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FOREWORD

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First Annual Report
Olfactory Stimuli in Virtual Reality Medical Training Applications
ARPA Grant #DAMD17-94-J-4113
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Introduction

This report describes the first year of a project to add olfactory stimuli to virtual reality applications. Since this project was given an eleven month extension because of an interruption in the funding and because of the death of an intimate of the key implementer working the project, this report actually covers the calendar period from 10/1/94 through 9/30/96.

To date, virtual reality simulations have primarily focussed on visual and auditory stimuli. Tactile and force feedback are sometimes included, but are primarily confined to systems whose explicit purpose is to study these issues or to develop technology to address them. Olfactory sensations are the real orphans of virtual reality and only a few preliminary efforts have been made to incorporate them. Denise Varner of Southwest Technical Research Center in San Antonio did a prototype of a system that might be used for training firefighters and Cliff Bragdon of the National Transportation Simulation Center at Dowling College on Long Island is in the process of adding odors to vehicle simulations.

The goal of this project is to investigate the technology and techniques required to add olfactory stimuli to virtual reality training simulations with a particular emphasis on medical training. The issues to be researched include the requirements of such simulations, the synthetic odors available to simulate real ones, the technologies and techniques which can be used to present them, and the effect of such odors on human performance and on the effectiveness of virtual reality training.

Research Effort

During the first year's effort, preliminary technology has been developed in a variety of areas, including odor synthesis, odor delivery, odor presentation, and natural movement in olfactory environments. In addition, extensive studies of the issues that surround the use of these stimuli in

virtual reality training applications have been performed. Something has been learned about the effects of odors on the performance of skills related to surgery. Much has been learned about the technical issues that must be addressed and solved to provide the optimal use of odors in the various forms of virtual reality.

Odor Experience

An integrated virtual reality system has been implemented which permits limited physical movement within an odor-rich virtual reality for a participant wearing a head-mounted display. With this system, a person can move his head in order to sniff a variety of graphic objects to see how they smell.

When the odor intensity is varied with the distance from the visual stimulus, the user gets a strong sense that he is smelling that object when he moves his head. However, even a familiar odor that is easy to identify with the appropriate visual cues is much more difficult to recognize if it is associated with an arbitrary object. Similarly, an ambient odor associated with a graphic environment is not as convincing as one which has a clear graphic source. So far, it seems that moving the body to seek localized odor sensation is more convincing than encountering diffuse odors by being moved around an environment in a vehicle mode in which body movement is not involved in seeking the sensation.

This perceptual effect may be fundamental or it may be the result of the rudimentary graphics environments that have been defined so far. It may also be a product of the fact that some of the odors that we are developing for surgical applications are not yet good enough representations of the real thing to be identified unambiguously by most participants. As the current sketch of the system is fleshed out, we expect that we will learn much more about what odors do best in virtual reality.

Odor Knowledge

One surprise has been that almost nothing is known about how people experience odors in the real world during their daily activity. It is not known how many odors people encounter, how many they notice, whether they can detect gradients, or whether they can follow them. Odors as part of physical movement has never been studied. Indeed, the lack of

sophisticated delivery systems, the adaptive behavior of olfactory sensitivity, and the priorities of research scientists severely limit the value of what has been done studying sedentary subjects. For instance, there has been a focus on the effects of simple chemicals rather than on the response to complex mixtures such as permeate both our natural and man-made environments. Similarly, odors are typically presented as static stimuli rather than constantly varying the way we encounter them in the real world.

The connection between olfactory perception and physical behavior is untouched. While we are sometimes able to trace an odor to its source, our ability to follow odor gradients is questionable given that the olfactory giants of the animal world tend to keep their noses to the ground where the trails have clearly defined boundaries. Moths that are renowned for their ability to locate a single female over a distance of miles are now known to be blind to gradients. They simply fly into an odor plume and turn upwind. Finding themselves in a textbook olfactory gradient in still air, they fly around randomly.[1] Since science has not studied any of our senses in the context of physical behavior, it appears that virtual reality may provide the instrument for studying human olfactory behavior rather than being influenced by what science already knows.

Odor Presentation

The presentation of odors in three different virtual reality formats has been explored: immersive VR with HMDs, desktop VR in a small booth appropriate for surgical simulation, and room-sized CAVE environments.

Of these, the HMD approach is easiest and most successful. This is because a person wearing an HMD is already encumbered and is not disturbed by the addition of a face mask below the display. Also, the amount of odorant that must be presented is the absolute minimum required for perception. Only the air that is breathed is odorized. Also, the exhaled air can be evacuated from the mask and not breathed again. A portable HMD system will make odor display even more convincing because odors will be encountered in response to the participant's movements about the virtual world. At the same time, the technical problems become more severe, because there will be much more for the participant to carry.

We experimented with mixing odorized air with room air to cut down on the amount that needs to be odorized. The small amount of exhaled air is

quickly diluted in the larger volume of the room. Only in the case of the strongest odors was there any problem rebreathing previously exhaled air. However, for subtle odors such as Betadine, a commercially produced, iodine-based, surgical scrub, the dilution with room air was unwelcome.

Another advantage of the HMD is the short tubing that connects the odor vaporization chambers and odor selection valves to the nose. This means that it is possible to switch odors or to alter the concentration of a given odor very quickly—in as little as 10 milliseconds. Thus, if a person moves his head quickly toward an object while he is inhaling, he is exposed to a changing concentration of the odorant that gets stronger as he approaches the source of the odor in the virtual world.

In the stationary system, we can use a pump to drive clean air through the odorizing chambers and the valves that select the individual odors without regard to weight.

In a portable system, several possibilities exist. First, we can carry enough power storage to drive a pump for the duration of an experience. This is undesirable because both the energy storage and the pump are heavy and the latter will vibrate as it operates. Second, we can carry a compressed air bottle and regulator that will substitute for the pump and energy supply. Again, the solution is heavy. Steel compressed-air bottles hold the most air, but will distort the readings of magnetic tracking devices. Aluminum bottles are lighter and will cause less distortion. Bottles made of composite materials of the kind used by firefighters are even lighter and will have much less effect on magnetic fields. Third, we can try to use the suction of the person's breathing to pull the clean air through the odorizing chambers.

With the small, fast valves that we are using in the current delivery system, it is simply not possible to suck enough air through them by normal breathing. The solution would be to use larger valves or to create even higher concentrations of odorized air which could then be mixed with the clean air. We cannot tell yet which of these approaches will work best. We will use the air bottle initially, because it is the easiest to implement. If it is combined with one of the optical tracking techniques, there will be no problem. On the other hand, we may be able to minimize the effect of the bottle on magnetic trackers. In our preliminary tests,

metal bottles have not disturbed the magnetic tracker as much as we had feared.

Simultaneously, we will look at several design alternatives. First, we will consider odorizing an even smaller proportion of the breathed air than we do now. This will require creating an even more concentrated odorant flow that is switched by the valves and then mixed with a much greater volume of clean air flow. Given the difficulty we have had in displaying subtle odors already, we are not certain this approach will succeed. Second, we will see if there is any way to use the suction of the person's breathing to reduce the pressure needed to drive the system.

Given that a person generates only 1 mm of mercury difference in air pressure between the ambient environment and their lungs when they breathe, the tiny apertures in the miniature valves make breathing through them impossible. Breathing through unobstructed 1/4" tubing is very difficult and very uncomfortable. Even a few feet of 1/2" tubing is hard to breath through without pressure from the other end. We will consider employing larger but slower valves with sufficient flow capacity that a person can breathe through them. However, the larger the valve, the greater the weight and the greater the power drain. It is likely that some form of pressure assist will always be required if there are any valves in the delivery system, especially since there is a further desire to clean the input air by passing it through activated charcoal.

Over time, we will look at alternative methods of powering the portable delivery system such as batteries, fuel cells, and mechanical or electrical power generated by the movements of the person's body. There also may be some means of saving power while the person is exhaling, because no odor display is necessary during that time.

Advanced Olfactory Displays for HMD Systems

The major deliverable at the end of the program is a portable olfactory display system. Two design approaches have been identified and will be evaluated during the second year.

The first of these is the most aggressive in terms of size. It also may not work for all of the odors that we are considering. It is based on depositing a droplet of each odorant liquid on a micro-hotplate. Because this hotplate is very small and has very low thermal mass, it can be turned on and off

very rapidly. Thus, small amounts of odor can be released with very little energy. The amount released can be controlled by varying the duty cycle of the hotplate or that of the valves that will control the flow of air through the chamber containing each odorant.

This approach will definitely work for some odorants. The strongest odors will probably be perceptible through microvalves if their output is mixed with enough clean air flow to permit breathing. However, odors which consist of many different compounds each with a different boiling point may not evaporate uniformly. Similarly, odors which can only be detected in high concentrations may not pass through this apparatus in sufficient quantity to be detected.

This design can either be fabricated on a single substrate consisting of hotplates and valves together. Or, the hotplates can be fabricated in one unit and the valves placed on another. The latter approach would be cheaper but more bulky. We have been assured that manifolds combining four or more valves in a single small package will be available in the next year. Larger manifolds will follow the year after.

An integrated package can be much smaller because the fittings for the tubing between different parts of the system are larger than the actual valves and heaters. However, getting such custom fabrication done will be expensive for this project and for followup work in the near future. In mass production, the integrated unit would be cheaper.

As a first step, we will see if we can deposit a odorant droplet on a very fine gauge nichrome wire which can then be heated very rapidly to cause the odorant to evaporate. This may work as well as the micro hotplate and will be much easier to fabricate.

A second approach is based on our experience with our preliminary delivery system so far. Odorants vary in their physical properties such as vapor pressure and stickiness. This means that a cc of acetone completely evaporates from the delivery system in seven minutes whereas a cc of another odorant lasts for a month. Also, most odors are mixtures of many ingredients each with their own properties rather than single compounds. While it does not appear that each odorant must have its own specialized delivery system, it is unlikely that one design will not work for all

odorants. For instance, the intestinal contents include gases that cannot be delivered by the means that we have discussed so far. Nevertheless, it would be desirable if a single approach could be found that would handle a wide range of odorants.

Conventional valves purchased in small quantities are almost certainly too expensive to create an attractively priced delivery system. In addition, the size, weight, and power associated with large valves make them unsuitable for portable systems and the tiny apertures in the small ones make it impossible to breathe through them.

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It would be preferable if odorants could be vaporized in the main air flow without having to pass through a separate chamber for evaporating each odorant. It would also be desirable to use valves that are already in mass production rather than buying individual units that sell for \$100 apiece. The only valves that are truly mass produced are the nozzles used in ink jet printers, which are very fast and permit a droplet to be released every 10 milliseconds. A small amount of the ink is heated to 900°F vaporizing it. The rapid increase in volume as the liquid becomes a gas applies enough force to overcome the surface tension of the liquid thereby ejecting a tiny droplet, about 1 millionth the volume of a drop of water, from the nozzle.

It would seem that the wide range of viscosities of the odorant liquids would defeat any attempt to use ink jet valves, but they would work with at least some odorants. The odorant droplets would then be vaporized when they struck a micro-hotplate at the side of the main air stream. The vapor from the droplet would immediately mix with the air stream and be fed to the user's nose. Concentration can be controlled by varying the rate at which droplets are released or by varying the number of droplets that are released in parallel through the nozzle matrix.

The range of odorants that could be used in this design would be expanded enormously if they all had the same viscosity. This can be arranged by micro-encapsulating the odorant and then mixing the microcapsuls in a carrier fluid to create a slurry of the desired viscosity. If the microcapsul size is chosen to fit through the ink jet nozzle, the rest of the design can work as before. The micro-hotplate will burst the microcapsul and evaporate the odorant inside. Alternatively, the nozzle can be redesigned so that the vaporized liquid is released from the nozzle rather than a

droplet. In principle, this design approach will work. However, it is necessary to experiment with each odorant to see what is necessary to microencapsulate it.

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Ambulatory Olfactory HMD Display

HMD delivery of odors and indeed HMDs themselves have little advantage if they require the user to have his head tethered to the computer. While long cables might allow the participant to walk around a modest sized area (very carefully, so as not to trip over the wires), in practice, people tend to stand still. In entertainment systems, participants are surrounded by a ring-shaped barrier that prevents them from moving.

The PI has argued for many years that the main advantage of the HMD over other formats of virtual reality is that it could permit participants to walk around in virtual reality naturally using the length of their stride to measure the space as they walk. This capability requires a wireless tracking technology that will let the user roam over a large area. Otherwise, the person's concern for their safety will make their movements too tentative to be natural. A walk-around capability would also permit odors to be delivered as part of physical exploration of an environment. Our experience with moving our heads to smell particular objects convinces us that encountering odors during physical movement makes the odors seem more real. As our simulations improve, we are hoping that it will also make them appear more real as well.

During the first year, we prototyped a wireless tracking system with rather modest goals. We used 8 ceiling-mounted video cameras to track a person walking down a 40' path wearing a target on his head. The views of the video cameras overlapped such that the person was always in view of one or two cameras. In the overlap areas, the computer averaged the readings of the two cameras. The intent was to replicate this single row of cameras eight times to create a two-dimensional grid of cells with about a 40' square extent.

This system provided a good measure of the person's x-y location along the path and a reasonably good measure of the direction that the person's head was turned. Both of these quantities were available 30 times a second. However, the tilt of the person's head was more of a problem. It

had to be averaged over several frames to achieve stable values. The altitude of the person's head was similarly unstable, because the low-resolution cameras being used did not provide sufficient information to calculate that quantity with precision.

Another problem we had with the system at that point came from the inability to transmit the video image to the HMD without getting lots of interference from other electrical devices and from reflections in the environment. These multipath nulls were extremely disturbing. However, late at night, it was possible to traverse the path, to be handed off from one camera to the next, and to look around in the virtual world. The multipath nulls meant that the experience was a little like walking through swiss cheese, in that small movements of your head would result in the virtual image going from acceptable to pure noise. Several vendors have indicated that they will soon have available diversity receivers that would eliminate that problem.

In the meantime, we have looked at a number of ways of improving the performance of the approach that we tried as well as a variety of related technologies that might offer advantages.

The most obvious approach would be to use cameras with higher spatial and temporal resolution. Very high speed cameras are available from Reticon and Kodak. These products sample at thousands of frames per second and cost \$17K for the camera alone. 500 hz cameras are also available, but are also too pricey for our purposes. 60 hz progressive scan cameras with VGA resolution have become available in the last year or so, but would still be too expensive if 64 units were required. Also, while the improvement in performance would be noticeable, 60 hz sampling might not be sufficient. As a point of reference, a person running a very slow (20 second) 100 yard dash is moving at about 1/6" per millisecond.

Cameras with higher spatial resolution (1Kx1K) are available, but these do not scan faster than 30 hz. The improved spatial resolution would probably not be sufficient to overcome the lack of temporal resolution. These devices are also quite expensive.

In general, it is our belief that temporal resolution is more important than spatial resolution, and absolute accuracy is not as important as relative

accuracy or monotonicity. If the participant moves and his view of the virtual world changes smoothly, it does not matter where he is in the real world—until he is about to bump into something in it.

In considering tracking options, it is important to consider the magnetic trackers that are the standard in the virtual reality community. These devices claim sampling rates on the order of 60 hz. However, their spatial accuracy is poorer than is commonly realized. For instance, the maximum spatial error in the CAVE, where Ascension trackers are employed, is one foot, assuming that the participant has not moved since the sample was taken. If the participant has moved, the error is one foot plus the distance moved.

However, if the readings change continuously as the participant moves, he does not have a very precise sense of absolute position which can be offended by these errors. On the other hand, if as the person moves, he receives exact positions with delays in between, most of the time, he will be viewing an old image which was once correct but is no longer. Thus, perfect positional accuracy with a low sample rate will be more disturbing than less accurate but stable data that is updated more rapidly.

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In order to improve the sample rate over the 30 hz of our original video approach, we examined a variety of optical sensor technologies. Among the most interesting options are smart cameras which can read out scan lines selectively and which can query an entire line to see if there is a spot falling on it—all in a single hardware cycle. If there is, the x-coordinate of the left edge of that spot can be read out directly without scanning the line to find it. Such cameras can track a single spot target at a rate of up to 30 thousand lines per second, because the spot cannot move very far in between samples. For a target consisting of five LEDs, the individual elements can be illuminated and located in sequence, resulting in a somewhat slower—but still impressive—sample rate. These devices are more expensive than standard cameras and are so far only available in 128 and 256 resolution, although a 512 version is expected in the near future. If the higher-resolution device were available now and if it were inexpensive, this approach would be very promising.

Another approach would be to use a position-sensing diode. This device outputs two analog values that correspond to the x & y coordinates of the

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centroid of a spot of light that is falling on it. It permits about one part in one thousand accuracy to be achieved. For a single LED target, it will instantly read out the spot's position on the sensor without scanning its whole surface as a CCD camera would have to. By sequencing multiple LEDs on a target, a much faster sampling rate can be achieved than is possible with any but the most expensive raster frame cameras.

One problem with our current cellular approach is the large number of sensors required and the high ceiling necessary for each sensor to cover a wide enough area. In our prototype, the cameras were mounted 16' above the floor or 10' above the participant's head. While the overhead approach has the advantage that multiple participants could be tracked simultaneously, it would be preferable if the system could operate in a room with a lower ceiling. In systems in which there is never more than a single individual, a smaller number of sensing cells could be used, if the sensors look into the room from the sides. For such side-looking sensors to operate over a large area, very high resolution sensors would be required. The only optical sensors with more than a thousand pixel resolution are line scan devices which go up to 6K pixels and scan at rates of 30 thousand lines per second. At 40', the spatial resolution of such a sensor is better than .1 inches.

Since a line scan camera with conventional camera lenses will see only one scan line of the scene in front of it, special optics are required to collapse all of the visual information in each column of that image down onto a single pixel along its horizontal scan. Such optics can be constructed, although there may be problems as we get into the prototyping.

Now, it may not be obvious what good it is to know one coordinate of a point of light at that distance. However, our plan is to use a second line scan sensor mounted orthogonally to the first to read the other two-dimensional coordinate of the LED. If it is viewed by multiple cameras from different positions, the LED's three-dimensional location can be determined with better spatial and temporal accuracy than is possible with conventional cameras or with magnetic sensors. In addition, such side-mounted sensors could be installed quickly and easily.

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However, there are a number of pitfalls that may derail this approach. First, the highest resolution sensors cost hundreds of dollars per chip. The cost issue is aggravated by the fact that two line scan sensors are required in each position where a single two-dimensional imaging camera would be required. It is also not yet clear that off-the-shelf optics will be adequate for this application. Custom optics could be prohibitively expensive to fabricate. (In fact, prototyping optics does not seem to have gotten easier in the PI's lifetime.) However, there is a low-cost approach that may work. 2K pixel devices used in scanners cost as little as \$16 in small quantities. If these can be made to work with off-the-shelf lenses, the cost per sensor could be as little as two hundred dollars. Double that because of the need for two orthogonal sensors to create a two-dimensional device. Then, figure that five cameras on each edge of the room might be enough to provide .3 inch accuracy over the entire distance. The result is potentially very attractive as long as only a single participant must be tracked.

We should note that there is an additional subtlety that comes into play. As long as the person is simply walking around the virtual world, his head is fairly level and the sensors can always see the LEDs. However, if he tilts his head down to look at the floor, some of the LEDs may not be visible. Therefore, it may be necessary to have additional LEDs on the target which are turned on selectively depending on the tilt of the person's head.

Another solution is to reverse the previous approach to make it inside out instead of outside in by placing sensors on the person's head and alternately scanning sheets of light horizontally and vertically through the volume and detecting the position of the scan when the light is detected by the head-mounted sensors.

Such a technology is already used for measuring position around construction sites. The current system is too slow for our purposes, but its developer believes that they could speed up the mechanical scanning if we could do the rest of the work. In addition, it currently records the coordinates for later off-line transfer to a computer.

It would be necessary to transmit the coordinates back to the computer as soon as they are calculated, although such serial transfer would delay the

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data. An alternative would be to have a bright LED on the person flash a very short but very bright pulse back to the computer indicating that the light had been detected. This would eliminate the need for on-board processing, speed up the system, and reduce its cost.

Yet another approach would be to mount laser diodes on the person's head. As he moved, the beams would create spots on the ceiling, floor, and walls. By aiming sensors at these surfaces, these spots could be located and their two-dimensional positions used to infer the three-dimensional position of the person. To make the system more robust, extra diodes could be placed around the person's head so that as he tilted his head, only the diodes that would cast their spots on the walls would be turned on. This system has the disadvantage of requiring the walls to be clear and is also limited to one participant.

A variation of this design is based on a range finding technology developed by Leica. It uses phase conjugation instead of time-of-flight to measure the distance of the laser from a target. It is currently available commercially with 1/8" accuracy and suffers from relatively low-speed operation. Its current speed is partly a function of the fact that it checks for reflections at every distance from zero to infinity until it reaches the target. If it knew the most recent distance, it could eliminate most of this scanning process. On the other hand, to improve the accuracy, it would need to take more readings around the most recent distance. It appears that a single unit could control multiple lasers and that the distances to known surfaces would provide sufficient information to determine where the person is located. This is a proprietary technology and while its developer would be interested in improving it to serve our purpose, it became apparent that they wanted more money than would be reasonable for this project.

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In all of the above options, it would be possible to augment them with additional information from on board the person. For instance, accelerometers could measure the speed and direction of movement instantaneously. Compasses could determine which way the person was looking. Tilt sensors could measure the pitch and roll of the person's head. In every case, it is more important to respond to where the person thinks

he is in virtual space rather than to worry about where he is exactly in the physical world. Unfortunately, each of these technologies has its own problems. Accelerometers can measure rapid changes in position or rate of movement, but it is difficult to measure absolute position or speed over any period of time. Gyros can also measure changes in direction, but again will drift over time.

Direction sensors such as electronic compasses are probably not accurate enough to provide much advantage. Tilt sensors have a limited range of angles they can operate in and take time to settle to a stable value. None of these devices can be used by themselves to track the person's position; however, they might be used in conjunction with one of the systems described above to improve its perceived responsiveness. The instantaneous response to rapid movements would be detected on board the person, but absolute position and orientation would be reset by an external system that would be more accurate. The on board system would provide information about immediate relative behavior and the external system would keep the person from walking into walls.

Lastly, a new option has surfaced very recently. After years of the PI asking why they could not make their systems wireless, Ascension has finally done so. Polhemus also has a wireless system for recording motion, although not yet for transmitting it. The Ascension system does not have the range that we require. However, in our discussions with them, it appears that it would be possible to use several overlapping transmitters and to hand off from one to the next as the person moves around. This practice might slow down the sample rate, but it would allow a much larger area than the 8' radius currently provided to be used.

Ironically, whereas most virtual reality applications are not severely affected by the sensitivity of magnetic sensors to metal objects, our designs for a portable system squarely confront this hazard. In the earlier discussion of the portable system, it was pointed out that we were planning to have the person carry a small dive bottle filled with compressed air to provide the pressure needed to drive the air through the valves. Our current concern is that this bottle will disturb the magnetic fields of the tracker and render its readings useless. Initial testing suggests that this problem may not be as bad as we feared.

While some of the optical approaches described above have higher

sampling rates and even higher accuracy than magnetic trackers, there is a reason to question whether tracking speed is really the bottleneck in current VR systems. High speed tracking can provide more stable values by filtering the data, it cannot improve the response rate of the total system unless the graphics are speeded up as well. Graphics frame rates are typically 30 hz or 60 hz. In a wireless system, you are condemned to the 30 hz of NTSC, because there is no commercially available product for transmitting VGA images at this time. Thus, 30 hz is the maximum cycle rate, assuming that you are careful and make sure that all responses are computed and delivered in 1/30 second. It would seem tracking faster than that would not make much difference.

For this reason, many people feel that magnetic tracking is as good as necessary until the other system components are speeded up. Indeed, the possible need for faster graphics as opposed to more complex graphics is seldom discussed in the VR community. However, Silicon Graphics says with some pride in the fact that they will only demonstrate 60 hz graphics on their high end systems. Thus, graphics update rates are likely to come under pressure in the next few years from other applications, if not from VR. Ultimately, HMD systems will certainly require a faster sampling rate.

However, when graphics are generated in response to the participant's physical movements, the lag between the participant's action and its perceived effect in the virtual world is more important than the sample rate. A response rate of 30 hz means that it is possible for the computer to generate a graphic response to any action in 1/30 second. To realize this standard, the tracking system has to detect the action, the VR system has to analyze its effect in the virtual world, and the graphics system has to generate a new image in that time.

If the tracking system is also sampling at 30 hz, it could take 1/30 second to get the next tracking sample and another 1/30 second to generate the graphic response. The result is 15 response cycles per second. While it is possible to overlap the acquisition of one tracking sample with the calculation of the graphic response to the previous one and thereby to maintain 30 responses per second, the lag between action and response is still 1/15 second. In general, while a fast tracking system does not permit the system to respond faster than the 30 hz graphics rate,

it does permit the system to generate a more elaborate response by providing the viewing coordinates earlier in the 1/30 second available between images. It also allows a number of tracking samples to be averaged to reduce noise.

Odor Display--Booth Environment

For surgical simulation, an HMD display may not be necessary. For preliminary training (rehearsal versus dress rehearsal), a desktop virtual reality system may be adequate. In this format, a medical student would sit in front of a conventional computer screen and interact through a scalpel instrumented to provide force feedback. Since interaction with a screen is routine in laparoscopic surgery, this format may even be consistent with the real procedure, especially if devices are provided which translate the surgeon's intuitive movements into the counterintuitive movements required when using laparoscopic instruments.

In a booth environment, we have found that the problems of odor display are somewhat more difficult. In general, odorizing a small room takes longer than odorizing the HMD. Also, the problem of evacuating odors, which does not exist with the HMD, is significant in even a very small booth. Previously presented odors linger for some time after they cease to be displayed.

To some extent, the individual will adapt to these odors and become less sensitive to them; however, we feel that it is very desirable to operate against as low a level of background odor as possible, so the subject will be sensitive to new odors and so lower concentrations of odorants can be used—both to conserve odorant and to reduce to the subject's exposure to materials that someday may prove to be less benign than is currently believed. Also, if a low ambient level of odors is maintained, the person will be able to perceive more gradations of each individual odor, leading to a better representation of odor gradients and hopefully to a better sense of presence.

The classical solution to presenting odors in a room is to create a laminar flow from floor to ceiling or vice versa. This did not seem attractive for several reasons. First, in practice, few such complex facilities are likely to be installed. Second, the time lag from the introduction of the odor to its perception by the participant can be several seconds. While this speed

may be sufficient for displaying slow changes in ambient odors, it means that more rapid events such as the rapid perception of alcohol on the surgeon's hands would be unrealistically slow.

Thus, our solution is to gently blow odorized air on the subject's face from an outlet about 6" in front of him. Since this is the only air he breathes, the residue of previous odors does not disturb his perception of the new air. We were afraid that the new air would mix with the old air, but have not observed that to be true. For this reason, there is less pressure on the removal of the previous air. An ordinary exhaust system is sufficient. In an office environment, the exhaust air could probably be vented from the room using the existing air circulation system.

While this in-your-face display solved the problem of residual air, the response of this system was considerably slower than with the HMD. The lag from display of an odor to its perception by the subject is at least a second. Whether this delay is all from air transport, we are not sure. Also, we found that some odors that are intense in the HMD are less so in the booth environment. For instance, the surgical scrub Betadine has a distinctive odor for a surgeon because it is wiped over a large area of the patient's body and also evaporates from his hands close to his nose. When Betadine is presented through our delivery systems, it does not make such a strong impression. We hope through further experimentation to improve the vividness of the more subtle odors.

Odor Display in CAVE

The CAVE environment is a third virtual reality format that is gaining favor in the research community.[2] It is a 10' cube with rear-projection of stereo images on three walls as well as the floor. The fourth wall is open to permit entrance and egress. The ceiling is also open to permit the image for the floor to be projected downward after being reflected off of a mirror mounted overhead.

The open wall and the open ceiling make it almost impossible to implement the traditional floor-to-ceiling laminar flow used in olfactory research environments. Closing the fourth wall would help, but the open ceiling and overhead mirror would still channel the flow, even if a grid of evenly spaced holes in the floor was used to assure a uniform presentation of odors into the room. Also, such a grid of holes would interfere with the

floor's current function as a graphic display surface.

Also, given the bizarre behavior of slow moving air flow in rectangular volumes (The PI did gas flow visualization for five years under a research contract with Pratt and Whitney, including the simulation of gas flow around a 3-sided rectangular structure.), it is likely that any scheme to introduce odors in this environment will be less than ideal. A main flow will be set up from the inlet air to the exhaust vent. Outside of this flow, slower moving air will be entrained. Residual air stuck in these recirculation zones will persist for quite some time. New odors will also take some time to reach them. We have constructed a CAVE-like environment. It does not have all of the attributes of a CAVE (because of our own lack of space), but odors in it behave in the ways that we would expect them to behave in a CAVE.

Our experience so far indicates that the problems with a large space are similar to those of the booth, only more severe. It takes longer for odors to be perceived. The time lag can range from two seconds to several minutes, depending on where the person is standing. This means that it would be difficult to display changes in odors or concentrations in response to a person's movements about the CAVE. It would also be difficult to display odor events such as a whiff of an odor that might be carried on a breeze. Even more significant is the time required to remove an odor from the room, which can be a matter of minutes. The most odor changes that the PI has seen claimed for an odor environment employing laminar flow is 100 per hour. Thus, while an ambient odor can be established, successive odor events are more problematic.

Odors which are obvious in the HMD and subtle in the booth may be imperceptible in the CAVE. There are several reasons this might be true. New odors are diluted by the air already in the environment. This dilution not only reduces the concentration, it also blurs the edges of the odor sensation by making the transition between no odor and odor take a period of time. During the transition, the person may be adapting to the lower concentrations which makes them less sensitive to the odorant, thereby raising their threshold so they do not detect it at all. When this possibility has been pointed out to odor scientists, they claimed that these thresholds are biologically fixed. However, the studies they are thinking of do not prove their point, because they always alternate

between no odor and an odor threshold. They never go from one intensity to another directly. Since this is a completely testable hypothesis, my comments may have spurred them to look at this issue more formally. If not, we will examine it further ourselves for our own practical purposes.

There are two possible reactions to what we have learned. In the first we try to optimize the performance of the room, both in the existing CAVE configuration and in the traditional floor-to-ceiling environment. The second is to abandon the requirement to odorize the entire room by asking the participant to carry a portable delivery system akin to that to be worn with an HMD.

In the first case, the problem of odorizing an enclosed room has been well studied, although not from the point of view of virtual reality. In some cases, odorized air is simply blown in and exhausted by a standard office air conditioning system. No concern is shown for what happens to the exhaust air in these less rigorous systems. In other cases, very elaborate systems are developed for maintaining floor-to-ceiling laminar flow. Since the air is continually being changed, a great deal of air must be odorized and moved. Instrumentation in the environment monitors the concentration of the odorant and adjusts the input to maintain the desired level. Even with all of this sophistication, existing odor chambers have been used for studying rather simple odor compounds and often for examining just the effects of a single odorant—such as an environmental pollutant—on human performance.

While there are systems for odorizing office buildings with a sequence of odors that changes slowly throughout the day, none of these systems has the goal of presenting rapidly changing sequences of complex odors which consist of many different compounds.

A number of techniques have been tried: passive evaporation from large drums of odorants, heating of large volumes of odorants, bubbling air through odorants, and flash evaporation. Passive evaporation works fine with simple odor compounds; however, surgery is accompanied by complex odors which consist of many constituents, each with a different boiling point. Passive evaporation or slow heating allows the more volatile ingredients to evaporate first, leaving the less volatile components behind. Thus, the odor changes over time as this differential evaporation proceeds.

The obvious solution would seem to be to add as much heat as possible, assuring that all of the materials would evaporate at once. However, heating a large volume of odorant has the hazard that some of these materials are potentially explosive by themselves and others contain ingredients that will react with each other—if not to combust or explode, at least to alter the perceived odor.

Heating the material just above the boiling point of the least volatile ingredient would seem to minimize, if not eliminate, the danger of explosion. However, the evaporation of the most volatile substances will tend to cool the heater, so that again the odor components are released sequentially rather than simultaneously.

The solution is to provide enough thermal mass at a temperature just above the highest boiling point to assure the complete evaporation of all of the ingredients. By heating a large mass of brass to the desired temperature, it stores enough energy at that temperature to vaporize all of the components without being cooled by the evaporation. A system based on this design exists at the Environmental Protection Agency where it is used for testing the effects of odors on people in the workplace. This system however only delivers a single odor compound. It has no provision for rapidly changing from one substance to another. Since it would take some time to change the temperature of the thermal mass, it is not clear whether a single mass operating at a single temperature would be sufficient for a wide range of odorants or whether materials with different boiling points would need to have their own heaters. Even a single odor delivery system based on this principle would cost at least \$40K. If a single heater could be used to display multiple complex odorants, the cost of a multi-odor system might not be too much higher than that. On the other hand, if multiple heaters were required, the cost might go considerably higher. On the other hand, eliminating some of the sophisticated monitoring, recording, and control technology from the current design might reduce its cost somewhat.

This elaborate system still does not provide any ability to position odors within the room environment to define odor sources and gradients and ephemeral events. Using selectable jets to display localized odors might work, but would further increase the cost.

A possibly acceptable alternative is to forget about odorizing the entire room and instead odorize only the air near the person by having him wear a delivery system which would present odors in front of his face through a device akin to a headset microphone. While some portion of the exhaled odorants would be rebreathed as part of the next breath, the volume of odorant presented is nowhere near enough to odorize the entire volume, meaning that it will quickly be diluted by the ambient air to the point where it will no longer be detectible. In addition, the air in the room would be continuously vented through the ceiling.

This technique is a portable version of the one used in modern theme park theaters which include odors in their experiences. Early odor theaters failed because, once presented, odors lingered indefinitely. But in Japan, special theaters for movies and simulation rides have delivery systems for each seat, either on the back of the seat in front or in a section of the viewer's seat that wraps around his head. A ceiling exhaust system assures that previously displayed odors are continuously removed.

The difference is that like the HMD delivery system, this approach can vary the odor and concentration rapidly in response to the actions of the participants or the demands of the scenario. Rapidly changing events such as a fleeting whiff of an odor can be depicted. This will make the sense of connection between the participant and the virtual world displayed more immediate. This may be important because while the CAVE is the most visually effective immersive display, its interactivity is limited, because its knowledge of the participant's body is limited to the location of the participant's head and the position and orientation of a hand-held wand.

While an encumbering olfactory display technology is counter to the spirit of the CAVE, which seeks to be less encumbering than HMDs, it may be welcome in some scenarios such as those that might be used for training medics.

Odorant Survey and Odor Development

A second area of effort related to odor delivery was intended to discover what odors would be needed for surgical simulations and to identify sources for procuring them.

There were three types of odors that were to be investigated: the man-

made odors present in operating rooms, the odors emanating from the patient's body, and the odors that would be present in emergency medical situations in the field.

While the assurances from odor experts had been that all of these subjects had been well studied and that at least some of the odorants required would be available off-the-shelf, that proved not to be the case. A study of these issues was performed and the resulting report is attached to this report as Appendix I.

First, it was found that the surgical theater for elective surgery is not as odorous as one might expect for a variety of reasons. In addition, the surgeon's perception of the odors that are present is confused by the mask he wears over his mouth which will tend to capture previous odors and reduce the entry of new ones.

Because surgeons must wear a lot of gear such as gloves, hair nets, face masks, etc, surgical rooms are kept at a fairly low temperature for their comfort. The low temperatures mean that there is less odor, because there is less tendency for odorous materials to vaporize or to stay vaporized. A recent study suggests that low temperatures are bad for patients, because they lower the patients' resistance to the germs that are already in their bodies. If this is true, it is possible that operating theaters will be warmer and therefore more odorous in the future.[3]

In addition to the low temperatures, the ventilation system is blowing clean air down on the patient and removing air from the room on a regular basis. Also, in elective surgery, the patient is likely to have been bathed and given an enema prior to the procedure. In this case, the consequences of nicking the bowel are not as odorous as they would otherwise be.

However, while routine surgery does not smell as much as we might have expected, emergency surgery is a completely different matter. Patients not only have not been prepped and bathed, but they enter fully dressed. They may well smell from sweat, bad breath, or alcohol. They may also be covered in their own bodily fluids such as blood, urine, feces, or vomit. In a simulator for training medics or paramedics to perform at injury sites, there would also be the odors associated with car accidents, chemical spills, fires, gasoline, deisel fuel, explosives, etc.

The man-made odors present during surgery comprise the alcohol- and iodine-based disinfectants, the soaps, and materials like the anesthetics which may not smell themselves but which like halogens have been given an odor (thymol) to make them detectable.

We have gathered a variety of these materials and have tested them in our delivery systems. The first problem is that we must use the products themselves rather than just the components that contribute to their smells. (We have been contacting the manufacturers to see if they will make up formulations that contain just the odorous components—so far without success.) In the case of alcohol- or iodine-based disinfectants, there is not too much problem in using them. However, alcohol must be introduced carefully because we have found that it is quite easy to get intoxicated from breathing its fumes. Iodine-based surgical scrubs present a different problem. They are very subtle odors that are difficult to present. They can be presented successfully in the HMD delivery system, poorly in the booth, and are undetectable in the CAVE environment. The soaps present a different problem in that they are likely to dry out in evaporation systems and likely to foam in sparging systems in which air is bubbled through the liquid odorant. Thymol, which smells like grapes, can be used to represent at least one commercial anesthetic.

Whereas as our odor experts had believed that the body odors had been well studied and would be available from the various research labs, this proved not to be the case. The underlying materials that produce the odors had been characterized, but less had been written about the odors themselves. Very few of the odors had been synthesized scientifically or approximated by aesthetic perfuming. Almost none of the odors available were immediately suitable for surgical simulation. Instead, while they might have seemed to be related, they had been developed for quite a different purpose altogether. For instance, IFF (International Flavors and Fragrances Corporation) had an odor that they represented as a blood/liver odor. It is much too powerful to portray the rather subtle odor of blood. Similarly, other odors had been developed for use in testing deodorizing products for kitty litter and baby vomit. However, these just had to be masked like the real thing, they did not really have to smell exactly like it.

As a result of this discovery, we postponed the study of outdoor and

battlefield odors and made an effort to try to recreate some of the odors needed for surgical simulation using the analysis from the published literature together with subjective perfuming. The odors produced included bladder contents, intestinal contents, and stomach contents. We also have an odor for representing infection (pseudomonis) which would be needed for simulating burst appendices. These odors all suggest the materials they are supposed to represent, but cannot be identified out of context as the real materials can be. Only the external body odor (axillary odor) is extremely convincing; however, it was the result of a several year project just to represent it. The formulations of the odors created are included as Appendix II.

There are also odors that we would like to represent such as each of the tissues such as liver and kidney that have their own smell. There is the smell of burning flesh from cauterizing with the Bovi Knife. Bone has a distinctive smell when it is being drilled during orthopedic surgery. In emergency situations, there might also be the odors of burn preparations.

Unfortunately, the process of synthesizing an odor typically involves mixing quantities that are too small to be of practical significance in testing odor delivery systems. Therefore, an unexpected additional effort was necessary to produce sufficient quantities of these materials for testing. Increasing the quantity of a chemical involves a different kind of effort and some of the materials involve difficult synthesis steps. Therefore, some of the materials could not be produced in sufficient quantity to be useful. Another odor, the blood/liver odor, is proprietary to IFF and could not be available unless they wanted to produce it. They have provided a summary of its ingredients but not its exact formulation. Since this material is not very convincing, we do not regard the problem of representing this odor as solved.

Of the odors that we now have, only the external body (axillary) odor is perfectly convincing. We only have a small quantity and it would be difficult to increase the quantity because of the chemistry involved. Fortunately, it is quite strong and we have enough to test in the HMD and booth environments. In scheduled surgery, the patient would have been bathed and this odor would not be present, but it would be useful in depicting emergency room scenarios and battlefield casualties.

The other odors suggest the materials they are to represent, but are missing some of the elements. We have exhausted the skills of the chemist who was performing this task for us and will engage a professional perfumer to see if she can improve what we have. We also want to see if she can start from scratch to produce a better blood odor. This smell should be much more subtle than knock-your-socks-off material we have from IFF.

The concern is that there are only 200 perfumers in the world, all trained by and most employed by major corporations. They typically make \$200K per year, which is very expensive by the standards of this project. Therefore, we have reallocated some of the funds originally earmarked for the study of the effects of odors on performance of surgical skills to apply more to the needs of the simulations.

Studies of Odor Effects on Performance

In addition to the faith that adding odors would lead to a better sense of presence and therefore to more effective training, there was the hope that odors might be used to enhance some of the skills that are needed during surgery, such as spatial reasoning and manual dexterity.

Two studies were performed to investigate these issues. These were both laboratory studies not involving virtual reality. The thought was to see if odors would have any effects outside of virtual reality and then later to see if they could be replicated within virtual reality. If the results were the same, that would suggest that the simulations were successful. If not, it would indicate that the simulations needed to be improved.

The first study examined the effect of odors on the performance of five tasks that have long been used in the psychological field to study spatial reasoning. (Appendix III) The result of this study was that some odors had a significant positive effect on the performance of some tasks. On one task, the benefit provided by peppermint was not only statistically significant, but of great enough magnitude to be of practical importance as well. A 10% performance improvement was observed with a significance of .003. Since 90 subjects were run for an hour apiece, this study should have as much authority as any done in olfactory research to date.

Given the success of the first study, we had high hopes for the second one which was to measure the effects of odors on the performance of manual dexterity skills. (Appendix IV) Again, this was a laboratory study not performed in virtual reality. In this case, we had a negative result. There was no evidence that the performance of any of the tasks was affected by the presence of any of the odors tested. Since some of the manual dexterity tasks involved at least some spatial reasoning, it is not obvious what conclusions can be drawn.

While peppermint is not an ingredient in realistic simulation, the first result suggests that if peppermint was added to actual surgical environments, an improvement in performance might result. However, the second result suggests that the performance of routine surgery which are essentially mechanical for the surgeon will not be affected by odors, but particularly tricky procedures may be. Since previous studies have shown that peppermint can improve vigilance, there may be a practical benefit to using it in certain situations, such as very complex or very long procedures.[4]

The original intent was to perform formal laboratory studies the first year before we had an odorized VR system working. Then, in the second year, less formal studies designed at the Monell Chemical Senses Center would be performed at Artificial Reality where the prototype systems would be. What we discovered during the first year is that formal studies of odor effects must involve huge numbers of subjects (90) to get definitive results. The large number of subjects is required because of the tremendous individual differences in ability to smell and awareness of odors. Since there are many issues to investigate and we are initially only interested in discovering obvious effects rather than subtle ones that can only be detected through statistics, we have decided to suspend formal studies in favor of preliminary exploration of a number of issues.

For instance, we will examine whether odors can serve as alarms and where they fit into the hierarchy of the senses when they are. Preliminary results that seem born out by our investigations will be proposed for further research to be done by ourselves and others for the future. Another problem with formal studies is that subjects typically have little experience making judgments based on odors, so little is learned about how trained personnel might use odors after long experience with them. A few researchers who are gaining experience throughout the project will

provide at least a few data points. A few long term subjects will also be involved to get their impressions. However, given the expense of formal studies and the equivocal nature of their results, we have decided to forego more such studies until we are sure that the simulation issues are well in hand.

At the end of the program, it will be desirable to test the effect of odors on the subjective perception of presence in virtual reality simulations. For the purpose of this project, we believe that these tests should be done as close to realistic simulation as possible. This means connecting our olfactory displays to the surgical simulators being developed by other groups. We have talked to HT Medical about this and they are interested in including our capability in their systems, at least on a trial basis.

Subcontract Change

In the original proposal, Monell Chemical Senses Center was to develop a preliminary delivery system, identify and acquire the odorants, and perform the studies of the effects of odors on performance. Since all of these efforts were to taper off in the second and third year and since the acquisition of the odorants needed for surgical simulation has proved to be much more difficult than they had anticipated, we have decided to reallocate the funds budgeted for them to provide closer support for the technical efforts required in producing the simulations.

In particular, we will engage a perfumer for the specific tasks of improving the odors we have, developing one or two that we do not have, and identifying the odorants available for simulating outdoor environments and battlefield casualty situations. We may also engage a physical chemist who can give us some advice on the behavior of the odorant materials in the delivery system. Finally, we may decide to have some of our odorants microencapsulated which requires a specialized service and costs at least \$5K per odorant to get done. We will see if we can get some support of this effort from industry. Previously, we deferred to Monell's contacts, but feel that we may be more successful than they were if we cultivate our own.

Future Work

In the first year, we have developed a sketch of a complete virtual reality system and have developed a small repertoire of odors that we can put

together virtual environments to test the efficacy of odor display. At the same time, we will flesh out the current VR testbed to improve the performance of each of the constituent technologies.

In particular, in the next few months, we will make the current delivery system movable, if not strictly portable. We will mount the mobile equipment on an IV-pole of the type that patients push around in hospitals. The participant must carry or push the following gear:

1. the olfactory delivery system
2. a compressed air bottle to drive it
3. an air flow regulator
4. a computer to control the odor delivery system
5. any sensors or targets required by the tracking system
6. a battery to power the computer and other circuitry
7. the RF equipment required to receive HMD images, 3D audio, and odor delivery commands
8. the RF equipment required to transmit voice commands and conversation back to the computer.
9. the RF equipment required to transmit tracking data back to the computer, if the tracking technique demands it

Clearly, this is quite a load, although much of it represents material that VR participants will have to wear if they want to go wireless, whether or not they want olfactory display. Making it all portable would require a considerable packaging effort which would postpone our experience with the display of odors during ambulatory behavior. The intermediate step of pushing the gear around lets us experiment with the issues that we are interested in while allowing time for the marketplace to start to deliver some of the other components in portable form on its own.

Initially, we will combine the wireless odor delivery with a single cell of wireless tracking. If we can get the Ascension to work with a standard dive bottle, we will use that. If not, we will develop one of the optical technologies for that purpose. Assuming that this effort is successful, we will expand the tracking capability to operate over a large enough area that we can portray odors in a space in which the participant must move around. This capability would be very useful for medic training. It would be valuable for training other dismounted personnel as well. It is possible that it can be combined with some of the systems that permit individuals to run on a treadmill or pedal their way around. When they have to walk

around a casualty, natural movement will almost certainly be superior to more contrived techniques.

Now that we have the odor delivery function represented and understand more of the issues in its design, we will examine the problems we have discovered in light of the actual odors that we will use. One goal is to be able to present the odors that are now too subtle to be detected. This will require us to generate higher concentrations of odorized air. This goal would also reduce the amount of pressurized air that we must carry or increase the interaction time for a given volume of air. If at all possible, we will seek to odorize the main air flow and to use natural breathing to pull the air through the delivery system. This would eliminate the weight of the gas bottle and regulator or the weight, power requirement, and vibration of a pump.

We will examine these design issues in the context of HMDs, booth environments, and CAVE environments with the highest priority on the first and second and the lowest on the last. The reason for these priorities is that the first two are certain to be needed for medical training scenarios, whereas the CAVE is not currently employed for this purpose.

To the degree we work on a CAVE, we will favor the portable delivery system rather than the environmental one which we know will be expensive to do well. If funds remain at the end of the project, we will look at this problem further. It should be noted that we do not in fact have a CAVE. Instead, we constructed a room of similar dimensions. If funds permit, we may create a single-sided CAVE using one stereo projection screen; however, we have no thought of constructing a full CAVE system with four workstations and four projectors generating stereo images.

We will also do some preliminary prototyping of alternative designs for the advanced delivery system. We are sure these ideas will work for some odors, but must see if they can be made to handle the full range of odors that we might want to use for medical training and other virtual reality scenarios.

We will also engage a perfumer as a consultant. We found that we need someone who has knowledge of a wide range of complex odorants and their sources at their fingertips rather than someone who knows a great deal

about the human response to a few simple compounds. Her task will be to try to improve the surgical odors we have, to develop a much better blood odor, to identify a repertoire of off-the-shelf outdoor odors, and to identify the odors that will be required to represent the smells of the battlefield to see what is needed, what is available, and whether these materials are hazardous.

The behavioral studies will be limited to the problems that are needed to implement virtual reality simulations and the techniques that will be needed to make such portrayal work well. We will look at odor alarms and odor codes in a preliminary way. We will also determine how well people can follow gradients. We will also see whether the stereo display of odors containing a trigeminal component can be used to steer the person's attention. We will examine how accurate odors must be and how aware people are if the odor display does not match the graphic context in which it is found.

If we find that one of our approaches to the advanced delivery system is going to work for the odors we are concerned with, we will proceed with its fabrication, so that we can get maximum experience with using it before it is delivered.

In the third year, we will perfect the technologies we have developed, incorporate them into complete scenarios, and evaluate their effectiveness with another research group's surgical simulators.

Conclusions

From the experience of the first year, it is clear that some odors can be added to virtual reality simulations using conventional technologies. It is also clear that there is not likely to be a universal delivery system that can operate with all odors in all virtual reality formats. Instead, each virtual reality format will need its own delivery techniques and there are a host of ideosyncratic issues that are specific to the physical properties of the various odorants.

Similarly, it is clear that the fragrance industry is organized for the aesthetic use of odors in perfumes and cosmetics, as well as in more prosaic products such as laundry detergents. The representation of real world odors is limited to those odors which are considered to be pleasing. Odor professionals find the idea of duplicating unpleasant odors to be

repugnant. Thus, the odors needed for medical applications are not only not on the shelf, it may be difficult and expensive to get all of the odors one might like to have created. At the same time, imitation is a pervasive practice in the fragrance industry, and the skills required to duplicate an odor are less exalted than those required to invent a completely new fine fragrance. Likewise, the outdoor and battlefield odors needed for field simulations are likely to be desirable for entertainment experiences as well as military training.

In addition to the use of odors to represent the real world, there is a body of evidence that suggests that odors can be used in a non-representational way to enhance memory, vigilance, and spatial reasoning. This suggests that odors also have a place in the design of other kinds of human-machine interfaces.

In the first year, we have probed all of the technological issues. We have a working set of odorants that will be sufficient to depict some kinds of surgical procedures and the delivery techniques to present them. In the future, we will seek to improve the constituent technologies and to test them in graphic environments that are closer to real applications.

Presentations & Publications

In addition to ARPA Principal Investigator Workshops

Myron W. Krueger, "How, When, and Whether to Participate in Virtual Worlds," Virtual Reality '95, Stuttgart, Germany, February 22-23, 1995, invited plenary speech described odor research.

Myron W. Krueger, "Encumbering --> Unencumbering Virtual Reality," VRMM95, International Conference on Virtual Systems and Multimedia '95, Sept 18-20, Gifu, Japan, invited paper.

Myron W. Krueger, "Reality Stinks," VRMM96, International Conference on Virtual Systems and Multimedia '96, Sept 18-20, Gifu, Japan, keynote.

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Appendix I

Odors for use in Virtual Surgical Training

Odor present in the operating theater can add greater realism and heighten the learning experience provided by virtual surgery training. In addition, olfactory stimuli can be emotionally poignant they can aid the surgeon's long-term retention of the procedures. Both background odors within the surgically theater as well as patient related odors have been explored. The latter not only add to the realism of the training but may also serve to alert the surgeon as to whether a vital organ has been accidentally nicked.

Mixtures of organic compounds of low molecular weight (e.g. 30 - 300 g/mole) that have a vapor pressure at body temperature, give rise to various body odors of the human body. The odors produced at various body locations or within organs are determined by the type and number of microflora present (on body surfaces such as the underarm or feet or in the intestines) and the substrates present.

Complexity is often the case for odors produced on or in the body. These odors may consist of dozens to hundreds of components some or all of which may contribute to the odor. Commonly encountered odors that contain hundreds of constituents include foods and beverages such as roasted nuts, coffee and strawberries. In certain instances, one or more of the volatiles from these mixtures may closely resemble the overall aroma: these volatiles are referred to as the "top notes", "impact odors" or "character impact compounds".

Odors from or within the human body have not drawn the attention of researchers to the level that food-stuffs have; however, they are just as complex and difficult to reproduce. Further the odor constituents are not always commercially available.

In general research has primarily focused upon the volatiles emitted by humans since they have the potential to supply important information about the physiological status of the

body. Prior to the development and use of modern, diagnostic instrumentation, physicians often relied on olfaction as an aid in diagnosis of various disorders. However, the majority of compounds providing the "olfactory information" generally occur in the concentration range of 10^{-11} - 10^{-8} g/L of air. The level of analytical sensitivity and specificity necessary to obtain identifications on such levels have only been available to organic-analytical chemists in the past 30 years. Therefore the diagnostic potential of monitoring body volatiles is still relatively untapped and developing with most modern health professionals knowing little or nothing about the origins of diagnostic body odors or their pathophysiological significance.

Research has been done to document the constituents present in the headspace (vapor phase) above a number of the odor producing areas of humans; however for some of these odors, the more critical experiments to pinpoint the important odor causing compounds have not been performed. For several of these body mixtures it has been possible to document both the vapor phase constituents and the "impact odors". Other body odors, particularly, those from internal organs may be created via the mixing of certain odors which are thought to resemble the mixture of volatiles from that site.

Some investigators have tried to collect and identify whole body odors by placing individuals in closed glass containers, clad only in underwear, and passing pre-purified air over them. The resultant volatiles were collected and concentrated using solid absorbents. Although numerous odoriferous compounds were found, many of the chemicals identified in these studies appeared to be exogenous in nature and the result of urban atmospheric pollution, diet, cosmetic and laundry products. These studies took place in the late 1960's and early 1970's and were, in part, initiated by the desire to develop "personnel detectors" for use in Vietnam/guerilla-type warfare.

More than 300-400 compounds were detected in the experiments using "whole humans" with about 135 compounds identified. These are listed in Table 1. No attempt was made to identify odors; however, the structural nature of many of the compounds suggests that although many were odoriferous, they appear to be mostly environmental contaminants. More successful investigations of characteristic human odors have centered upon the odor producing areas of humans.

Those body and internal organ odors we've been able to document from both our own research and from the literature are listed below. Those compounds which have been identified in the vapor phase of these odors are listed in Tables. In a number of cases, the research results linking odors to physiological and pathological states are noted in the summary tables.

- (a) Human "body odor": axillary and upper torso odors - see Table 2
- (b) Oral/lung/esophageal - see Table 3 and 3a
- (c) Genital region - see Table 4
- (d) Blood/liver odor - see Table 5
- (e) Stomach contents - see Table 6
- (f) Urine odor - see Table 7
- (g) Corpse odor - this odor mixture is available from Sigma Chemical Company.

However it is a proprietary mixture whose contents we are still trying to obtain using a confidentiality agreement.

- (h) Fecal/large bowel - see Table 8
- (i) Foot odor - see Table 9
- (j) Infected burn wounds - see Table 10

Background odors present in surgical theater which are readily obtainable for use are listed below. Although the odors associated with these products, maybe available from manufacturers, they may be used as is to provide the necessary odor. We are however trying to obtain either the composition of the odors used in these products or samples of just the fragrances for use in our studies.

- (a) Antimicrobial soaps - odor varies with the brand used
- (b) Antimicrobial surgical preparations used for sterilization and disinfection; these include chlorhexidine gluconate, iodine and glutaraldehyde based scrubs with odors added according to brand.
- (c) Odors associated with local anesthetics. These may be "fruity-type" odors such as banana and cherry.
- (d) Odors associated with general anesthetics. Although these are for the most part halogenated organic gases with little distinct odor, some such as Halothane have an odor added to them (eg. thymol).

TABLE 1. Volatiles from Whole-Body Headspace

Compound Type	Number Found	Straight-Chain	Branched	Cyclic	Other Constituents and Comments
Saturated hydrocarbons	15	9	4 (all methyl)	2	n-C ₁₂ was the largest in this group
Unsaturated hydrocarbons	23	14	6 (ethyl and methyl)	3	Pinene, camphene, and cyclohexene
Alcohols	24	10	8 (ethyl and methyl)	1	Three unsaturated ones, ethylene glycol, and glycerol
Acids	2	2	-	-	Lactic and pyruvic
Amines	8	5	2	-	NH ₃
Ketones	9	6	2 (all methyl)	-	Cyclohexanone
Aldehydes	8	6	1 (ethyl)	-	Crotonaldehyde
Esters	6	6	-	-	Methyl, butyl, amyl and allyl esters
Nitriles	4	4	-	-	C ₅
Mercaptans (thiols)	5	5	-	-	C ₁ , C ₄ , C ₅ , C ₆ , and C ₇ reported
Ethers	2	2	-	-	Dimethyl and diallyl ethers
Halogenated hydrocarbons	1	1	-	-	A dichlorobutane
Aromatic hydrocarbons and heterocycles	24	N,O,S-containing compounds all found.			

TABLE 2*,¹ Compounds Identified in Combined Male and Female Body Odors

Compound (listed by decreasing volatility)	Molecular Weight	Chromatographic		Present in Combined Female (F) Male (M) Extract
		Retention Time (Ethyl Ester Unit)	Unit	
n-hexanoic acid ^G	116	12.20		F/M
2-methylhexanoic acid ^G	130	12.39*		F/M
3-methylhexanoic acid ^G	130	12.55*		F/M
(E)-3-methyl-2-pentenoic acid	114	12.60*		F only
dimethylsulfone ^G (C ₂ H ₆ SO ₂)	94	12.63		F/M
γ-C ₈ -lactone ^G	142	12.79		F/M
4-ethylpentanoic acid ^G	130	12.97		F/M
(Z)-3-methyl-2-hexenoic acid ^G †	128	13.10*		F/M
2-ethylhexanoic acid	144	13.13		F/M
n-heptanoic acid ^G	130	13.22*		F/M
2-methylheptanoic acid ^G	144	13.36*		F/M
(E)-3-methyl-2-hexenoic acid ^G †	128	13.50*		F/M
phenol	94	13.65		F/M
γ-C ₉ -lactone ^G	156	13.91		F/M
n-octanoic acid ^G	144	14.28*		F/M
2-methyloctanoic acid ^G	158	14.41		F/M
4-ethylheptanoic acid ^G	158	14.81*		F/M
7-octenoic acid ^G	142	14.95*		F/M
2-piperidone ^G	99	14.55		F only
γ-C ₁₀ -lactone ^G	170	15.01		F/M
n-tetradecanol ^G	214	15.21		F/M
n-nonanoic acid ^G	158	15.28		F/M
2-methylnonanoic acid ^G	172	15.38		F/M
(E)-3-methyl-2-octenoic acid ^G	156	15.45*		F only
4-ethyloctanoic acid ^G	172	15.64*		F/M
("goat acid")				
unsaturated C ₉ acid ^T	156	16.04*		F/M
n-decanoic acid ^G	172	16.28		F/M
2-methyldecanoic acid ^{T,G}	186	16.36		F/M
unsaturated C ₁₀ acid ^T	170	16.46*		F/M
4-ethylnonanoic acid ^{T,G}	186	16.69*		F/M
9-decenoic acid ^G	170	16.90*		F/M
n-hexadecanol	242	17.24		F/M
n-undecanoic acid ^G	186	17.29		F/M
4-ethyldecanoic acid ^{T,G}	200	17.66		F/M
10-undecenoic acid ^G	184	17.76*		F/M
benzoic acid ^T	122			
→ Volatile Steroids ⁺⁺ ←				

¹The following symbols are also used in this Table: T = tentatively assigned by mass spectral data; G = correspondence of mass spectrum and relative chromatographic retention times with commercially available or synthetic sample.

* = Compounds judged to be important contributors to axillary odor, from data reported in male samples.

‡Adapted from Zeng et al (1996) J. Chem. Ecology vol. 22, pp 237-257.

† The E:Z ratio differed in males and females: males 10:1; females 16:1.

⁺⁺only androstenone was seen in the characteristic odor fraction of the male extracts; only androstenol found in the characteristic odor fraction of the female extract.

TABLE 3

Salivary and Lung Air Volatiles

Hydrogen sulfide*	Hydrogen sulfide*	2-Ethyl-1-hexanol	
Methyl mercaptan*	Methyl mercaptan*	Decanal	
Dimethylsulfide*	Dimethylsulfide*	Acetic acid*	
	Acetone	Propanoic acid	Phenylacetic acid
	Dimethyldisulfide	Isobutyric acid	4-hydroxyphenylpropanoic acid
	Limonene	Isovaleric acid	
	Pyridine*	Methol	
	Acetoin*	Aniline*	
	2-methyl pyridine	o-toluidine	
	Octanal	Dodecanol*	
	Dimethyltrisulfide*	Phenol*	
	Nonanal	Tetradecanol	
	Dichlorbenzene*	Caprolactam	
	1-Octen-3-ol*	Indole	
		p-cresol*	
		Skatole	
		Diphenylamine*	

*Indicates compounds which characterize oral diseases and anaerobic oral infections leading to halitosis.

TABLE 3a

Oral/Breath Volatiles Associated with

Oral and Systemic Pathologies

<u>Pathology</u>	<u>Volatile Compounds of Importance</u>
SYSTEMIC:	
<u>Diabetes mellitus:</u> (ketonic breath)	acetone and other ketones
<u>Uremia/kidney failure:</u> (fishy odor)	
dimethylamine	[(CH ₃) ₂ NH
trimethylamine	(CH ₃) ₃ N]
<u>Lung Carcinoma</u>	a. Acetone, methylethylketone and n-propanol b. Aniline and o-toluidine
<u>Upper Respiratory/Oropharyngeal Carcinoma</u>	C ₂ -C ₈ , normal and branched organic acids
<u>Liver Disease</u>	a) Noncholestatic: H ₂ S, limonene b) Primary biliary cirrhosis: H ₂ S c) Decompensated Cirrhosis of the liver: (Fetor Hepaticus) C ₂ -C ₅ aliphatic acids, methylmercaptan (CH ₃ -SH), ethanethiol (CH ₃ CH ₂ SH), and dimethylsulfide (CH ₃ S CH ₃)
<u>Trimethylaminuria</u>	Trimethylamine
ORAL:	
<u>Periodontitis and other Periodontal Diseases</u>	Volatile sulfur compounds, pyridine, methylpyridines C ₂ -C ₅ organic acids.
<u>Persistent Halitosis from Anaerobic Tongue Plaque</u>	Volatile sulfur compounds, dimethyl di- and trisulfides C ₂ -C ₉ organic acids.

TABLE 4. Organic Constituents from the Female Genital Area

	Mol. wt.		Mol. wt.
Aliphatic acids		Aromatic compounds	
acetic	60	Aldehydes	
propanoic*	74	benzaldehyde*	106
n-butyric*	88	phenylacetaldehyde*	120
isobutyric*	88	furfural	96
isovaleric*	102	Alcohols	220
2-methylbutyric*	102	phenol	94
4-methylvaleric*	116	p-cresol	108
myristic	228	furfuryl alcohol	98
isomyristic	228	butylated hydroxytoluene	220
pentadecanoic	242	Acids	
isopentadecanoic†	242	benzoic	122
palmitic	256	p-hydroxyphenylpropionic*	156
palmitoleic	254	salicylic‡	138
stearic	284	phenylpropionic*	150
oleic	282	phenylacetic*	136
linoleic†	280	Nitrogen-containing	
		pyridine	79
		indole*	117
		uracil	112
		thymine	126
Alcohols	186	Lactams	
n-dodecanol	214	2-piperidone*	99
n-tetradecanol	242	Sulfur-containing compound	
n-hexadecanol	270	dimethylsulfone	94
n-octadecanol	130		
1-octen-3-ol			
Glycols		Hydrocarbons	
propylene glycol	76	n-pentadecane	212
ethylene glycol‡	62	n-hexadecane	226
glycerol	92	n-heptadecane	240
		n-octadecane	254
		n-nonadecane	268
Hydroxyacids		Miscellaneous	
lactic	90	cholesterol	386
		squalene	410
		urea	60
		p-hydroxymethylbenzoate	152
		o-hydroxymethylbenzoate	152
Hydroxyketones			58
3-hydroxy-2-butanone	88	Trimethylamine^b	
2-hydroxypropanone	74		

*Found in subjects who are acid producers

†Tentatively identified

‡Artifact

^a Adapted from Huggins, G.R. and Preti, G. Clinical Obstetrics and Gynecology, vol. 24, 355-377, 1981.

^bOdor characteristic of anaerobic infection with *Gardenella vaginalis* ("Bacterial vaginosis")

TABLE 5. Blood/Liver Odor*

<u>Compound</u>	<u>Molecular weight</u>
4-methyl-5-(β -hydroxyethyl) thiazole	143
1-octen-3-ol	128
methyl-2-methyl-3-furyl-disulfide	160
methional (3-methyl-thio-propionaldehyde)	104
4-hydroxy-2,5-dimethyl-3(2H)-furanone	128
difurfuryl disulfide	226
2-phenyl-5-methyl-2-hexenal	188

*This combination of odors was put together from a "library" of fragrance chemicals to recreate the blood/liver note by a creative perfumer.

TABLE 6. Stomach Contents/Vomit

The main odoriferous constituents (top notes) of stomach contents/vomit appear to be volatile aliphatic acids from digestive degradation of fats and oils. In addition stomach contents and vomit also contain hydrochloric acid (HCl) in unknown, albeit noticeable concentration. While HCl does not have much "odor" it is quite evident from its pungent-burning sensation in the oral cavity and nose

Acids in Stomach Contents and Vomit

HCl

formic

acetic

propanoic

isobutyric

butyric

isovaleric

valeric

isohexanoic

hexanoic

TABLE 7. URINE

More than 300 volatile chemicals have been identified in the urine of neonates, children and adult humans. Fresh human urine from a normal individual does not have a strong odor except in those individuals, generally neonates (and some adults), who suffer from amino acid or other metabolic disorders (such as diabetes or trimethylaminuria). Food derived metabolites may also influence the odor of fresh urine such as eating asparagus. Offensive and characteristic urine odors are encountered when urine is allowed to stand (e.g. uncleaned urinals and urine deposited in subway stations). Important volatiles for both odor and diagnostic purposes are listed below by compound classification.

Ketones: acetone; 2-butanone; 2,3 butandioni, 2-pentanone, 3-pentene-2-one, 3-hexanone; 4-heptanone; 2-heptanone; carvone

Alcohols: ethanol propanol; isobutyl alcohol; 1-butanol

Sulfur and Nitrogen-Containing Compounds: dimethylsulfide^{*}; pyrrole; n-methyl pyrrole; dimethylsulfone; S-methylthioacrylate[‡]; S-methyl-3-(methylthio) thiopropionate[‡]; dimethyltrisulfide; and tetrahydrothiophene[‡].

Aliphatic and Aromatics Acids: acetic; propanoic, isobutyric; butyric; isovaleric, valeric, caproia, lactic; α - and β -hydroxybutyric; γ -hydroxybutyric, α and β -hydroxyisovaleric and α -methyl- β -hydroxybutyric; phenylacetic^{*4}; hydroxyphenylacetic^{*}; phenyl propanoic; phenylcinnamic^{*}; phenol; p-cresol

Volatile Steroids: androstenol* and androstenone*

*indicates compounds that may provide important top-notes for urine odor

‡asparagus derived food odors.

TABLE 8. Large Bowel/Fecal Odors

Hydrogensulfide

Methanethiol*

Dimethylsulfide*

Dimethyldisulfide*

Indole

Skatole

Acetic acid

Propanoic acid

Isobutyric acid

Butyric acid

Valeric acid

*Indicates the "top "notes" in fresh fecal samples; however, the remaining compounds appear to complete the entire odor bouquet in healthy individuals.

TABLE 9. Foot Odor

Acetic acid
Propanoic acid
Isobutyric acid
Isovaleric acid*
Hexanoic acid
Heptanoic acid
Octanoic acid
Nonanoic acid
Methane thiol‡
Methylthioacetate‡
Dimethyldisulfide‡

*"Top note" present in individual with strong foot-odor

‡Sulfur compounds indicative of foot colonization with Micrococcus sedentaris - these are highly malodors compounds and exacerbate foot-odor problems in individuals infected with this organism.

TABLE 10. Infected Burn Wounds‡

Dimethyldisulfide

Dimethyltrisulfide

2-Aminoacetophenone*

2-Nonanone

2-Undecanone

Butanol

2-Butanone

1-Undecene

‡*Pseudomonas aeruginosa* is thought to be the major organism involved in these infections.

*"Grape" top note reported in these infections most likely arises from this compound

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Appendix II

Odor Recipes for Virtual Surgical Training

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Large Intestine Odor

<u>Chemical Name</u>	<u>Volume or Weight</u>
Dimethyldisulfide	30 ml
Dimethyltrisulfide	3 ml
Dimethylsulfide	0.25 grams
Skatole (3-methylindole)	5 ml
Acetic Acid	5 ml
Propanoic Acid	5 ml
Butyric Acid	5 ml
Isovaleric Acid	10 ml
n-Pentanoic Acid	5 ml
Water	3 ml
Propylene Glycol	400 ml

Stomach Contents

<u>Chemical Name</u>	<u>Volume or Weight</u>
12N (normal) Hydrochloric Acid	10 ml
Glacial Acetic Acid	2 ml
Water	10 ml
Isobutyric Acid	100 ml
Butyric Acid	50 ml
Pentanoic Acid	80 ml
Isovaleric Acid	70 ml
4-Methyl-Valeric Acid	0.5 ml
2-Methyl-Hexanoic Acid	0.5 ml
Propylene Glycol	100 ml

Pseudomonas Aeruginosa Infection

<u>Chemical Name</u>	<u>Volume or Weight</u>
Ortho-Amino Acetophenone	55 ml
Dimethyldisulfide	1 ml
Dimethyltrisulfide	1 ml
Water	50 ml
Propylene Glycol	300 ml

Body Odor

<u>Chemical Name</u>	<u>Volume or Weight</u>
<u>E</u> (trans)-3-Methyl-2-Hexenoic Acid	0.2225 grams
<u>Z</u> (cis)-3-Methyl-2-Hexenoic Acid	0.006 grams
Mixture of Isomers including <u>E+Z</u> -3-Methyl-3-Hexenoic Acid and 3-Methylidene-Hexanoic Acid	0.006 grams
Propylene Glycol	50 ml

Urine Odor

As noted in earlier correspondence, several of the principle ingredients in this IFF fragrance are proprietary; however, to that pre-fabricated mixture I added the ingredients listed below.

<u>Chemical Name</u>	<u>Volume or Weight</u>
Ethyl Alcohol, 180 proof	51.5 ml
Anhydrous (200 proof) Ethyl Alcohol	34.5 ml
Tyramine	46 grams
Para-Hydroxy-Phenylacetic Acid	5 grams*
Phenylacetic Acid	0.20 grams*
5 α -Androst-16-en-3-one	
(Androstenone)	0.05 grams

*Not in IFF mixture - added by G. Preti

Blood/Liver Odor

Proprietary to
International Flavors and Fragrances
Developed for Monell Chemical Senses Center
for Artificial Reality Corporation
for Advanced Research Projects Agency

Appendix III

The Effect of Ambient Odors on Visual-Spatial Task Performance

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Abstract

Ninety women and men worked on five visual-spatial performance tasks and completed mood, health and environmental quality questionnaires during exposure to one of three ambient odor conditions. Exposure to peppermint odor improved performance on two of the five tasks. Peppermint also tended to improve the well-being of women while lavender tended to have a beneficial effect on the well-being of men. The results have implications for occupational tasks (such as surgery) that require a high level of visual-spatial skills.

Introduction

Once basic necessities are met individuals become interested in improving upon what they have. In industrial countries it is estimated that people spend over 90% of their time indoors (Committee on Indoor Pollutants, 1981; Samet, Marbury and Spengler, 1988), therefore, it is not surprising that improvements to indoor home and work settings are the focus of more and more attention. As a part of this effort there is a growing interest in scenting the ambient air in homes and public spaces such as offices, schools and subways. The intention is to improve the mood, well-being and performance of the occupants. In Japan there are already hotels and banks which have air conditioning systems that emit different low-intensity odors throughout the day (Shimizu Corporation, 1988). But while there is a great interest in environmental scenting, few scientific studies have actually tested how ambient odors influence human beings.

A review of the literature concerning ambient odor's effect on mood shows that while several studies have found no mood effects associated with odor exposure (Warm, Dember and Parasuraman, 1991; Ludvigson and Rottman, 1989; Cann and Ross, 1989; Knasko, 1993), in general, pleasant odors have been found to improve mood while unpleasant odors have been found to have a negative effect (Ehrlichman and Bastone, 1992; Baron, 1990; Rotton, Barry, Frey and Soler, 1978; Rotton, 1983). One study that looked at a variety of pleasant odorants found reports of good moods during exposure to all of the odors but for certain ones there were stronger responses on specific mood scales (Warren and Warrenburg, 1993). Studies concerning the physiological effects of odor exposure also indicate that various pleasant odors can elicit different physiological responses (Torii, Fukuda, Kanemoto, Miyanchi, Hamauzu and Kawasaki, 1988; Lorig and Schwartz, 1988). This suggests that factors other than odor hedonics are involved.

Although historically people have used odors to improve their health there is also a scarcity of research concerning the effect of pleasant odors on the perception of health. This is all the more surprising since aromatherapy, an art that has regained popularity in recent years, makes many claims in this area. The studies in this area have shown that the presence of certain pleasant odors can reduce the number of health symptoms individuals report experiencing but suggest that the findings may be due to health-related associations the individuals may have with the odors rather than to any pharmacological effect of the odorants (Knasko, 1992; 1995).

The studies concerning the effect of ambient odors on task performance (i.e., tasks often encountered in offices, factories or schools such as verbal and math problems, vigilance, or typing) have been diverse in their findings. Five studies found no effect of ambient odor on task performance even though the types of tasks used were varied and differed in their degree of difficulty (Kirk-Smith, Van Toller and Dodd, 1983; Rottman, 1989; Baron, 1990; Knasko, 1992; Knasko, 1993). Of note is the fact that in two of these studies unpleasant odors were used. This implies that exposing individuals to malodors will not necessarily negatively influence their performance.

A negative effect of odor on performance was found in three studies (Rotton, 1983; Ludvigson and Rottman, 1989; Lorig, Huffman, DeMartino and DeMaro, 1991). Since in two of these studies a pleasant odor was used, it is unwise to assume that scenting a room with pleasant odors will have either no effect or a positive one.

In the study by Rotton (1983), only the more complex of the two tasks employed (proofreading) was negatively effected during odor exposure. This same task was used in a previously mentioned study where no odor effect was detected (Knasko, 1993). Subjects were exposed to unpleasant odors in both studies, but in one the odor was presented

continuously (Rotton, 1983) while in the other it was presented intermittently (Knasko, 1993). Therefore, a factor that may play an important role in the effect of odor on task performance is the odor's delivery schedule.

Four studies have found a positive effect of odor on task performance (Hashimoto, Yamayuchi and Kawasaki, 1988; Warm, Dember and Parasuraman, 1991; Baron and Thomley, 1994; Baron and Bronfen, 1994). In the first of these studies there was a decrease in the number of errors on a data-entry task when subjects were exposed to pleasant odors. However, the speed with which the task was completed also decreased, indicating that the results may have been due to a speed and accuracy trade-off. Of note, is the fact that in all four of these studies that found a positive performance effect, pleasant odors were used. Also of note is that the time frame of the tasks varied from a 5 min anagram task, to a 40 min vigilance task, to a multiply-week data-entry task. This implies that pleasant odors can positively influence the performance of tasks that vary greatly in the amount of time involved.

The present study was designed to investigate the effect of ambient odor on a category of tasks not previously tested, those involving visual-spacial skills. Visual-spacial skills are important in a variety of occupations and have been noted as one of the three major qualities required to be a good surgeon (Lippert and Farmer, 1984). If pleasant ambient odors can improve performance on tasks requiring these skills, it may be beneficial to add these odors to such settings as hospital surgery units.

The odorants used in the present study, lavender and peppermint, are two scents believed by aromatherapists to differ in their arousing nature. Peppermint is considered to be stimulating while lavender is considered to be sedative (Tisserand, 1990). There is some evidence in the scientific literature to support this notion (Torii, et al., 1988). These two

scents also were chosen for this study because they were two of the odors that in previous studies influenced task performance (lavender-negative effect, Ludvigson and Rottman, 1989; lavender-positive effect, Hashimoto et al., 1988; peppermint-positive effect, Warm et al., 1991).

From the above research it was hypothesized that peppermint would improve performance on the five spacial-visual tasks while lavender would have a negative effect. Since both odors were, in general, considered somewhat pleasant, both were predicted to improve mood over the no odor condition. Peppermint was hypothesized to have an effect on health symptom reporting, although the direction was not predicted since on the one hand it was possible that subjects could associate the odor with poor health (e.g., medicines) while on the other hand the odor could be associated more with good health (e.g., health care products such as toothpaste and shampoos). Lavender was not expected to influence health symptom reporting since it is not generally associated with health products or situations.

Materials and Methods

Subjects

A total of 120 individuals, 18-35 years old, were recruited from advertisements placed in the campus newspapers and posted around the campuses of 6 universities located in center and west Philadelphia. In a telephone interview, potential subjects were screened to eliminate individuals who were in poor health, who had allergies or sinus problems, whose primary language was not english, and who were familiar with the test center.

Ten subjects were eliminated from the analysis because they were not fluent in english (before this was added as a screening question), 5 individuals were eliminated because they were chewing gum, 3 were eliminated because they showed up with colds, and 12 were eliminated because of various testing-room disturbances or testing errors. Therefore, the

data analysis was conducted on a total of 90 individuals who were randomly assigned to three odor conditions (with 15 women and 15 men in each condition). Subjects were paid \$15 for their participation.

Experimental Odor Conditions

The three ambient-odor conditions used in this study were: no odor, peppermint odor, and lavender odor (essential oils from Aromatherapy Products Limited, Sussex, England). The testing room was scented as soon as the experimenter was notified that the subject had arrived at the testing center. Two perfume blotters, each containing 0.039 grams of peppermint or 0.047 grams of lavender, in the respective peppermint and lavender conditions, were taped out-of-sight underneath the testing table. The blotters were placed at either end of the table, one 30 cm from the examiner's chair and one 30 cm from the subject's chair. The air vents in the testing room were closed.

In pilot testing when the room was scented in this manner pilot subjects rated the intensity and pleasantness of the room odor and how alert and relaxed they felt, every 5 min for 1 hr. On average over the hour, pilot subjects in both odor conditions rated the room odor as moderately intense and pleasant (4 on a 9-point scale where 0 = does not smell at all and 8 = extremely strong, and 2 on a 9-point scale where -4 = extremely unpleasant and 4 = extremely pleasant, $n = 6$). On average, subjects in both conditions reported that they felt moderately alert (2 on a 9-point scale where -4 = extremely not alert and 4 = extremely alert). Subjects in the lavender condition reported their relaxation level to be, on average, fairly strong, while people in the peppermint condition rated themselves to be moderately relaxed (3 and 2 respectively on a 9-point scale where -4 = extremely unrelaxed and 4 = extremely relaxed).

At the end of the experiment, the testing room air vents were opened and the testing room was cleared of the odorant with a special air-purging system that is designed to completely turnover the room's air 12 times per hr. The testing room was allowed to purge for at least 30 min between subjects. In the no odor condition unscented blotters were used.

Procedure

Subjects participated in the study individually. They were first taken into an unscented room where they signed a consent form and completed the Perceived Stress Scale (Mind Garden, Palo Alto, CA). This scale consists of ten questions that ask individuals how much stress they feel they experienced in various areas of their life during the past month. Subjects respond to a question by circling a number from 0 to 4 where 0 = never and 4 = very often. Total scores on the scale can range from 0 (very low level of perceived stress) to 40 (very high level of perceived stress).

After completing the stress scale they were taken into a testing room that was scented according to the experimental odor condition to which they had been randomly assigned. The room contained a table and two chairs, one for the subject and one for the experimenter. Subjects completed five timed paper-pencil tests that they were given in random order. To increase stress during all five of the tests, the experimenter announced the number of minutes left to finish at each one-minute interval.

One of these tests was the Guilford-Zimmerman Aptitude Survey: Part 6/Spatial Visualization (Consulting Psychologist Press, Inc., Palo Alto, CA). It is a 10 min, 40-item test which measures the cognition of figural transformations i.e., an individual's ability to mentally manipulate visually presented concepts (Sweetland & Keyser, 1986). The subject is asked to visualize the outcome when a black and white, two-dimensional representation of a

wind-up alarm clock is moved in various directions. The total test-score is calculated by subtracting $1/4$ the number wrong from the number right.

A second test was the Guilford-Zimmerman Aptitude Survey: Part 5/Spatial Orientation (Consulting Psychologist Press, Inc., Palo Alto, CA). This is a 10 min, 67-item test that measures the cognition of figural systems i.e., an individual's ability to perceive the arrangement of items of visual information in space. The subject is shown two similar black and white perspective pictures and must determine which way the second picture has changed direction or position from the first picture. The total test-score is calculated by subtracting $1/4$ the number wrong from the number right (Guilford & Zimmerman, 1981).

The Employee Aptitude Survey: Test 3/Visual Pursuit, Form A (Psychological Services, Inc., Glendale, CA) was a third test used in the study. This one page, 5 min, 30-item test measures an individual's ability to make rapid, accurate, scanning movements with the eyes. The page is filled with a maze of lines that weave their way from their starting points (numbered 1 to 30) on the right-hand side of the page to a column of boxes on the left-hand side. The task is to identify for each starting point the box on the left at which the line ends. The total test-score is calculated by subtracting $1/4$ of the number wrong from the number right (Ruch & Stang, 1994).

A fourth test used in the study was the Closure Speed-Gestalt Completion test (London House, Park Ridge, IL). This 3 min, 24-item test measures an individual's ability to see apparently unrelated parts as a meaningful whole, to construct a complete picture from fragmentary material and to comprehend and unify a complex situation. Each item consists of an incomplete picture drawn in black on a white background. The subject must identify the object in the picture. The total test-score is equal to the number of correct items (Human Resources Center of The University of Chicago, 1959).

The Closure Flexibility-Concealed Figures test (London House, Park Ridge, IL) was a fifth test used in the study. It is a 10 min, 49-item test that measures an individual's ability to hold a configuration in mind despite diversions, as demonstrated by perceiving a given figure embedded in a larger, more intricate drawing. For each item the subject indicates in which of four complex drawings a given figure appears. The total test-score is calculated by subtracting the number wrong from the number right. (Baehr, 1965).

After the subjects completed the five tests they were given three questionnaires to complete. The first concerned physical symptoms that subjects were currently experiencing. It consisted of six 10-point scales that assessed health symptoms and two 10-point scales that assessed hunger and thirst. The scales ranged from 0 to 9. Marking 0 on a scale indicated that the subject did not have the symptom, while marking 9 on the scale indicated that the symptom was severe. The health symptoms included: irritated eyes, headache, fatigue/malaise, stuffy/runny nose, dry/sore throat and dry/itchy skin. These are symptoms often reported in sick-building syndrome (Donnell et al., 1989; Letz, 1990) and are thought to possibly be related to odor exposure (National Institute for Occupational Safety and Health, 1987). The analysis of the health symptoms involved two measures, the number of health symptoms reported and the overall intensity of the reported symptoms. The health symptom analysis did not include the hunger and thirst scales which were analyzed separately.

The second questionnaire was the Profile of Mood States (EdITS/Educational and Industrial Testing Service, San Diego, CA). This inventory, which is factor analytically-derived, measures six affective states: tension-anxiety, depression-dejection, anger-hostility, vigor-activity, fatigue-inertia, and confusion-bewilderment. The inventory consists of 65 items. For each item, an adjective is given and the subjects must rate how they "feel right

now" on a scale of 0 (not at all) to 4 (extremely). The score for a given affective state is obtained by combining the responses of the items which correspond to that affective state.

In the third questionnaire subjects were asked to rate four physical aspects of the testing room (noise, lighting, temperature and odor) on 9-point scales, ranging from -4 to 4 with 0 equal to neutral. The scale end-points are: very noisy/quiet, very uncomfortable/comfortable lighting, very uncomfortable/comfortable temperature and very unpleasant/pleasant odor.

Following the questionnaires subjects were taken back to the first (unscented) room where they completed two final questionnaires. The first asked if they had noticed any odor in the previous testing room. If they responded affirmatively they were also asked: when they had first noticed the odor, whether they thought it was part of the study, how pleasant it had smelled and to try and identify it.

The second questionnaire asked the subjects to rate how they thought the odor of the previous testing room (whether scented or unscented) had affected their performance on the five paper-pencil tests, their mood, and their health. Subjects rated the perceived effects on scales that ranged from -5 (greatly impaired performance/negative effect) to 5 (greatly enhanced performance/positive effect, where 0 = neutral). At the end of the study subjects were thanked and paid.

Statistical Analysis

Four MANOVAs were conducted looking at the effect of Odor Condition (no odor, peppermint, lavender), Gender (female or male) and Stress Level the previous month (low, high) on: the five performance tasks (spacial visualization, spacial orientation, visual pursuit, gestalt completion and concealed figures), the six Poms mood scales (tension, depression, anger, vigor, fatigue, and confusion), the four environmental rating scales (light, noise,

temperature, and odor) and the seven retrospective evaluations of odor's effect (spacial visualization performance, spacial orientation performance, visual pursuit performance, gestalt completion performance, concealed figure performance, mood and health). Another MANOVA tested the effect of room-odor hedonic ratings (neutral, pleasant) on the seven retrospective evaluations of the odor's effect.

Three ANOVAs were conducted looking at the effect of Odor Condition (no odor, peppermint, lavender), Gender (female, male) and Stress Level the previous month (low, high) on: the total number of performance items completed correctly, the number of health symptoms reported, and the intensity of the health symptoms reported. The two health measures were analyzed separately since number of symptoms was reported by all subjects (0-6) while only those actually reporting one or more symptoms had an intensity score. Five other ANOVAs were conducted looking at the effect of Odor Condition (no odor, peppermint, lavender), Gender (female, male) and Order in which subjects performed a given task (one of the first two tasks, one of the last two tasks) on performance of the five tasks (spacial visualization, spacial orientation, visual pursuit, gestalt completion, concealed figures).

Chi-Square tests were conducted to determine whether Odor Condition (no odor, peppermint, lavender), Gender (female, male), or Stress Level during the previous month (low, high) influenced whether subjects noticed a room odor, when they first noticed the odor, and whether they thought that room odor was part of the study. Summary statistics are reported as means \pm SEM.

Results

Task Performance

There was a significant effect of odor condition on task performance which was significant for the spacial visualization and the concealed-figures tasks [Wilks = .75, $p = .02$; $F(2,77) = 6.87$, $p = .002$; $F(2,77) = 6.34$, $p = .003$, respectively]. Individuals in the peppermint odor-condition performed better on the spacial visualization task compared to individuals exposed to lavender or to no odor (\bar{x} peppermint = 21.6 ± 1.5 , \bar{x} lavender = 15.0 ± 1.6 , \bar{x} no odor = 14.3 ± 1.6). On the concealed-figures task, individuals exposed to peppermint and no odor performed better compared to subjects exposed to lavender (\bar{x} peppermint = 96.7 ± 3.3 , \bar{x} no odor = 91.0 ± 5.4 , \bar{x} lavender = 74.9 ± 4.0). Although not significantly so, scores on the spacial orientation, gestalt completion and visual pursuit tasks also were highest in the peppermint condition (spacial orientation: \bar{x} peppermint = 18.3 ± 1.5 , \bar{x} lavender = 15.4 ± 1.9 , \bar{x} no odor = 14.9 ± 1.9 ; gestalt completion: \bar{x} peppermint = 9.6 ± 1.1 , \bar{x} no odor = 8.5 ± 1.0 , \bar{x} lavender = 7.9 ± 1.1 ; visual pursuit: \bar{x} peppermint = 16.9 ± 0.7 , \bar{x} no odor = 16.0 ± 1.0 , \bar{x} lavender = 14.7 ± 1.1).

There was a significant effect of gender on task performance which was significant for the spacial visualization, spacial orientation and visual pursuit tasks [Wilks = .77, $p = .002$; $F(1,77) = 14.42$, $p = .001$; $F(1,77) = 7.84$, $p = .006$; $F(1,77) = 8.43$, $p = .005$, respectively]. Men performed better on the tasks compared to women (spacial visualization: \bar{x} men = 20.7 ± 1.2 , \bar{x} women = 13.3 ± 1.3 ; spacial orientation: \bar{x} men = 19.4 ± 1.4 , \bar{x} women = 13.0 ± 1.3 ; visual pursuit: \bar{x} men = 17.2 ± 0.7 , \bar{x} women = 14.5 ± 0.8). Although not significantly so, men also performed better than women on the other two tasks (gestalt completion: \bar{x} men = 9.0 ± 0.9 , \bar{x} women = 8.3 ± 0.8 ; concealed figures: \bar{x} men = 88.0 ± 4.1 , \bar{x} women = 87.0 ± 3.5).

When the number of correct responses for all the tasks combined was examined, there was a significant effect for both odor condition and gender [$F(2,77) = 6.32, p = .003, F(1,77) = 5.34, p = .02$, respectively]. Subjects exposed to peppermint odor got more total items correct compared to subjects exposed to no odor or to lavender (\bar{x} peppermint = 191.9 ± 5.2 , \bar{x} no odor = 173.1 ± 7.7 , \bar{x} lavender = 158.8 ± 6.0) and men got more total items correct than did women (\bar{x} men = 184.4 ± 5.3 , \bar{x} women = 164.8 ± 5.4).

Individuals performed the gestalt completion and the spacial visualization tasks better when these tasks were presented as one of the first two tasks compared to when they were presented as one of the last two tasks [$F(1,66) = 4.41, p = .04; F(1,56) = 4.64, p = .04$, respectively]. However, the order in which the five tasks were presented did not interact with odor condition to influence performance on any of the tasks.

Health

There was a significant interaction between odor condition and gender in the intensity of the health symptoms that individuals reported experiencing [$F(2,76) = 3.29, p = .04$]. Men exposed to lavender reported less intense symptoms compared to men exposed to no odor (men: \bar{x} no odor = 10.4 ± 2.1 , \bar{x} peppermint 6.8 ± 1.3 , \bar{x} lavender = 6.0 ± 1.0 ; women: \bar{x} no odor = 7.5 ± 1.6 , \bar{x} peppermint = 5.8 ± 1.5 , \bar{x} lavender = 10.3 ± 2.0). There was no significant effect of odor condition, gender or stress level in determining the number of health symptoms subjects reported.

Mood

There was a significant odor condition by gender interaction for mood which was significant for both the tension and fatigue mood scales [Wilks = $.74, p = .04; F(2,77) = 2.97, p = .057; F(2,77) = 3.38, p = .04$, respectively]. Women exposed to peppermint were significantly less tense than women exposed to lavender. And men in the lavender

condition were less tense than women in that condition (women: \bar{x} peppermint = 6.1 ± 1.0 , \bar{x} no odor = 8.9 ± 1.5 , \bar{x} lavender = 10.5 ± 1.6 ; men: \bar{x} peppermint = 8.6 ± 1.8 , \bar{x} no odor = 8.9 ± 1.4 , \bar{x} lavender = 6.7 ± 1.1). Women exposed to peppermint also were less fatigued than women exposed to no odor or to lavender (women: \bar{x} peppermint = 4.7 ± 0.8 , \bar{x} no odor = 8.4 ± 1.4 , \bar{x} lavender = 10.3 ± 1.6 ; men: \bar{x} peppermint = 7.8 ± 1.6 , \bar{x} no odor = 10.3 ± 1.7 , \bar{x} lavender = 6.7 ± 1.2).

A main effect of stress level was also found for mood which was significant for the tension, depression, anger and confusion mood-scales [Wilks = .84, $p = .04$; $F(1,77) = 8.08$, $p = .006$, $F(1,77) = 11.32$, $p = .001$, $F(1,77) = 5.54$, $p = .02$, $F(1,77) = 4.59$, $p = .04$, respectively]. Subjects were more tense, depressed, angry and confused if they had experienced a high level of stress the previous month compared to if they had experienced a low level of stress (tension: \bar{x} low stress = 6.7 ± 0.6 , \bar{x} high stress = 9.7 ± 0.9 ; depression: \bar{x} low stress = 2.3 ± 0.7 , \bar{x} high stress = 5.9 ± 0.9 ; anger: \bar{x} low stress = 2.0 ± 0.4 , \bar{x} high stress = 4.5 ± 1.0 ; confusion: \bar{x} low stress = 6.1 ± 0.6 , \bar{x} high stress = 8.4 ± 0.6).

Environmental Ratings

There was a main effect of gender that was significant for ratings of room temperature and odor [Wilks = .82, $p = .005$; $F(1,77) = 11.94$, $p = .001$; $F(1,77) = 5.84$, $p = .02$, respectively]. Men rated both the temperature and odor of the testing room as more pleasant than did women (temperature: \bar{x} men = 2.2 ± 0.3 , \bar{x} women = 0.8 ± 0.3 ; odor: \bar{x} men = 0.9 ± 0.2 , \bar{x} women = 0.2 ± 0.1).

Retrospective Odor Perceptions

Only a small percentage of individuals reported retrospectively that they had noticed an odor in the testing room and subjects in the two scented conditions did not differ

significantly from each other in this regard (no odor = 7%, lavender = 20%, peppermint = 40%). Of the two subjects in the no-odor condition that reported smelling an odor, one said it had smelled like dust, the other said it had smelled like an office. Those who reported an odor in the peppermint condition generally said it had smelled like mint or sweet, while individuals who reported noticing an odor in the lavender condition described it as having smelled like a flower, perfume, or a sweet plant.

When just the two scented conditions were looked at, there was a significant effect of gender ($\chi^2 = 8.19$, $df = 2$, $p = .02$), men were more likely to report that they had noticed an odor compared to women (men 47%, women 13%). There were no significant differences for gender, odor condition, or stress level regarding when subjects reported they had first noticed an odor or whether they had thought it was part of the study.

Perceived Odor Effects

There was no significant effect of odor condition, gender or stress level on how individuals retrospectively reported that the odor of the testing room had influenced their performance on any of the tasks, their mood or their health. When the consequences of how individuals had rated the hedonic quality of the room odor (neutral or pleasant) was tested, a significant effect was found for visual pursuit task-performance, mood and health [Wilks = .80, $p = .009$; $F(1,88) = 7.62$, $p = .007$; $F(1,88) = 11.85$, $p = .001$; $F(1,88) = 13.18$, $p = .001$, respectively]. Individuals who had rated the room as smelling pleasant, retrospectively reported that the odor had had a more positive influence on their visual pursuit performance, mood and health than did individual who had rated the room as smelling neutral (visual pursuit: \bar{x} pleasant = 0.5 ± 0.2 , \bar{x} neutral = 0.03 ± 0.01 ; mood: \bar{x} pleasant = 1.1 ± 0.4 , \bar{x} neutral = 0.1 ± 0.1 ; health: \bar{x} pleasant = 1.1 ± 0.4 , \bar{x} neutral = 0.1 ± 0.01).

Discussion

As predicted, subjects performed two of the visual-spatial tasks significantly better under the peppermint odor condition compared to the no odor and/or lavender odor conditions. And for the other three visual-spatial tasks the results were in the predicted direction. This suggests that in situations where individuals have to perform visual-spatial tasks, actual performance may be improved by scenting the room with certain odors such as peppermint while the use of other odors (e.g., lavender) may harm performance.

Surgery is one type of behavior that requires a high level of visual-spatial skills. It may be beneficial, therefore, to scent operating rooms with peppermint odor in order to improve the performance of surgeons. The results of this study also suggest that odors such as peppermint may be beneficial in helping medical students develop better visual-spatial skills. This proposition could be tested by looking at the performance of medical students under different ambient odor conditions during mock surgery in virtual reality setups.

Previous studies have shown that in certain situations the congruency of the odor to the setting may be important in determining how odors influence behavior in that environment (Mitchell, Kahn and Knasko, 1995). Therefore, odors strongly related to surgery (e.g., blood scent) may have an even stronger influence on visual-spatial surgical skills than the scent of peppermint which is a non-surgery related odor. Future studies need to compare the effect of hedonically different surgery and non-surgery related odors on surgical performance. A virtual reality setting would be one of the safest ways to conduct a well-controlled experiment on this topic.

Other findings from this study showed that although two of the tasks were performed better when they were one of the first two tasks performed compared to being one of the last two tasks, task order did not interact with odor condition. This implies that the effect of the

ambient odor was not limited to early or late tasks but tended to exert an effect during the entire testing period.

The hypothesis that subjects would be in a better mood in the two pleasant odor conditions compared to the no odor condition was partially supported. For women, peppermint tended to be a beneficial odor while lavender tended not to be very advantageous.

Women exposed to peppermint reported that they were less tense and less fatigued than women exposed to lavender and that they were less fatigued than women exposed to no odor. Men's moods, on the other hand, tended not to be influenced by odor. Men in the lavender condition only reported being less fatigued than women exposed to lavender.

The hypothesis that peppermint would exert a different effect on reported health symptoms compared to no odor or lavender odor was not supported. Rather an interaction between odor condition and gender appeared. Men exposed to lavender scent reported less intense health symptoms compared to men exposed to no odor. Combining this result with the mood findings it seems that, in general, lavender tended to be beneficial for the mood and health of men while peppermint was more beneficial for the well-being of women. This was the case regardless of the fact that for both genders peppermint improved task performance.

Individuals who rated the room as smelling pleasant rather than neutral, were significantly more likely to retrospectively report that they thought the room odor had had a more positive effect on their task performance (for the visual pursuit task), their mood and their health. A previous odor study found that people who were exposed to malodors tended to retrospectively report that the odor exposure had negatively influenced their mood, health and performance, even when no effects occurred during exposure (Knasko, 1993). Studies with music also have shown that individuals often retrospectively report that music

improved their performance even if it actually did not (Deverux, 1966; Lucaccini and Kreit, 1972; Newman, Hunt and Rhodes, 1966) and that the less complex the task the greater the perceived effect (Jacoby, 1968). These music studies found that even without an actual improvement in performance, workers preferred working with music. Thus, the addition of pleasant odors into a work setting may be useful even in situations where no actual effects occur if it is important for workers to feel that their work environment is beneficial to their well-being and productivity.

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Appendix IV

The Performance of Fine-Motor Tasks During Exposure to Ambient Odors

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Abstract

Ninety-six women and men worked on six fine-motor tasks and completed mood, health and environmental quality questionnaires during exposure to one of three ambient odor conditions: no odor, peppermint odor, or lavender odor. Individuals who rated the room odor as smelling pleasant reported the best effect of odor on steadiness and pinch strength performance as well as mood and health. Women in the peppermint condition rated the room as smelling more pleasant than did the men in that condition while the opposite was true for lavender. On the steadiness test low-stress subjects performed better when exposed to lavender while high-stress subjects performed better when exposed to peppermint. Low stress individuals in the two scented conditions were less bored on the steadiness test than low stress individuals exposed to no odor. In general, odor had little effect on the performance of the fine-motor tasks. Odor mostly affected people's perceptions, often in interactions with the subject's gender and level of stress the previous month.

Introduction

The training of surgeons is problematic since they need to practice and try new techniques without endangering patients. In the past, several devices were developed to permit such training e.g., the Psychomotor Skills Lab (Lippert and Farmer, 1984) and the Suturing Training Device (Salvendy and Pilitsis, 1980). However, the operating room is still the main classroom for the surgeon. This is true even though it is stressful, gives no direct feedback, and limits the range of skills that can be learned by the availability of cases (Lippert and Farmer, 1984; Salvendy and Pilitsis, 1980; Kopta, 1971).

Because of these problems there is a growing interest in training surgeons with the new technology of virtual reality (VR) (Waggoner, 1995; Satava, 1994; Thalmann and Thalmann, 1994; Patterson, 1994; Richardson, 1994). Theoretically, individuals in VR would be able to practice surgical procedures on 3-D models of the human body and receive various types of sensory feedback (Satava, 1994). Besides being a training device, VR could also be used in actual surgery especially endoscopic or laproscopic surgery. It would be particularly beneficial in geographically remote areas or in dangerous situations such as with infectious patients or in combat environments (Satava, 1994; Richardson, 1994).

Adding olfactory stimuli to VR has been proposed as one way to improve VR surgery experiences. The telepresence of wound odors from a remote sight might help a surgeon make a diagnosis (Lippert and Farmer, 1984). Scenting a VR environment with various types of artificial hospital or body odors might make a VR training experience seem more real to the operators (Krueger, 1995). It is also possible that scenting the room with odors that do not necessarily relate to surgery may have an influence on task performance.

Studies concerning the effect of ambient odors on task performance have been diverse in their findings. Five studies found no effect of ambient odor on task performance (Kirk-

Smith, Van Toller and Dodd, 1983; Rottman, 1989; Baron, 1990; Knasko, 1992; Knasko, 1993). A negative effect of odor on performance was found in three studies (Rotton, 1983; Ludvigson and Rottman, 1989; Lorig, Huffman, DeMartino and DeMaro, 1991). And four studies found a positive effect of odor on task performance (Hashimoto, Yamayuchi and Kawasaki, 1988; Warm, Dember and Parasuraman, 1991; Baron and Thomley, 1994; Baron and Bronfen, 1994). In a recent study, Knasko, Wong and Krueger (in preparation) found that ambient peppermint odor could improve performance on visual-spacial tasks. This finding is important for medical training purposes since it has been determined that higher level visual-spacial and perceptual skills are factors that separate good surgeons from mediocre ones (Schueneman and Pickleman, 1993). The finding suggests that adding peppermint odor to a VR surgical environment can improve performance on the visual-spacial tasks.

To a large extent, surgery also involves manual dexterity. And although most surgeons seem to develop a proficiency in fine motor skills, thus not making it a factor that distinguishes a great surgeon from an average one (Schueneman and Pickleman, 1993; Lippert and Farmer, 1984; Lazar, DeLand and Tompkins, 1980), it would be beneficial if ways could be found to also improve performance on this common surgical skill. The present study was conducted to determine if ambient odors (such as the ones used in the visual-spacial performance study) could influence performance on a series of fine-motor tasks.

The odorants used in the present study, lavender and peppermint, are two scents believed by aromatherapists to differ in their arousing nature. Peppermint is considered to be stimulating while lavender is considered to be sedative (Tisserand, 1990). There is some evidence in the scientific literature to support this notion (Torii, et al., 1988). These two

scents also have been found in previous studies to influenced task performance (Ludvigson and Rottman, 1989; Hashimoto et al., 1988; Warm et al., 1991; Knasko et al., in preparation).

Methods

Subjects

A total of 105 individuals, 18-35 years old, were recruited from newspaper and flyer advertisements posted at the University City Science Center and six universities located in center and west Philadelphia. In a telephone interview, potential subjects were screened to eliminate individuals who were in poor health, who had allergies or sinus problems, who were foreign students or whose primary language was not english, who were familiar with the test center, who had any injuries that would prevent them from freely using their fingers, hands or arms, and whose fingernails exceeded the length of 1/4 inch.

From this number, 2 subjects were eliminated from the analysis because of previous experience with one or more of the performance tasks, 1 was eliminated because of an injury that prevented free use of his arm, 2 were eliminated because of a testing-room malfunction, 2 were eliminated because they were outliers and 2 were eliminated because of a disturbance during testing. Therefore, the data analysis was conducted on a total of 96 individuals who were randomly assigned to three odor conditions (with 16 women and 16 men in each condition). Subjects were paid \$15 for their participation.

Experimental Odor Conditions

The three ambient odor conditions used in this study were: no odor, peppermint odor, and lavender odor (essential oils from Aromatherapy Products Limited, Sussex, England). The testing room was scented as soon as the subject arrived at the testing center. Two perfume blotters, each containing 0.039 grams of peppermint or 0.047 grams of lavender, in

the respective peppermint and lavender conditions, were taped out-of-sight underneath the testing table. The blotters were placed at either end of the table, one 30 cm from the examiner's chair and one 30 cm from the subject's chair. The air vents in the testing room were closed.

In pilot testing when the room was scented in this manner pilot subjects rated the intensity and pleasantness of the room odor and how alert and relaxed they felt, every 5 min for 1 hr. On average over the hour, pilot subjects in both odor conditions rated the room odor as moderately intense and pleasant (4 on a 9-point scale where 0 = does not smell at all and 8 = extremely strong, and 2 on a 9-point scale where -4 = extremely unpleasant and 4 = extremely pleasant, $n = 6$). On average, subjects in both conditions reported that they felt moderately alert (2 on a 9-point scale where -4 = extremely not alert and 4 = extremely alert). Subjects in the lavender condition reported their relaxation level to be, on average, fairly strong, while people in the peppermint condition rated themselves to be moderately relaxed (3 and 2 respectively on a 9-point scale where -4 = extremely unrelaxed and 4 = extremely relaxed).

At the end of the experiment, the testing room air vents were opened and the testing room was cleared of the odorant with a special air-purging system that is designed to completely turnover the room's air 12 times per hour. The testing room was allowed to purge for at least 30 min between subjects. In the no odor condition, unscented blotters were used.

Procedure

Subjects participated in the study individually. They were first taken into an unscented room where they signed a consent form and completed the Perceived Stress Scale (Mind Garden, Palo Alto, CA). This scale consists of ten questions that ask individuals how

much stress they feel they experienced in various areas of their life during the past month. Subjects respond to a question by circling a number from 0 to 4 where 0 = never and 4 = very often. Total scores on the scale can range from 0 (very low level of perceived stress) to 40 (very high level of perceived stress). After completing the stress scale the subjects were asked to remove all watches, bracelets, rings and long necklaces. Fingernail lengths were also checked to make sure they did not exceed 0.7 cm.

The subjects were then taken into a testing room which was scented according to their randomly assigned experimental odor condition. The room contained a table, two chairs, and a plastic tower of shelves that held the testing equipment. Subjects worked on six motor-tasks which they were presented in a random order. Before each task the examiner read the instructions and gave a brief demonstration. Subjects were encouraged to ask questions if the instructions were unclear and they were told to rest their hands in their laps whenever they were not testing (i.e., during the instructions and in-between trials) to alleviate fatigue. In order to eliminate feedback that subjects might use to compete with themselves on the different trials, subjects were prevented from seeing their scores on all the tests that had more than one trial, except for the Hydraulic Pinch Gauge task where it was not possible to hide the scores. Immediately following each of the six tasks, subjects rated the test by completing a Task-Rating Questionnaire. This questionnaire had four 9-point scales that ranged from -4 (difficult, stressful, boring and exhausting) to 4 (easy, relaxing, exciting, and invigorating).

One of the motor tasks involved the Automatic Scoring Mirror Tracer (Lafayette Instrument Company, Lafayette, IN, Model 58024). This test measures reversal ability, hand-eye coordination and learning. The test consists of a black star-pattern made of a nonconducting material which is anodized to the surface of an aluminum plate. There is a

second metal plate which blocks the subject's direct view of the star pattern which they can only see in an attached mirror. Subjects are instructed to trace the star pattern with a metal-tipped stylus as quickly and accurately as possible while only watching its mirror image (Instruction/Owner's Manual, Lafayette Instrument). The stylus and plate are both connected to a digital stopclock (Lafayette Instrument Company, Model 54030) which records the amount of time (to 0.00 sec) that the stylus is outside of the star pattern.

Subjects used their dominant hand to hold the stylus. They traced in a clockwise direction, starting on a corner of the star that was marked with a START arrow. They were instructed to stay within the star pattern at all times, to not lift the stylus and to not cut corners in the star pattern. The subjects completed five trials with a brief rest period in-between while the examiner recorded the scores. A trial equaled one complete trace around the star pattern. The examiner explained that the total trial time would be measured as well as the total amount of time that the stylus was not on the star pattern. Subjects had two scores for each of the five trials, error time (time off the star pattern) and corrected time (total trial-time minus error time).

A second test was the Steadiness Tester (Lafayette Instrument Company, Lafayette, IN, Model 32011) which measures hand steadiness. It consists of an upright metal plate with 9 holes of diminishing size on the face (ranging in diameter from 1.25 to 0.195 cm), a metal-tipped stylus and a digital stopclock (Lafayette Instrument Company, Model 54030). The plate was placed at the edge of the table and subjects held the stylus in their dominant hand, extending their arm so that it did not rest against anything. When signaled, subjects inserted the stylus into a given hole and held it there for 20 sec until they were given the signal to remove it. The examiner explained that the stopclock measured error time (to 0.000 sec) by recording the amount of time that the stylus touched the side of the hole. Subjects were

given three trials for each hole with a brief rest period in-between trials while the examiner recorded the results. Only the second, fourth, sixth and eighth holes were used in this experiment. The analysis was conducted on the average error-time for each of the four holes.

The JAMAR Hydraulic Pinch Gauge (Lafayette Instrument Company, Lafayette, IN, Model PC 5030HPG) was a third test used in the study. It tests for various types of hand strength (in this study palmar pinch-strength was measured). It consists of a button which is compressed by the thumb during the pinch maneuver and a gauge which measures the pinch force. Subjects are instructed to flex their dominant arm at 90 degrees and to hold their forearm and wrist in a comfortable position. They then place their index and middle finger-pads under the pinch button and their thumb pad on the top of the button. The instructions are to pinch as hard as they can, hold for one second and then release. The examiner holds the instrument during the maneuver so that the weight of the pinch gauge is not supported by the subject (Jamar Hydraulic Pinch Gauge PC5030HPG, User Manual). Nine trials were given in this study and subjects were allowed a short rest period in between trials while the examiner recorded the scores. Scores could range from 0 to 50 kg and were rounded off to the nearest 0.5 kg. The analysis was conducted on the average pinch-strength scores for the first three pinches, the second three pinches and the last three pinches.

A fourth test used in the study was the Purdue Pegboard (Lafayette Instrument Company, Model 32020) which measures both gross movement of the hands, fingers and arms and also assembly skills or fingertip dexterity. After the examiner demonstrated each of the four parts of the task the subject was given a set amount of practice. The test consists of a board which has four wells at the top (holding pins, collars, washers and pins) and, below the cups, 2 rows of 25 holes. Four scores were obtained for each subject. The first

was the number of pins subjects could place in the row closest to their dominant hand in 30 sec. using their dominant hand. The second was the number of pins subjects could place in the row corresponding to their non-dominant hand in 30 sec using their non-dominant hand. The third was the number of pairs of pins subjects could place in the two rows in 30 sec, using both hands simultaneously. And the fourth score was the number of pieces used in one minute when subjects made assemblies with both hands together, where one complete assembly consisted of a pin with a washer over it, followed by a collar and another washer (Instructions and Normative Data for Model 32020 Purdue Pegboard, Lafayette Instrument Company).

The Crawford Small Parts Dexterity Test (The Psychological Corporation, San Antonio, TX), a fifth test used in the study, measures fine eye-hand coordination. The first part of the test, Pins and Collars, measures dexterity in using tweezers to insert small pins in close-fitting holes in a plate and to place small collars over the protruding pins. The second part of the test, Screws, measures dexterity in starting small screws in threaded holes in a plate and screwing them down with a screwdriver. The test consists of a board which has three wells holding pins, screws and collars and a metal plate, with rows of plain and threaded holes, which fits over part of the board (Crawford Small Parts Dexterity Test Manual, The Psychological Corporation). During administration, the board was placed approximately three inches from the edge of the desk. For both parts of the test, subjects first practiced by filling in the first row of the respective plates and then were instructed to fill the remaining 36 holes as quickly as possible. The examiner recorded the amount of time it took to complete each task.

The Finger Tapper Test (Lafayette Instrument Company, Lafayette, IN, Model 32726) was a sixth test used in the study. The test, which measures finger endurance and

speed, involves tapping a metal lever as many times as possible in a set period of time. The test consists of a small wooden board with a metal lever attached to a counter on one end of the board. Subjects placed their dominant arm on the board, with their index finger resting on the metal lever and with their wrist and other fingers resting on the board at all times. Each time the subject's finger pressed the lever the counter recorded the action. Subjects' scores were the number of taps they made in 3 min.

After subjects had completed each of the six fine-motor tasks they were given several questionnaires to complete. The first concerned the individual's mood. It contained twelve 9-point scales from the Semantic Differential Measures of Emotional State questionnaire (Mehrabian and Russell, 1974). Six scales load on a pleasure factor and six scales load on an arousal factor. Scores on each scale can range from -24 (very bad mood/very unaroused) to +24 (very good mood/very aroused).

The second questionnaire concerned physical symptoms that the subjects were currently experiencing. It consisted of six 10-point scales that assessed health symptoms and two 10-point scales that assessed hunger and thirst. The scales ranged from 0 to 9. Marking 0 on a scale indicated that the subject did not have the physical symptom, while marking 9 on the scale indicated that the symptom was severe. The health symptoms included: irritated eyes, headache, fatigue/malaise, stuffy/runny nose, dry/sore throat and dry/itchy skin. These are symptoms often reported in sick-building syndrome (Donnell et al., 1989; Letz, 1990) and are thought to possibly be related to odor exposure (National Institute for Occupational Safety and Health, 1987). The analysis of the health symptoms involved two measures, the number of health symptoms reported and the overall intensity of the reported symptoms. The health symptoms analysis did not include the hunger and thirst scales which were analyzed separately.

In the next questionnaire subjects were asked to rate four physical aspects of the testing room (noise, lighting, temperature and odor) on 9-point scales, ranging from -4 to 4 with 0 equal to neutral. The scale end-points are: very noisy/quiet, very uncomfortable/comfortable lighting, very uncomfortable/comfortable temperature and very unpleasant/pleasant odor.

The Profile of Mood States [(POMS), EdITS/Educational and Industrial Testing Service, San Diego, CA] was the fourth questionnaire subjects completed. It is a factor analytically-derived inventory which measures six affective states: tension-anxiety, depression-dejection, anger-hostility, vigor-activity, fatigue-inertia, and confusion-bewilderment. The inventory consists of 65 items. For each item, an adjective is given and the subjects must rate how they "feel right now" on a scale of 0 (not at all) to 4 (extremely). The score for a given affective state is obtained by combining the responses of the items which correspond to that affective state.

In the next questionnaire subjects were told that the testing room may or may not have been experimentally scented. They were asked to rate how they thought the odor of the room (whether scented or unscented) had affected their performance on each of the six fine-motor tasks, their mood and their health. Subjects rated the perceived effects on scales that ranged from -5 (greatly impaired performance/negative effect) to 5 (greatly enhanced performance/positive effect, where 0 = neutral).

Following this, subjects were given a questionnaire that asked if they had noticed any odor in the room. If they responded affirmatively they were also asked when they had first noticed the odor, whether they thought it was part of the performance study, and to try to identify it.

The final questionnaire was the Locus of Control personality test developed by Levenson (1974). The test measures the extent to which individuals believe that they control events in their lives (Internal), others control events in their lives (Powerful Others) or that events occur by chance (Chance). It consists of 24 statements which the individual responds to on a 6-point scale where 1 = Strongly Agree and 6 = Strongly Disagree. Eight statements correspond to each to the three elements of control. Scores for each element of control (Internal, Powerful Other, Chance) can range from 8 to 48. After completing this questionnaire subjects were brought back into the first (unscented) room where they were debriefed and paid.

Statistical Analysis

Six MANOVAs were conducted testing the effect of Odor Condition (no odor, peppermint, lavender), Gender (female, male) and Stress Level the previous month (low, high) on the six fine-motor tasks (mirror tracing, hand steadiness, pinch strength, finger-tapping, Crawford Small Parts, Purdue Pegboard). Four MANOVAs were conducted looking at the effect of Odor Condition (no odor, peppermint, lavender), Gender (female, male) and Stress Level the previous month (low, high) on: the six POMS mood scales (tension, depression, anger, vigor, fatigue, and confusion), the four environmental rating scales (light, noise, temperature, and odor) the two ingestion-related measures (hunger, thirst) and the eight retrospective evaluations of odor's effect (mirror-tracing performance, hand-steadiness performance, pinch-strength performance, finger-tapping performance, Crawford Small Parts performance, Purdue Pegboard performance, mood and health). Another MANOVA tested the effect of room-odor hedonic ratings (unpleasant, neutral, pleasant) on the eight retrospective evaluations of the odor's effect. MANOVAs also tested the effect of Odor Condition, Gender and Stress Level on ratings of how difficult, stressful,

boring, and exhausting the six fine-motor tasks were thought to be after each task was completed.

Four ANOVAs were conducted looking at the effect of Odor Condition (no odor, peppermint, lavender), Gender (female, male) and Stress Level the previous month (low, high) on: the pleasure mood-scale scores, the arousal mood-scale scores, the number of health symptoms reported, and the intensity of the health symptoms reported. The two health measures were analyzed separately since number of symptoms was reported by all subjects (0-6) while only those actually reporting one or more symptoms had an intensity score. The two mood scale measures (pleasure and arousal) were analyzed separately as recommended by the scale developers. Six other ANOVAs were conducted looking at the effect of Odor Condition (no odor, peppermint, lavender), Gender (female, male) and Order in which subjects performed a given task (one of the first three tasks, one of the last three tasks) on performance of the six tasks (mirror tracing, hand steadiness, pinch strength, finger-tapping, Crawford Small Parts, Purdue Pegboard).

Chi-Square tests were conducted to determine whether Odor Condition (no odor, peppermint, lavender), Gender (female, male), or Stress Level during the previous month (low, high) influenced whether subjects noticed a room odor, when they first noticed the odor, and whether they thought that room odor was part of the study. Correlations were conducted between the health and two sets of mood scores as well as between the Locus of Control personality variables and the mood, health and performance scores. Summary statistics are reported as means \pm SEM.

Results

Task Performance

In general ambient odors did not influence performance on the fine-motor tasks except for the hand-steadiness test. In that test, odor condition interacted with stress level in influencing performance.

Finger Tapping. There was a significant effect of gender on the finger tapping task. Men tapped more times during the 3 min testing period compared to women [$F(1,80) = 13.02$, $p = .001$, \bar{x} men = 677.54 ± 14.41 , \bar{x} women = 593.52 ± 15.23].

Crawford Small Parts. There was no effect of odor condition, gender or stress level on how individuals performed the Crawford Small Parts test.

Purdue Pegboard. Subject gender played a significant role in how subjects performed on the Purdue Pegboard. Women put in more pegs with their dominant hand, non-dominant hand and both hands together and completed more assemblies than did men [Wilks = .77, $p = .001$; dominant hand: $F(1,80) = 9.91$, $p = .002$, \bar{x} women = $15.73 \pm .26$, \bar{x} men = $14.42 \pm .22$; non-dominant hand: $F(1,80) = 8.34$, $p = .005$, \bar{x} women = $15.85 \pm .28$, \bar{x} men = $13.85 \pm .20$; both hands: $F(1,80) = 14.28$, $p = .001$, \bar{x} women = $12.52 \pm .21$, \bar{x} men = $11.19 \pm .24$; assembly: $F(1,80) = 19.57$, $p = .001$, \bar{x} women = $41.13 \pm .91$, \bar{x} men = $36.04 \pm .86$].

Pinch Strength. A significant main effect of gender also appeared for pinch strength. Men had more pinch strength than women for each set of three trials [Wilks = .82, $p = .001$; first set: $F(1,80) = 16.86$, $p = .001$, \bar{x} men = $10.12 \pm .32$, \bar{x} women = $7.77 \pm .26$; second set: $F(1,80) = 15.91$, $p = .001$, \bar{x} men = $10.29 \pm .34$, \bar{x} women = $7.98 \pm .27$; third set: $F(1,80) = 12.94$, $p = .001$, \bar{x} men = $10.36 \pm .37$, \bar{x} women = $8.20 \pm .26$].

Hand Steadiness. There was a significant interaction between odor condition and stress level for the hand-steadiness test (Wilks = .80, $p = .02$). For the second hole, low stress subjects performed significantly better in the lavender condition than did high stress subjects and low stress subjects in the lavender condition performed better than low stress subjects in the peppermint condition [$F(2,80) = 6.63, p = .002$, lavender/low stress: $.08 \pm .02$, lavender/high stress: $.24 \pm .08$, peppermint/low stress: $.26 \pm .10$]. For the third hole subjects in the peppermint condition performed significantly better if they were in the high stress compared to the low stress condition [$F(2,80) = 4.52, p = .01$, peppermint/high stress: $.82 \pm .17$, peppermint/low stress: $1.84 \pm .44$]. And for the fourth hole, subjects in the peppermint condition did significantly better on the task if they were in the high stress compared to the low stress condition and subjects in the high stress condition did better if they were in the peppermint compared to the lavender condition [$F(2,80) = 5.59, p = .005$, peppermint/low stress: $7.55 \pm .82$, peppermint/high stress: $5.25 \pm .69$, lavender/high stress: $7.44 \pm .51$]. For all four holes the general trend was for subjects who had experienced a low level of stress the previous month to do better in the lavender condition while subjects who had experienced a high level of stress the previous month tended to do better in the peppermint condition.

Mirror Tracing. There was a significant main effect of gender on the mirror tracing task (Wilks = .84, $p = .02$). Women took less time to complete each of the five trials, significantly so on the first, second and fifth trials [first trial: $F(1,79) = 6.78, p = .01, \bar{x}$ women = $47.22 \pm 5.04, \bar{x}$ men = 65.07 ± 4.93 ; second trial: $F(1,79) = 5.45, p = .02, \bar{x}$ women = $36.39 \pm 3.13, \bar{x}$ men = 50.36 ± 4.35 ; fifth trial: $F(1,79) = 6.78, p = .01, \bar{x}$ women = $25.99 \pm 1.79, \bar{x}$ men = 33.44 ± 2.32].

The order in which the six tasks were presented did not influence performance on any of the tasks.

Health

Odor did not influence the number of health symptoms subjects reported in the study. However, there was a significant effect of stress level on the number of the health symptoms subjects reported experiencing. Individuals who had experienced a low level of stress during the previous month reported fewer symptoms compared to individuals who had experienced a high level of stress [$F(1,91) = 8.83, p = .004, \bar{x}$ low stress = $2.23 \pm 0.21, \bar{x}$ high stress = 3.16 ± 0.27]. There was no significant effect of odor condition, gender or stress level on the intensity of the reported symptoms or reports of hunger and thirst.

Mood (POMS Scales)

Odor condition did not influence scores on the POMS inventory. A main effect of stress level was found for mood which was significant for the vigor, depression, anger, fatigue and confusion mood-scales [Wilks = .72, $p = .01$; $F(1,53) = 6.65, p = .01$; $F(1,53) = 16.36, p = .001$; $F(1,53) = 5.81, p = .02$; $F(1,53) = 5.38, p = .02$; $F(1,53) = 8.21, p = .006$, respectively]. Subjects had less vigor and were more depressed, angry, fatigued, and confused if they had experienced a high level of stress the previous month compared to if they had experienced a low level of stress (vigor: \bar{x} low stress = $15.67 \pm 0.85, \bar{x}$ high stress = 10.48 ± 1.07 ; depression: \bar{x} low stress = $2.40 \pm 0.43, \bar{x}$ high stress = 11.36 ± 1.78 ; anger: \bar{x} low stress = $2.73 \pm 0.48, \bar{x}$ high stress = 7.43 ± 1.46 ; fatigue: \bar{x} low stress = $7.58 \pm 0.72, \bar{x}$ high stress = 12.57 ± 0.99 ; confusion: \bar{x} low stress = $5.44 \pm 0.45, \bar{x}$ high stress = 9.43 ± 0.85). The number of health symptoms reported was significantly correlated with all of the POMS mood scales at the .001 level (tension: $r = .43$, depression: $r = .40$, anger: $r = .39$, vigor: $r = -.37$, fatigue: $r = .37$, confusion: $r = .50$).

The intensity of the reported health symptoms was significantly correlated with the vigor, fatigue and confusion scales (vigor: $r = -.41$, $p < .001$; fatigue: $r = .43$, $p < .001$; confusion: $r = .32$, $p < .01$).

Mood (Pleasure-Arousal Scales)

As with the POMS inventory, odor condition did not influence scores on the Pleasure/Arousal mood scale. There was a main effect of stress level on the pleasure scale. Individuals who reported having a low level of stress the previous month were in a better mood than subjects who reported a high level of stress [$F(1,91) = 13.87$, $p = .001$, \bar{x} low stress = 6.17 ± 0.73 , \bar{x} high stress = 0.77 ± 1.36]. There was no effect of odor condition, gender or level of stress on the arousal scale. The pleasure scale was significantly correlated (at the .001 level) with all six of the POMS mood scales (tension: $r = -.52$, depression: $r = -.76$, anger: $r = -.65$, vigor: $r = .52$, fatigue: $r = -.48$, confusion: $r = -.60$). For the arousal scale there were significant positive correlations with the POMS tension and vigor scales also at the .001 level (tension: $r = .41$, vigor: $r = .40$). The pleasure scale was also correlated with the number and intensity of health symptoms reported (number: $r = -.40$, $p < .001$; intensity: $r = -.38$, $p < .01$).

Environmental Ratings

There was a significant interaction between odor condition and gender for ratings of the room's noise and odor [$Wilks = .81$, $p = .04$; $F(2,80) = 6.98$, $p = .002$; $F(2,80) = 5.08$, $p = .008$, respectively]. Women in the peppermint condition rated the noise level to be more pleasant than men in that condition while men in the lavender condition rated the noise level as more pleasant than women in the lavender condition. Men in the lavender condition also rated the noise level as more pleasant than men in the peppermint condition (women/peppermint = 1.50 ± 0.58 , women/lavender = -0.25 ± 0.68 , men/peppermint

= -0.44 ± 0.67 , men/lavender = 1.44 ± 0.58). Women in the lavender condition rated the odor as less pleasant than women in the peppermint condition or men in the lavender condition (women/lavender = -0.06 ± 0.35 , women/peppermint = 0.94 ± 0.37 , men/lavender = 1.19 ± 0.49 , men/peppermint = 0.31 ± 0.44).

Retrospective Odor Perceptions

Individuals in the no odor condition reported noticing an odor less often than those in the two odorized conditions but the odorized conditions did not differ significantly from each other in this regard ($\chi^2 = 18.18$, $p = .001$; no odor = 13%, lavender = 44%, peppermint = 56%). Of the four subjects in the no odor condition that reported smelling an odor, one did not identify the odor, one said it smelled like dust, one said it smelled like air, and one said it smelled like copy ink. Individuals who reported noticing an odor in the lavender condition generally said it smelled like flowers, scented soap or perfume, while those who reported noticing an odor in the peppermint condition generally described it as smelling like mint, chewing gum, or a sweet plant. When just the two scented conditions were compared, there was no significant effect of odor condition, gender or stress level regarding when subjects reported they had first noticed an odor or whether they had thought it was part of the study.

Perceived Odor Effects

There was no significant effect of odor condition, gender or stress level on how individuals retrospectively reported that the odor of the testing room had influenced their performance on any of the tasks, their mood or their health. When the consequences of how individuals had rated the hedonic quality of the room odor (unpleasant, neutral or pleasant) was tested, a significant effect was found for perceived odor effects on hand steadiness, pinch strength, mood and health [Wilks = .54, $p = .001$; $F(2,93) = 12.93$, $p = .0001$;

$F(2,93) = 3.70, p = .03; F(2,93) = 4.93, p = .009; F(2,93) = 3.73, p = .03,$ respectively]. Subjects who had rated the room as smelling pleasant reported that the odor had a more positive effect on their mood than subjects who had rated the room as smelling neutral and that it had a more positive effect on their health than subjects who rated the room as smelling unpleasant. Individuals who had rated the room as smelling pleasant or neutral retrospectively reported that the odor had a more positive effect on hand steadiness and pinch strength than individuals who had rated the room odor as unpleasant. Those who rated the room odor as pleasant also reported a more positive effect of the odor for hand steadiness than subjects who rated it neutral (mood: \bar{x} pleasant = $1.04 \pm 0.29, \bar{x}$ unpleasant = $0.29 \pm 1.10, \bar{x}$ neutral = 0.06 ± 0.13 ; health: \bar{x} pleasant = $0.44 \pm 0.24, \bar{x}$ neutral = $0.03 \pm 0.14, \bar{x}$ unpleasant = -0.86 ± 0.50 ; hand steadiness: \bar{x} pleasant = $0.24 \pm 0.12, \bar{x}$ neutral = $-0.06 \pm 0.04, \bar{x}$ unpleasant = $-1.00 \pm .62$; pinch strength: \bar{x} neutral = $0.02 \pm 0.04, \bar{x}$ pleasant = $-0.04 \pm 0.09, \bar{x}$ unpleasant = -0.43 ± 0.32).

Personality

The two genders did not differ in how they scored on any of the three Locus of Control personality scales. Neither did subjects in the three odor conditions or in the high and low stress categories. No consistent correlations were found between the Locus of Control personality variables and the mood, health or performance scores.

Task Ratings

There was a significant interaction between odor condition and stress level in how boring subjects rated the hand-steadiness task and the Crawford Small-Parts test [$Wilks = .71, p = .008; F(2,80) = 4.75, p = .01; F(2,80) = 3.36, p = .04,$ respectively]. For the steadiness task subjects who had experienced a low level of stress the previous month reported being less bored in the two odorized conditions compared to the no odor condition.

In the peppermint odor condition, subjects exposed to low stress were less bored than subjects exposed to high stress (low stress: \bar{x} no odor = $-1.31 \pm .56$, \bar{x} peppermint = $.57 \pm .53$, \bar{x} lavender = $.50 \pm .36$; high stress: \bar{x} no odor = $-.07 \pm .42$, \bar{x} peppermint = $-1.06 \pm .52$, \bar{x} lavender = $-.15 \pm .51$). Also, for the Crawford Small-Parts test, low stress subjects in the peppermint odor condition were less bored than high stress subjects in that condition (\bar{x} low stress/peppermint = $-.50 \pm .62$, \bar{x} high stress/peppermint = $-2.00 \pm .41$).

Discussion

Scenting the testing room with an ambient odor only influenced performance on one of the six fine-motor tasks. For the Hand-Steadiness test, lavender proved to be more beneficial for the performance of subjects who had experienced a low level of stress during the previous month while peppermint was more beneficial for those who had experienced a high level of stress. Performance on the other fine-motor tasks was unaffected by odor condition. These findings differ from those found previously for visual-spatial tasks where peppermint proved to be beneficial to performance (Knasko, Wong and Krueger, in preparation). These differences imply that ambient odors have more of an effect on higher-level processing skills compared to motor skills and that attempts to manipulate task performance through olfactory stimuli should focus on tasks requiring higher-level processing. They also suggest that scenting an operating room with peppermint will not harm the motor performance of surgeons and can actually improve their performance on the more difficult tasks that separate fair from good surgeons.

Level of stress the previous month was the main factor in determining mood and health in this study. Individuals who reported experiencing a low level of stress the previous month reported fewer health symptoms and a better mood (on two mood questionnaires) compared to individuals who reported that they had experienced a high level of stress the

previous month. An interaction between stress level and odor condition also arose in the ratings subjects gave to how boring the tasks were. For two of the tasks, subjects in the low stress condition were less bored when exposed to peppermint compared to subjects who had experienced high stress. And for one task, low stress subjects were less bored in the two odorized conditions compared to the no odor condition. These findings support the stress literature that has shown that experiencing several stressful life events over a period of a year can lead to decrements in health and have a negative influence on mood (Turner and Wheaton, 1995). These findings also suggest that in some cases the influence that ambient olfactory stimuli has on an individual will be moderated by their level of stress.

As had been found in the earlier study concerning odors' effect on visual-spatial tasks (Knasko et al., in preparation), how subjects rated the hedonic quality of the odor played a role in their perception of its effects. If subjects rated the room odor as pleasant they also reported that the odor had the most positive effect on their mood and health and that it improved their performance on two of the tasks. A previous study found that people who were exposed to malodors tended to retrospectively report that the odor exposure had negatively influenced their mood, health and performance, even when no effects occurred during exposure (Knasko, 1993).

Studies with music also have shown that individuals often retrospectively report that music improved their performance even if it actually did not and that workers preferred working with music even if it did not influence performance (Deverux, 1966; Lucaccini and Kreit, 1972; Newman, Hunt and Rhodes, 1966) Thus, scenting the work environment (e.g., a operating room) with odors that the surgeons find pleasant may be beneficial to their perception of well-being.

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US ARMY MEDICAL RESEARCH AND MATERIEL COMMAND
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