Chem. Senses 34: 85–91, 2009
doi:10.1093/chemse/bjn057
Advance Access publication October 1, 2008

Effect of Acute Exposure to a Complex Fragrance on Lexical Decision Performance

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Abstract

This study tested the effect of acute exposure to a commercial air freshener, derived from fragrant botanical extracts, at an average concentration of 3.16 mg/m^3 total volatile organic compounds on the lexical decision performance of 28 naive participants. Participants attended two 18-min sessions on separate days and were continuously exposed to the fragrance in either the first (F/NF) or second (NF/F) session. Participants were not instructed about the fragrance. Exposure to the fragrance did not affect high-frequency word recognition. However, there was an order of administration effect for low-frequency word recognition accuracy. When the fragrance was administered first before the no-odor control condition, it did not affect accuracy, but when it was administered second after the control condition, it significantly decreased low-frequency word recognition accuracy. Reaction times to low-frequency words were significantly slower than those for high-frequency words, but no effect of either fragrance or order of administration on reaction times was found. The presence of fragrance in the second session apparently served as a distraction that impaired lexical task performance accuracy. The introduction of fragrances into buildings may not necessarily facilitate all aspects of work performance as anticipated.

Key words: complex odor, fragrance, lexical decision

Introduction

Over a decade ago, the size of the US commercial air freshener industry was estimated to be in excess of 350 million dollars annually (Strom 1991) and the use of fragrances to affect mood and improve perceived indoor air quality is widespread (Moss et al. 2003). Acute exposure to a pleasant fragrance has been shown to facilitate the performance of mathematical tasks (Baron 1990), vigilance tasks (Warm et al. 1991), word construction and decoding written messages (Baron and Bronfen 1994; Baron and Thomley 1994), and simulated driving performance (Baron and Kalsher 1998). The Shimizu Corporation, one of the largest architect/engineering/construction firms in Japan, has a patented ''Fragrance System'' (EP 1994), designed to introduce fragrances into the supply air of large buildings to facilitate occupant's affective state and work performance. However, not all studies have found that exposure to fragrances improves task performance. No effects of odorants have been found for mood ratings, creativity tasks, or room odor ratings although exposure to a pleasant odor decreased reported health symptoms (Knasko 1992, 1993).

Many fragrances are complex mixtures of volatile organic compounds (VOCs), and some mixtures of VOCs in indoor air have been linked to a range of adverse health effects and sick-building syndrome symptoms (for a recent review, see Wolkoff et al. 2006). Acute exposure for 2.75 h to a complex mixture of VOCs, characteristic of the emissions from building materials, elicited reports of unpleasantly strong odor, degraded air quality, increased headache, and general discomfort at 25 mg/m^3 but found no effects on the performance of 13 behavioral tests for 66 normal healthy male subjects (Otto et al. 1990, 1992; Hudnell et al. 1992). Other research has reported that exposure to VOCs at 80 ppm ($\sim$184 mg/m^3) results in mild impairment in attention and concentration and decreased performance on some verbal learning tasks (Reinhartz 2006).

Studies of the effects of essential oils, such as lavender and rosemary, on cognitive task performance have produced equivocal results. Although affective reactions to the aroma of lavender are positive, this impairs arithmetic reasoning task performance (Ludvigson and Rottman 1989). Working memory and reaction times on memory and attention tasks are also impaired by the aroma of lavender, whereas memory processes are enhanced by the aroma of rosemary (Moss et al. 2003).

Many types of air fresheners comprise a complex mixture of VOCs. Animal research has shown that the perception of odor mixtures appears more complex than simply the sum of their constituents (Kay et al. 2005). Little is known of the effects of complex fragrances on higher cognitive functions, such as those that are operational during a lexical decision task (Balota and Chumbley 1984).

The present study investigates the effects of acute exposure to a complex fragrance, commercially sold as a beneficial air freshener, on lexical access, which is the recognition of a word, its meaning, and its syntactical properties, and this is an essential cognitive component of reading and writing. Models of word recognition employing the concept of lexical access include search models that match input to entries in the lexicon (Becker 1979; Forster 1981), connectionist models, and their precursors that achieve lexical access via activation of nodes by word inputs or a similar mechanism (Morton 1969; McClelland and Rumelhart 1981; Seidenberg and McClelland 1989) and the diffusion model for 2-choice situations, where a choice is based on the rate at which information accumulates until a word or nonword criterion is reached (Ratcliff 1978; Ratcliff et al. 2004). The lexical decision paradigm is the task of choice for measuring lexical access (Meyer and Schvaneveldt 1971; Forster 1976, 1979; Schvaneveldt et al. 1976; Scarborough et al. 1977; Ratcliff et al. 2004). In the visual form of the lexical decision task, strings of letters are presented on a computer screen and participants decide as quickly and as accurately as possible if the string of letters is a word in English or a nonsense word in English (other languages can also be used) and reaction times and response accuracy (% correct) are measured. Typically high- and low-frequency words are included in the stimulus set and reaction times and response accuracy to these different frequencies are compared. The present research extends this psychological paradigm to investigate the effect of a fragrant mixture on lexical decision task performance. This task also measures processes that characterize information work, where words have to be read and recognized, and consequently the results of this study have some relevance to the use of complex fragrances in the workplace.

There is considerable research on the cognitive aspects of odor detection (Rotton 1983; Knasko and Gilbert 1990; Knasko 1992, 1993, 1995; Chebat and Michon 2003, Danuser et al. 2003), on odor detection and environmental and/or health perceptions (e.g., Dalton 1996, 1997, 1999, 2002; Shusterman 2001; Paustenbach and Gaffney 2006; Smeets et al. 2006), and on the factors affecting odor detection (Zellner and Kautz 1990; Distel and Hudson 2001; Herz and von Clef 2001; Sakai et al. 2005). Instructions can affect participants' classification of, perception of, intensity of, and apparent adaptation to odors (Dalton 1996). Participants rated odor intensity higher when they were told the odor name and participants who correctly identified an odor when not given its name tended to rate its intensity higher than participants who did not identify it (Distel and Hudson 2001). Invariant odors are rated differently by the same participants in different sessions when the context of the label (positive or negative) that accompanies the odor differs from session to session (Herz and von Clef 2001). The ability to correctly name an odor interferes with the establishment, retention, or retrieval of presemantic unconscious odor memories as demonstrated by a decreased ability to link odors to different rooms that included a picture of the test room where an incidental odor exposure had been experienced (Degel and Köster 1999; Degel et al. 2001). Although exposure to lavender can impair some memory processes (Moss et al. 2003), acute exposure to essential oils does not appear to affect reaction time (Ilmberger et al. 2001) and exposure to a pleasant odor can facilitate performance in some tasks, such as word construction and decoding written messages (Baron and Bronfen 1994; Baron and Thomley 1994) or produce differing scores on various tests, such as having no affect on mood scores or creativity tasks or room odor ratings but decreasing reported health symptoms (Knasko 1992) when compared with no odor or an unpleasant odor. Consequently, the present study used a complex odorant derived from natural plant extracts, that in pretesting was judged to have a pleasant but not identifiable odor, and tested the hypothesis that exposure to this pleasant but complex fragrance will improve lexical decision task performance.

Materials and method

Pilot test

The pilot testing consisted of exposing 5 participants, 3 males and 2 females with an age range of 21–55 years who were not screened for their olfactory sensitivity or fragrance preferences, to the laboratory air after the experimental fragrance had been aerosolized. Participants were asked to rate the odor of the air immediately upon entering the laboratory, and all were positive about this and rated it as pleasant, but none could name the fragrance. Subsequently, 2 additional female participants, aged 21 and 53 years, performed the lexical decision task in the presence of the aerosolized fragrance. Both were asked if an odor was noticeable and both said yes, and they were asked if the odor was overpowering and both said no. The lexical decision files were scanned to check an acceptable percent correct responses and acceptable reaction times.

During pilot testing, the level of total volatile organic compounds (TVOC) in the breathing zone of a seated participant during a test condition with the aerosolized fragrance was measured using a photoionization detector (Graywolf DirectSense PPC Monitoring Kit including a tg502 probe with a PID sensor) sensitive to 237 VOCs, with a detection range from 20 to 20 000 ppb. Three such test measurements were conducted. The average concentration over the duration of participant exposure, between 10 and 35 min after the beginning of the aerosol generator, was 3.16 mg/m^3 with a standard error (SE) of 0.26 mg/m^3 (1376 ppb with a SE of 113 ppb).

Main experiment

Participants

Twenty-two female and 8 male participants naive to the hypothesis gave informed consent and were paid $10.00. All participants were undergraduate or graduate students at Cornell University. All reported learning and understanding English as their first language. None reported any history of serious vision, hearing, smell or speech problems, or special sensitivity to air pollutants or odors. The focus of this study was on the performance effects of exposure to a complex fragrance rather than any sensory threshold effects and participants were not screened for specific odor sensitivity. The mean age of participants was 20.5 years with a range of 18–26 years. Two participants were unable to complete the task correctly and were dropped leaving 28 participants in the analysis. Four participants were left handed. The study design was approved by the Institutional Review Board of Cornell University.

Materials

Four hundred English words were selected from the English Lexicon Project database (Balota et al. 2002). Two hundred words were high-frequency words, and 200 were low-frequency words. The high- and the low-frequency words were randomly assigned to 2 stimulus subsets, 1 for each version of the experiment (i.e., A and B versions). For set A, the mean log frequency of high-frequency words was 11.695 and the mean log frequency of low-frequency words was 8.490. For set B, the mean log frequency of high-frequency words was 11.772 and the mean log frequency of low-frequency words was 8.528. In addition, 200 nonwords in English were created as foils. The nonwords were created by starting with a real word in English and adding, deleting, or substituting a letter. The resulting nonwords were all phonotactically legal, were easily pronounceable using the rules of English, and had no embedded words in English longer than 2 letters. The same set of nonwords was used in both versions of the experiment.

The experiment required 2 conditions that were run on separate days for each participant. Rather than exposing participants to a mixture of VOCs at concentrations that are known to cause nose and throat discomfort, headache, fatigue, skin irritation, and eye irritation or that could be toxic (Dalton 2003; Environmental Protection Agency 2007) in the present study, a commercially available air freshener, typical of what might be found in some offices, was used as the source of the fragrance. The commercially available air freshener concentrate (GoodAire BotaniCARE Canopy) is described by the manufacturer as "a soothing blend of lavender, eucalyptus, and tea tree reminiscent of a morning in temperate forest," and the constituents were listed as being only botanical extracts and essential oils. The fragrance concentrate was diluted 1:20 and analyzed using an Agilent model 6890N gas chromatograph (GC) equipped with Agilent 5973 network mass spectrometer (MS) detector and automatic injector for the sample analysis. GC separation was achieved using a 30 m × 0.25 mm inner diameter fused silica capillary column. The gas was used as the carrier gas at flow rate 1.7 ml/min. Column temperature was maintained 50 °C for 1 min, then programed at 25 °C/min to 260 °C, and held 1 min. The injector port and detector temperature were 250 °C and the injection size was 1 μl and splitless. MS data were acquired using scan mode at 70 eV. Library search for the MS spectra were carried out using the NIST and Wiley GC/MS spectral database and by comparing with the mass spectral data in the literature (Adams 1995) under identical operating parameters. The fragrance concentrate was found to contain 221 organic compounds, mostly in trace amounts, with the dominant compounds being terpenes, such as 1,8-cineole (eucalyptol) (10.18%) and 3-carene (6.4%), Bicyclo[2.2.1]hept-2-ene (5.0%), and alcohols, such as alpha-terpineol (4.3%), with all other compounds being <3% each. The terpene 1,8-cineole can be an inhalation irritant and is used in many medicinal products, such as inhalation vapors for nasal decongestion, upper respiratory tract expectorants, cough and cold lozenges, some mouthwash and dental preparations, and some topical ointments. Thresholds for odor, nasal pungency, and eye irritations for 6 terpenes, including 1,8-cineole and 3-carene, appear to be similar for normosmics and anosmics. The lowest odor threshold was 0.1 (ppm by volume) for geraniol and the highest was 1.7 parts ppm by volume for 3-carene. Nasal pungency and eye irritation thresholds were similar, and the nasal pungency threshold for 1,8-cineole was 235 ppm and for 3-carene it was 1636 ppm (Cometto-Muñiz et al. 1998).

The airborne fragrance was continuously generated from 20 min prior to the start of a test session to the end of the session, which lasted between 15 and 18 min, by a small, quiet, motorized desktop unit (GoodAire Revitalisor GA5201) that aerosolized a solution of 1 ml of the concentrated fragrance diluted in 140 ml of distilled water, and this resulted in an average TVOC concentration of 3.16 mg/m^3 (~1.3 ppm) for the test condition compared with 0.0 mg/m^3 for the control condition. The control session was conducted in the same way but only 140 ml of distilled water was continuously aerosolized throughout the session. Relative humidity was measured with a portable data logger (Onset Computer HOBO 8), and room noise was measured with a digital sound pressure level meter (UEI DSM101). Levels of relative humidity (mean = 26.9%) and room noise (mean = 45.2 dBA) were comparable for all test conditions.

A postexperiment survey questionnaire was developed with 3 questions asking participants to rate the difficulty of the experiment, their comfort during the experiment on a 7-point scale, and to respond to the open-ended question "Was there anything about the room that you particularly noticed? If so, please explain."

Procedure

Stimulus presentation and response collection were controlled by a computer (Dell Precision 690) using an experimental control program created with E-prime software (Schneider et al. 2002). The display was a 48-cm TFT LCD monitor (Dell AS501, 1280 × 1024 pixels). The display was viewed from an average of 53 cm. The test room was approximately 3.6 × 5.5 × 3 m. Ambient lighting was daylight through windows with no additional lighting turned on in the room. To avoid any problem with glare, sunlight was not allowed to fall directly on the display. No instructions about odor were given to participants at any time during the experiment. The first 10 trials of the experiment were practice trials, and these never varied and were not included in the analysis. The experimental trials followed seamlessly after the final practice trial. All trial display material was presented in black, 18-point, courier new type presented against a uniform white background. At the beginning of each trial a series of 5 crosses (e.g., +++++) appeared on the display centered vertically and horizontally. The crosses served as a fixation point whose duration was 1000 ms. The crosses disappeared and were immediately replaced by a string of letters. The duration of the letters was a maximum of 2500 ms or until a keyboard response was made, whichever came first. Participants were instructed to place their right index finger on the "m" key and their left index finger on the "z" key. They were further instructed to press one key as quickly and accurately as possible to signify that the string of letters was a real word in English and the other key to signify that the string of letters was a nonsense word in English. Separate "left" and "right" versions of the experiment were created so that the "word" key was always paired with the dominant hand of the participant, thus "m" signified a word for right handed participants and "z" for left handed participants. The dependent variables were reaction time to correctly identify a real word in English and percentage correct (accuracy). The probability of a string of letters constituting a real word in English on any trial was 0.5, and the lists were randomized individually for each participant. The order of presentation of the A and B stimulus sets was counterbalanced for each participant. The order of fragrance conditions (i.e., fragrance exposure during the first session and no exposure during the second session—F/NF; no exposure during the first session and fragrance exposure during the second session—NF/F) was counterbalanced and orthogonally crossed with order of presentation of stimulus sets A and B. All participants were run individually. Each participant did only one order of fragrance session, so there were 14 participants for each order (NF/F or F/NF). At the end of the experiment, all participants completed the questionnaire.

Data analysis

Only correct responses to word trials were analyzed. Reaction times under 250 ms or over 1750 ms were deemed outliers and removed from the analysis; less than 1% of trials were omitted as outliers. The accuracy (% correct) and reaction times data were not normally distributed in a majority of the test conditions. The effect of fragrance on responses was analyzed separately for high- and low-frequency words. For both accuracy and reaction times, the difference between the response data for the F and NF sessions was computed and used as the dependent variable. The difference data were not normally distributed and consequently distribution free, nonparametric tests were used. Within a WORD FREQUENCY condition, either high or low frequency, the effect of ORDER (F/NF or NF/F) was tested as the between participants independent variable using Mann–Whitney U tests. The effect of WORD LIST (version A or B) was tested within WORD FREQUENCY and within ORDER using Mann–Whitney U tests. The effect of WORD FREQUENCY was tested within participants for both NF and F sessions using Wilcoxon matched-pairs signed-ranks tests. All P values were 2 tailed, and for each analysis, the conventional significance level of $P \leq 0.05$ was adjusted accordingly using a Bonferroni correction.

Results

Accuracy data

There was a significant effect of WORD FREQUENCY, and as expected, accuracy was greater for high-frequency words than for low-frequency words for both the NF sessions ($Z = -4.274$, $P = 0.0001$) and F sessions ($Z = -4.252$, $P = 0.0001$) and recognition accuracy averaged 97.8% for high-frequency words and 93.5% for low-frequency words. There was a significant effect of ORDER for low-frequency words ($U = 47.5$, $N_1 = 14$, $N_2 = 14$, $P = 0.02$) but not for high-frequency words (Figure 1). Participants responded less accurately to recognizing low-frequency words in the presence of the fragrance when this was administered second in the NF/F order (91.1% correct) than when it was administered first in the F/NF order (95.4% correct). For the F/NF order, 7 participants showed a slight improvement in their low-frequency word recognition for the F condition, 6 showed a slight decrease in recognition accuracy, and 1 showed no difference. However, for the NF/F order, all 14 participants showed a decrease in their low-frequency word recognition accuracy. There were no other significant effects.

Reaction time data

There was a significant effect of WORD FEQUENCY, and as expected, reaction times were significantly faster for high-frequency words than for low-frequency words for both the NF sessions ($Z = -4.509$, $P = 0.0001$) and F sessions ($Z = -4.623$, $P = 0.0001$). The estimated marginal mean reaction times for high-frequency words = 526 ms and for low-frequency words = 575 ms. There were no other significant effects.

Postexperiment interview

Ten participants (36%) reported noticing an odor in either session when filling out a postexperiment questionnaire. Of these, 3 were from the F/NF order group and 7 were from

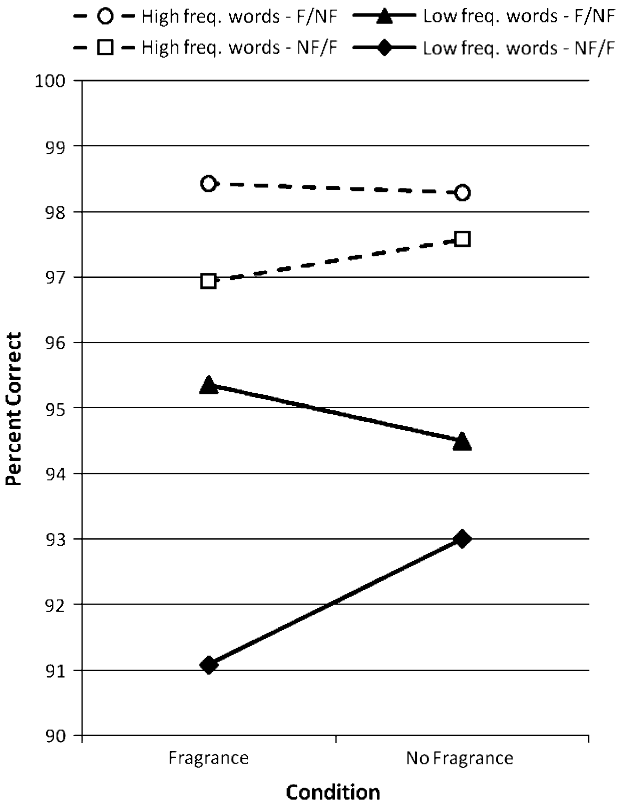

Figure 1 Effect of ORDER on response accuracy for high- and low-frequency word recognition

the NF/F order group. Although proportionally more participants who experienced the fragrance exposure second seemed to note the presence of the odor, a continuity-corrected chi-square analysis was not significant. Interestingly, for the NF/F order group, there was no significant difference in the accuracy between those who did (n = 7) and did not report an awareness of the odor (n = 7).

Discussion

The significant main effect of word frequency for reaction times validates that the word lists were constructed correctly, and this agrees with a very highly reliable finding in lexical decision tasks (Scarborough et al. 1977; Posner and Carr 1992; Ratcliff et al. 2004).

Although some studies have found that exposure to a pleasant fragrance can facilitate linguistic task performance (Baron and Bronfen 1994; Baron and Thomley 1994), this study found an asymmetrical effect of order of administration of the fragrance on the accuracy of lexical decision performance. When the acute fragrance exposure occurred during the first test session, there was no significant difference in the accuracy of lexical decision performance between the test and control sessions. However, when acute exposure to the fragrance occurred in the second test session on a separate day following the control session, the word recognition accuracy for low-frequency words was significantly impaired, suggesting that the fragrance exposure inhibited linguistic performance. Fragrance exposure had no effect on reaction times, which agrees with previous research (Ilmberger et al. 2001). This result does not support our original hypothesis that the exposure to a pleasant but unidentifiable fragrance will facilitate performance on a lexical decision task and challenges simple assumptions that the introduction of fragrant air into a building will necessarily improve worker performance. The uncovering of an order effect is interesting and contrary to expectations. It seems that when exposure to the fragrance occurred during the first session, the participants may have accepted it as part of the novel laboratory test environment. Only 3 of these 14 participants noted the presence of an odor when asked in the postexperiment questionnaire. However, when the fragrance exposure occurred during the second session, then word recognition accuracy was significantly impaired. The effect of order of administration of the fragrance, first or second, resulted in around a 4% decline in recognition accuracy for low-frequency words between these conditions. The magnitude of this effect compares well with results from other studies using visual lexical decision tasks, for example, Ratcliff et al. (2004) found accuracy differences for low-frequency words averaging 5% (average accuracy = 91.2%) among a series of experiments that varied word frequency and whether nonwords were pronounceable pseudowords or unpronounceable random strings of letters to test the fit of lexical decision data to the first author's diffusion model (Ratcliff 1978). Berent (1997) found accuracy differences for low-frequency words averaging 2.2% (average accuracy = 92.8%) in 2 experiments varying the regularity (predictability of pronunciation) of words demonstrating an accuracy advantage for regular words.

If there was a direct effect of the complex fragrance on lexical task performance, then we should have seen this effect for the test sessions in both orders (NF/F and F/NF) but that was not found. If there was some odor adaptation over the course of each test session, this adaptation should have been comparable for all participants and it is unlikely that an adaptation effect could explain the asymmetrical findings.

For the NF/F group, it is possible that the presence of the unfamiliar fragrance in what was a familiar unscented laboratory setting may have elevated the anxiety level of participants. Reinhartz (2006) described a case of an occupational exposure to a mixture of solvent VOCs supposedly resulted in frontotemporal hypoperfusion and neuropsychologic deficits in verbal learning and poor organizational memory in a woman worker and created "olfactory panic" for this person when the odor was smelled. Anxiety could impair lexical access. We did not measure levels of anxiety, and subsequent studies could usefully do this. However, the manufacturer claims that the botanical extract that we used should facilitate a soothing, relaxed state, which should have decreased rather than increased anxiety when present in the second test session which, if correct, suggests that changes in anxiety changes were not responsible for the effect.

We suggest that a plausible explanation of our findings is that in the NF/F order the participants were distracted from performing the lexical decision task by the presence of fragrance because they sensed a difference between the control and test sessions, either consciously or subconsciously, and expended mental effort in identifying the source of the difference, possibly even attempting to identify the fragrance. Although it failed statistical significance, 7 of these 14 participants consciously noted the presence of an odor in this order of conditions, suggesting a trend favoring this interpretation. Naming an incidental odor has been shown to interfere with the establishment, retention, or retrieval of presemantic unconscious odor memories (Degel and Köster 1999; Degel et al. 2001). The fragrance used in the present study was a complex mixture that was not easily namable, and it is possible that any mental effort expended in searching for an appropriate name interfered with their cognitive resources available to process the low-frequency words in the lexical decision task. Future studies to elucidate the basis for this order effect should investigate whether this also occurs for other fragrances, especially easily namable odors that are associated with pleasant experiences, as well as how the effect is influenced by the odor concentration and duration of exposure.

These present results may have practical implications for the workplace. The development of systems to introduce fragrances into the building air supply has been claimed to improve occupant well-being and productivity (Strom 1991), but supportive evidence is lacking. The present study suggests that it is also possible that the introduction of fragrant mixtures where there was none before may lead to at least short-term decrements in higher cognitive function as in the conditions in this experiment where exposure occurred during the second session. Whether the performance decrement that was demonstrated will dissipate or continue with longer or repeated exposures is unclear and also requires further research.

Funding

United States Environmental Protection Agency grant (#CR-83199201-0).

Acknowledgements

We gratefully acknowledge the technical support of James Smith, Department of Mechanical and Aerospace Engineering at Syracuse University. We are grateful to Richard Yang, the Goodaire Pte Ltd Company, for supplying the Revitalisor unit and the concentrate supplies. We thank Françoise Vermeylen, Cornell Statistical Consulting Service, for her assistance with the statistical analysis. We also thank Jagdish Tewari of the Fiber Science and Apparel Design Department at Cornell University for performing the GC/MS analysis.

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Accepted August 27, 2008