on the six NASA-TLX subscales are correlated with scores from the cognitive measures. However, after controlling for multiple comparisons no significant correlations were found.
Table 3. Pearson Correlation Coefficients between subjective workload and cognitive measures.

<table>
<thead>
<tr>
<th></th>
<th>Final learning trial</th>
<th>Learning Total Time</th>
<th>Omission Total Time</th>
<th>Sequence Time</th>
<th>Sequence Errors</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mental Demand</strong></td>
<td></td>
<td></td>
<td>.186 (p = .013)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Physical Demand</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Temporal Demand</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Performance</strong></td>
<td>-.150 (p = .044)</td>
<td>-.173 (p = .02)</td>
<td>.202 (p = .007)</td>
<td></td>
<td>.234 (p = .002)</td>
</tr>
<tr>
<td><strong>Effort</strong></td>
<td></td>
<td></td>
<td></td>
<td>-.180 (p = .016)</td>
<td>-.169 (p = .024)</td>
</tr>
<tr>
<td><strong>Frustration</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Hypothesis 3c.** Pearson Correlation Coefficients were calculated to determine whether scores on the six NASA-TLX subscales are correlated with scores from the Bond-Lader VAS. Results are shown in Table 4. These results remain significant even after correcting for multiple comparisons.
Table 4. Pearson Correlation Coefficients between subjective workload and mood measures.

<table>
<thead>
<tr>
<th></th>
<th>Alert Post</th>
<th>Content Post</th>
<th>Calm Post</th>
<th>Alert Difference</th>
<th>Content Difference</th>
<th>Calm Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mental Demand</td>
<td>.182 (p = .014)</td>
<td>0.024 (p = .751)</td>
<td>-.167 (p = .025)</td>
<td>.025 (p = .736)</td>
<td>-.132 (p = .078)</td>
<td>-.293 (p &lt; .001)</td>
</tr>
<tr>
<td>Physical Demand</td>
<td>-.136 (p = .069)</td>
<td>-0.210 (p = .005)</td>
<td>-.123 (p = .099)</td>
<td>-.072 (p = .338)</td>
<td>-.308 (p &lt; .001)</td>
<td>-.215 (p = .004)</td>
</tr>
<tr>
<td>Temporal Demand</td>
<td>-.049 (p = .512)</td>
<td>-0.107 (p = .153)</td>
<td>-.235 (p = .002)</td>
<td>-.125 (p = .097)</td>
<td>-.183 (p = .014)</td>
<td>-.271 (p &lt; .001)</td>
</tr>
<tr>
<td>Performance</td>
<td>-.266 (p &lt; .001)</td>
<td>-.290 (p &lt; .001)</td>
<td>-.003 (p = .971)</td>
<td>-.172 (p = .021)</td>
<td>-.174 (p = .02)</td>
<td>0.000 (p = .999)</td>
</tr>
<tr>
<td>Effort</td>
<td>.252 (p = .001)</td>
<td>0.065 (p = .389)</td>
<td>-.204 (p = .006)</td>
<td>.114 (p = .128)</td>
<td>-.047 (p = .532)</td>
<td>-0.323 (p &lt; .001)</td>
</tr>
<tr>
<td>Frustration</td>
<td>-.197 (p = .008)</td>
<td>-0.339 (p &lt; .001)</td>
<td>-.286 (p &lt; .001)</td>
<td>-0.141 (p = .06)</td>
<td>-.380 (p &lt; .001)</td>
<td>-.275 (p &lt; .001)</td>
</tr>
</tbody>
</table>

*Bold typeface: correlations that reached significance after calculating FDR.*
CHAPTER IV

DISCUSSION

The main purpose of this study was to evaluate whether significant differences existed between natural and synthetic versions of two fragrances in terms of their ability to affect cognition, mood, and subjective workload. The initial results from this study reinforced the assertion that fragrances are capable of altering cognition, with further evidence that the natural aroma of peppermint is superior to its synthetic counterpart in bringing about these changes. However, after performing a statistical correction for conducting multiple comparisons, these results largely do not remain significant. No significant differences between groups were found on the mood or subjective workload measures, or the correlations between subjective workload and cognitive outcomes, after correcting for multiple comparisons. Significant results that remain involve correlations between the subjective workload measures and the mood outcomes. The results of this study are discussed below, along with an evaluation of study limitations and future directions.

Conclusions

Specific Aim 1.

To compare the effects on cognition after inhalation of natural fragrances compared with the inhalation of synthetic fragrances.

Hypothesis 1. The inhalation of natural peppermint will be associated with higher mean scores on measures of inhibition, accuracy, error detection, implicit learning, verbal learning, and delayed memory than will the inhalation of synthetic peppermint. Similarly, lower mean scores will be found on measures of processing speed and reaction time.
The initial results of this study clearly show a superior advantage of natural peppermint compared to both synthetic peppermint and no odor on multiple outcome measures. Similar to results seen in the literature, peppermint increased verbal memory and decreased reaction times and processing speeds, with natural peppermint outperforming its synthetic counterpart. Evaluation of the purity factor (natural vs. synthetic) also demonstrated that the natural fragrance groups outperformed the synthetic groups on measures of verbal learning and processing speed. Analyses of interaction effects indicate that the influence of purity is more pronounced in the peppermint group.

Lavender (both the natural and synthetic groups) was shown to be related to an increase in errors across multiple tests compared to both peppermint groups and no-odor controls. This effect remained when evaluating the two collapsed scent groups (lavender vs. peppermint) after being normalized to the control group. The increased number of errors was accompanied by decreased time to complete the tests compared to controls, suggesting that the decreased amount of time spent on tasks was at the expense of committing more errors.

While the peppermint groups also demonstrated significantly faster processing speed and reaction time, this increase in speed was not associated with the decrease in performance seen the lavender group, findings consistent with the literature.

However, the above results no longer remain significant after performing a correction for conducting multiple comparisons. Also, the effect sizes for results that were initially found significant were all of a small magnitude, rendering any positive findings difficult to interpret in a context outside of this study.
Specific Aim 2.

To evaluate the effects of inhalation of natural fragrances, compared to synthetic fragrances, on a measure of subjective mood.

Hypothesis 2. Inhalation of natural lavender and peppermint compared to inhalation of synthetic lavender and peppermint will be associated with greater difference scores on the Bond-Lader VAS factors of calmness, contentedness, and alertness.

Surprisingly, there were no significant differences found when comparing the five groups’ scores on the mood outcome measures, even before performing the correction for multiple comparisons. This is likely due to the large amount of variability that existed within all five groups, rendering any influence of aromas harder to discover with such a small sample size.

Specific Aim 3.

To compare the ability of natural fragrances versus synthetic fragrances to decrease subjective workload, and to assess whether subjective workload is a mediator of cognition and mood.

Hypothesis 3a. Inhalation of natural lavender and peppermint compared to synthetic lavender and peppermint will lead to lower mean scores on the NASA-TLX subscales of mental demand, physical demand, temporal demand, effort, and frustration, with higher mean scores on the performance subscale.

Surprisingly, no significant differences were found between groups on measures of subjective workload, even before correcting for multiple comparisons.

Hypothesis 3b. Lower scores on the NASA-TLX subscales of mental demand, physical demand, temporal demand, performance, effort, and frustration will correlate
with higher mean scores on cognitive measures of inhibition, accuracy, errors committed, implicit learning, verbal learning, and delayed memory, as well as lower mean scores on processing speed and reaction time.

As expected, most scores on the NASA-TLX were negatively correlated with cognitive outcome measures, such that the more work someone felt a task required, the lower their performance. Interestingly, higher scores on the effort scale were positively correlated with two measures of time. This demonstrates that the harder a subject felt they were working at a specific task, the faster they performed. However, these significant scores do not remain after performing the correction for multiple comparisons.

**Hypothesis 3c.** Lower scores on the NASA-TLX subscales of mental demand, temporal demand, physical demand, performance, effort, and frustration subscales will correlate with higher scores on the Bond-Lader VAS factors of calmness, contentedness, and alertness.

A majority of scores on the NASA-TLX were negatively correlated with the mood scales as expected. However, higher scores on mental demand and effort are positively correlated with increases in alertness. This finding corresponds with that found between subjective workload and cognitive measures, such that increased alertness and mental demand are required for improved task performance.

Thus, although there were no significant differences between groups on the mood measures, these combined results indicate that there were likely mood effects present. This data supports the Yerkes-Dodson inverted-U hypothesis relating arousal to performance, such that when subjects are more alert, content, and calm, tasks feel less arduous and performance on them seems improved.
Limitations

There were a number of limitations specific to the study that might account for the small number of significant results obtained.

To begin with, the sample size of 180 participants was likely far too small. Each of the aroma groups did reach the anticipated sample size required by power analysis; however, a medium effect size was used to determine that number. A more conservative effect size should have been used due to the anticipated subtle, unidirectional nature of the effects. However, this would have increased the number of subjects required substantially (N = 1,200), to a number not feasible given the time and budget constraints of this study.

A larger sample would have allowed for a reduction in the considerable variance displayed in this study. However, other forms of inherent variability would have still existed, such as pre-existing differences between groups such as cognitive ability and central state. Also, and perhaps most important, while the Screening Form administered during recruitment of subjects was designed to mitigate for some differences in olfactory perception (e.g. anosmia, cigarette smoking), there are other factors this study did not have the means to be aware of and/or control for. For example, individual differences in odor receptor expression may predispose some individuals to be more or less sensitive to specific chemicals. Also, women have been shown to be both more physiologically attuned (Goel, Kim, & Lau, 2005) and emotionally reactive (Herz, 2009) to odors, and, significant differences have been found in odor detection between women who are in different phases of their menstrual cycles cite.
Another limitation of this study was the large volume of analyses that were conducted. The scope of this study was too broad, and likely overshadowed any existing differences that could be found between the main groups of interest—the natural and synthetic versions of the two fragrances. Fewer analyses would have mitigated the impact that the correction for multiple comparisons had on the results found, such that fewer significant findings would have been lost.

Finally, a large number of researchers on the study likely introduced additional variability that clouded significant findings that may have existed. Two research assistants, as well as the lead researcher, all saw subjects for the study; while extensive training was conducted for each research assistant, it is likely that there was variability in the administration of the protocol due to individual differences.

**Future Directions**

Although the results of this study were largely inconclusive, there are patterns in the data that suggest a difference does indeed exist between the natural and synthetic versions of the peppermint aroma. A modification of the way the analyses were carried out might result in a different set of outcomes after narrowing the scope to study only these two groups.

Also, any further study into the effects aromas can have on altering central state should likely not be conducted with the premise of proving one of the two theories proposed by the literature, as it is likely these are really two aspects of the same theory. To approach the question in terms of either a pharmacological or psychological hypothesis is to assert that a dualist perspective is in force, when in reality the effect is likely monoist in nature. The mechanism of action behind the change cannot be purely
psychological in nature without first altering the body at a molecular level. Neuronal changes in the olfactory epithelium must take place in order to transmit the message to the brain, where further electrical and chemical changes occur. These changes translate into the conscious perception of the aromas. Thus, future researchers should consider a confluence of the two current theories as they attempt to explain the nature of the influence aromas can have on aspects of cognition, mood, and subjective workload.
REFERENCES


