Device for the Presentation of Olfactory Stimuli to Monkeys

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Clients:
Goran Hellekant
Vicktoria Danilova
Thomas Roberts

Advisor:
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May 9, 2002

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Abstract:

In order to gain a better understanding of the human olfactory sense, it is beneficial to study the sensory abilities of non-human primates. The two-choice discrimination method is and ideal method to determine the threshold sensory concentration of a particular stimulus. Our clients would like a device that would allow them to perform this testing with Rhesus monkeys located at the University of Wisconsin Regional Primate Center. To fulfill the needs of the clients, we elected to design a device with a simple gravity-operated locking mechanism that offers the monkey a pair of stimuli in a simultaneous manner. Upon designing our solution, we proceeded to construct a prototype using aluminum sheeting for the casing, and brass for the components of the locking mechanism.

Problem Statement:

The olfactory stimulation device is designed to assist in research designed to compare the ability of young and aging monkeys to make correct, discriminatory selections of specific odors and tastes. The device must have the capacity to conduct experiments using either tastes or smells with equal ease. The device must be able to present two different samples to the monkey: one that contains a taste or smell stimulus of variable concentration, and another that contains no stimulus. The monkey will have the option to select the positive (correct) stimulus after testing both options. If the correct choice is selected, the monkey will receive a reward; the reward should be hidden behind a door corresponding to the stimulus selection. Upon choosing one door, the other door must be inactivated by a locking mechanism. The device should be readily movable between cages, and all interactions between the monkey and the device must occur either inside the testing cage or within reach of the caged monkey. The device needs to be lightweight, yet durable and reliable.

Background:

Researchers wish to study the abilities of animals to taste and smell. Animals of particular interest to sensory researchers are primates, due to their close physiological relationship to humans. Information gleaned from primate research often has significant parallels in human physiology, which makes this type of research very valuable. It is hoped that the results of this research may one day help increase our understanding of how the human brain senses and interprets taste and olfactory stimuli.

One of the methods used by researchers to study the sensory performance of monkeys is the two-bottle preference test. This test examines whether a monkey prefers to drink from a water bottle or from a bottle containing water that has been sweetened with sugar. The two-bottle preference test is a simple test that yields clear data: it is easy to infer which fluid the monkey prefers from the volume consumed (Danilova, 2002). However, this test cannot be used to determine whether the monkey can distinguish between, say, 1% sugar and ½ % sugar solutions. It also cannot be used to determine preferences in odors.

Research has shown that sensitivity to smells and tastes changes over the life of the monkey; there are significant differences between the sensory abilities of young and old monkeys (Hellekant, 2002). Different age groups of monkeys more easily sense certain smells or tastes. Our clients wish to perform experiments that would work at or near the "threshold concentration" – the lowest concentration of a substance that the monkey can still positively detect. The two-bottle preference test provides qualitative information of the monkey's sensory abilities, but conclusions are limited to simply whether the monkey prefers one taste or smell to another. The testing method does not provide any quantitative data. In order to obtain quantitative data, a different testing method must be used. First, experiments should be performed using near-threshold concentrations of scents or tastes. Also, the animal must be trained to make an intentional choice, choosing one and only one stimulus from a simultaneously presented pair. An experimental design integrating both of these factors would yield quantitative measures of an animal's olfactory and tasting abilities, rather than only qualitative results produced by the two-bottle preference test.

The goal of our project is to develop a system that can be used to perform an olfactory discrimination test with Rhesus monkeys (*Macaca mulatta*) as subjects. By the word "system," we imply the creation of an apparatus able to carry out the experiments designed by our clients. Other olfactory discrimination experiments have been carried out with humans, reptiles, pigeons, dogs, and other species of primates (Hubener, 2001). Two different experimental methods have been used to study olfactory performance in test subjects. The first method, introduced in 1992 and used in a 1998 study, simulated natural foraging behavior to determine olfactory performance in monkeys when multiple choices were presented simultaneously. The experimental method was called "multiple-choice discrimination." (Hubener, 1998) The later experimental method is termed "two-choice discrimination"; this method was used in a 2001 study to determine the olfactory sensitivity of pigtailed macaques for the odors of peanuts, *iso*-amyl acetate (a banana-like smell), and *n*-pentanoic acid (a component of primate body odor) (Hubener, 2001). Our client, Goran Hellekant, wishes to perform experiments using a new apparatus that would make use of the two-choice discrimination method in the testing of both olfactory and tasting abilities in Rhesus monkeys.

The two-choice discrimination method can be described as follows: The animal is offered a choice of two stimuli, one being "positive," and the other one being "negative" – in the sense that the positive stimulus indicates a "correct" choice, and the negative stimulus infers an "incorrect" choice on the part of the monkey. The two stimuli are presented simultaneously, yet distanced apart from one another. The animal may investigate one stimulus at a time; yet, it also may move freely back and forth between the stimuli for further investigation. The stimuli are presented on an apparatus that provides a reward for the correct choice – an example apparatus would be a box containing a reward inside, with the stimulus placed on the lid of the box. For a two-choice discrimination test, one wishes to use a technically-simple testing apparatus, in order to make the connection between a positive stimulus and a reward is as readily obvious as possible.

When using primates as experimental subjects, extensive training of the monkeys is necessary. First, a monkey must be trained to operate the experimental apparatus itself. This involves teaching the monkey how to effectively sample the stimulus (whether through smelling or tasting), how open the door or box, and finally how to access the reward. It becomes clear at this point that there exists "beauty in simplicity" – the more straightforward the apparatus, the faster the monkey can become proficient in its use. If proficiency in operation is gained rapidly, then experiments can begin earlier. Valuable time is therefore saved.

After the monkey has mastered the operation of the experimental apparatus, the monkey must be taught to associate a certain stimulus with a corresponding reward. Finally, the monkey must learn to preferentially choose the positive (correct), rewarded stimulus over the negative stimulus. In the 2001 study that used a two-choice discrimination method, the macaques required between 480 and 900 trials before acquiring the skills necessary to complete the experiment as designed. In performing a two-choice discrimination experiment, the learning process is the most time-consuming; from the above example, the number of trials required to teach the necessary behaviors equates to a time period of between fifty and ninety days.

According to the description of experiments that our client wishes to perform, the monkey would be offered two different stimuli, either in the form of scented paper strips (in the case of odors) or bottles filled with flavored fluids (in the case of tastants). Each stimulus would have a "door" or other opening associated with it: a covered, recessed space into which a reward would be placed in the case of a correct choice, and no reward in the case of a wrong choice. By sampling the odors and/or tastes, the monkey would be taught to choose one of the two doors based upon its preference between the stimuli. A correct choice would earn a reward, and an incorrect choice would be met simply with the lack of a reward (as opposed to a punishment). In either case, the initial choice of the monkey would have to be final; a mechanism must be in place to prevent the monkey from either opening both doors simultaneously, or from opening the other door after already making a choice.

Design Constraints:

Several important design constraints exist for our device. First, a point of attachment is needed: In order for it to be best compatible with existing primate cages, it should have a mounting plate that will fit into a slot on the exterior of the monkey cage. Currently, the slot is used to hold a food tray. The mounting plates on food trays are generally rectangular in shape, being 20.3 cm wide and 12.8 cm high. Our device must have a mounting plate of identical dimensions.

Secondly, our device will be operated by monkeys, in their living environments, for several hundred separate trials. This means that the device must be sturdy and durable, and able to withstand abuses from either monkey contact or falling on the floor. The device should be of a material that can be washed and sterilized repeatedly without degrading. And ideal material would be stainless steel, which is durable and will not corrode if given the proper care. In lieu of steel, a more workable metal such as aluminum would be acceptable for the initial designing and testing phases of the device.

Related to the issue of the mounting plate is the need for the holes and doors – sites where the primate interacts with the device – to be in a standard location. On cages currently in use, there are four larger square holes of 4.67 cm x 4.67 cm located directly above the feeding tray; these exist for the animal to reach out and grab its food. Otherwise, the standard cage mesh is a square network of 2.50 cm holes. Our device must position the monkey/device interaction sites in such a way as to make use of these existing cage features.

The monkey, upon sampling the two stimuli, will have a choice of two sites – one of which will contain a reward. Once the monkey makes a choice, the other choice must be “locked out” so that the monkey learns to associate a reward with a positive stimulus. This locking mechanism must be durable, must operate for hundreds of trials without needing replacement components, and must be easy for the operator to reset between trials. Also, the moving components of the mechanism should have low friction coefficients (to prevent “sticking”) and should not cause substantial wear to one another.

Alternative Solutions:

Alternative 1: Electronic Design

This design is fully electronic and is operated by the user via the use of push-buttons or screen touch interfaces. The stimuli would be incorporated into rotating discs that would be shuffled for a random time interval by the push of a button. The apparatus would use electronic circuits to transmit and display information from both the human operator and from the monkey. The monkey would choose the sample that he wants by pushing a button. As soon as the button is pushed, both choices would retract on sliding drawers; if the choice were correct, a third door would open with the reward on it. If the choice were incorrect, no drawer would open. The stimuli-discs would be placed on trays that rotate in a manner similar to that of a CD changer. The electronic apparatus would record the choices of monkey and print out a copy of the results at the end of a testing session.

Alternative 2: Mechanical Design

This design is very simple and meant to be operated by any person regardless of knowledge or experimental experience. The stimuli are presented in two locations (one on the left side and one on the right) with corresponding reward drawers located beneath the stimuli. The monkey chooses one of the stimuli by pushing in on the door. There is a mechanism inside to lock the doors; as one door is pushed, a semicircular piece of wire is also moved. As the wire moves, its angular orientation changes, and it falls (from the force of gravity) into a “groove”. Once in this groove, the wire cannot move because the groove prevents it from altering its orientation. In the locked position, a pad attached to the other end of the wire now presses up against the back of the other door, preventing it from being opened.

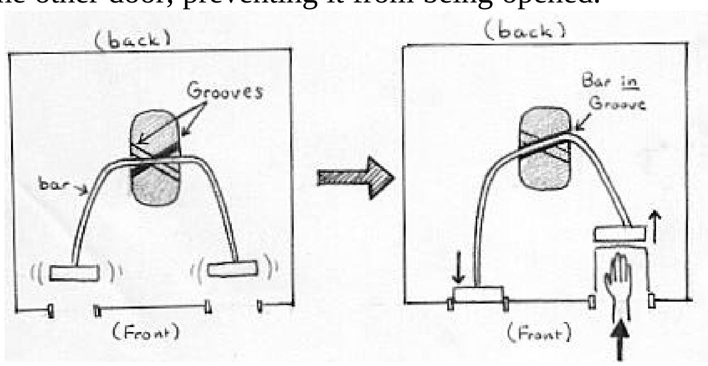

Figure 1: Diagram of how a wire locks the second door upon the opening of the first (Kolpin, 2002).

The area where stimuli are presented allows for easy inter-conversion between tastes and smells. For tastes, there are clamps upon which drinking bottles can be attached. For smells, these bottles can be removed, and strips of paper containing the odors can be easily inserted in their place. This device is simple, yet achieves all of the desired goals within its simplicity. Anyone can use it, and its use is easy to learn for both operator and monkey.

Alternative 3: Revolving Presentation Design

This design is also mechanical in nature, but uses a vertically-oriented revolving mechanism to present stimuli to the monkeys. On the cage-facing side of the device, the two doors for stimulus presentation would be located directly above one another; meanwhile, the doors for distributing the reward (or lack thereof) would be located at the same vertical level on either side of the device. The stimuli would be affixed to a wheel inside the device; the operator could change the arrangement of stimuli on this wheel. In order to give a random pair of stimuli to the monkey, the wheel would be spun, and the presented stimuli would be those that corresponded to the location of the presentation doors when the wheel stopped.

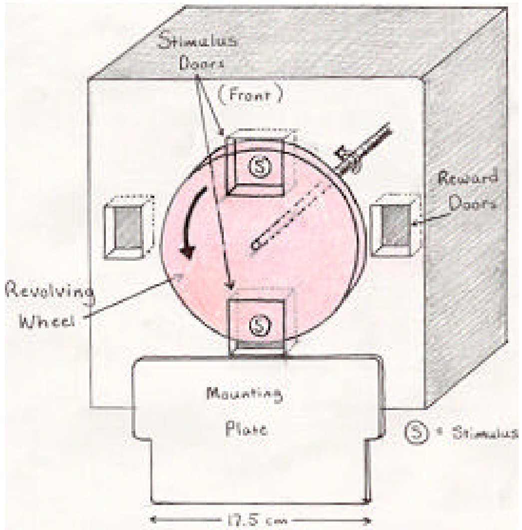

Figure 2: Drawing of the revolving wheel design (Kolpin, 2002)

This design presents the advantage that the stimuli would be offered in a truly randomized fashion. However, there are several drawbacks. First, the locations of the presentation and/or reward doors would not line up with the appropriate openings in the mesh of the monkey cage. Secondly, the arrangement of the presentation doors (in a vertical fashion), as well as the arbitrary assignment of the reward doors, is potentially confusing to the monkey. It is preferable to allow the monkey to choose between 'left' and 'right,' rather than between 'up' and 'down.'

New Alternatives: Door locking mechanisms:

Sliding Bar Mechanism:

The sliding bar mechanism operates using a long bar that is free to slide back and forth between the two doors. The idea is that as one door is pushed open, the motion of the door would displace the bar, pushing it laterally along a track in such a way as to lock out the second door. Presumably, once the bar had slid into the position necessary to lock the second door, something would need to lock the bar itself in place and prevent it from being "pushed back" of force was exerted on the "locked" door.

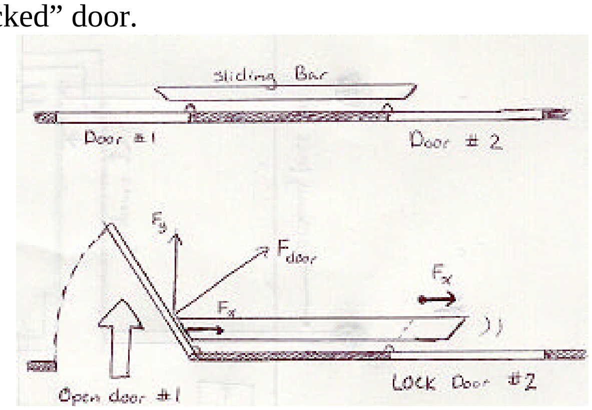

Figure 3: Sliding Bar Mechanism inactive (top) and activated (bottom)

There were a few key disadvantages to this design. First of all, in order for it to be effective, the monkey would have to open the first door *all the way* – otherwise, the second door would not be completely locked. If the first door was only opened a crack, the second door would not be locked and the mechanism would fail in its intended purpose. Also, there is the issue of force-redirection. The motion of opening a door, hinged on one side, produces forces on the bar directed both towards the other door (desired) and towards the back of the device (unwanted). To keep the bar moving laterally, it would need to be confined to a track or groove; over time, friction forces could erode the track and hinder the smooth operation of the mechanism.

Gravity-Operated Mechanism:

The gravity-operated system functions by using a bar or pin that falls into a position to block the second door once the first door is opened. In the inactivated state, the pin is supported on a "ledge" that extends from the opposite door. When the door is opened, the support moves, and the pin falls and blocks the opening of the second door. The design of this mechanism also eliminated the friction of pieces rubbing together or getting tangled in the bar and groove mechanical design. We choose to use brass because it is very durable, rust resistant, and has a low coefficient of friction (unlike aluminum). It is also strong and stiff, and is easily available in lengths sufficient for our purposes.

We appreciated the design of this gravity-operated mechanism for its simplicity, durability, and functionality. Thomas Roberts was similarly pleased. It offers several advantages. First, only a slight push is necessary to trip the locking mechanism, so the monkey can't "peek" behind one door and still have the ability to open the second door. The mechanism is adequately sensitive, but not *so* sensitive that it will activate spontaneously. Secondly, there is no need to redirect the force of the door in order to activate it. The device minimizes unnecessary friction between moving parts, since the locking pins fall straight down through the guides. Lastly, this mechanism is easy to reset. The operator needs only to lift up the pin, close the door, and allow the pin to rest once again on its support.

Design Matrix for Overall Design ONLY:

	Electronic design	Revolving design	Mechanical design
easy for taste	0	0	+
easy for smell	+	+	+
simplicity	0	0	+
user friendly	+	0	+
durable	0	+	+
lightweight	+	+	+
movable	0	+	+
monkey friendly	0	0	+
easy to learn	0	0	0
attach cage easily	0	0	0
locking easy to do	0	+	+
TOTAL	3	5	10

Selected Design:

The design, shown below, which can be incorporated into "new," modern cages was chosen as our selected design. From conversations with our client, we have decided that a design that incorporates side-by-side reward doors with the odor/tastant presentation sites located directly above the reward is the most applicable and functional design. All of the new cages in use at the University of Wisconsin Regional Primate Center have a standardized feeding tray mounting plate (Appendix C), which secures the feeding tray to the cage. An identical mounting plate will be incorporated into the front of the device, which avoids concerns pertaining to mounting our device on a variety of cages – thanks to the current trend towards cage standardization. The new cages also possess four larger holes (about 4.67 cm square) in the cage mesh through which the caged monkey can easily reach to manipulate the device (see figure below). This eliminates the problem due to the monkey's inability to reach through the cage to perform the tests; a Rhesus monkey of almost any age or size will have no difficulty in extending its reach beyond the cage in order to operate the device. As was mentioned earlier, these "new" cages are fast becoming a standard in laboratory settings; therefore, this design could be easily applied in any lab utilizing these modern cages.

The specific design of the stimulus presentation mechanism was selected for both its simplicity and ability to incorporate a tasting bottle – the latter is a feature that client requires. This design is superior to the other designs in both these regards. The vertical revolving door design, presented as the third design alternative, could not be developed to incorporate a fluid-tasting bottle, which is used to deliver a liquid stimulus to the monkey. A design that presents stimuli in a side-by-side fashion can easily incorporate drinking bottles and/or sample tubes by securing them internally within the box, with the nozzles protruding through the odor/tastant presentation holes. Also, the horizontal arrangement of the four large mesh holes makes the implementation of the vertical revolving door impractical. Thus, the design that presents stimuli in a side-by-side manner becomes the obvious choice.

The top half of the device is recessed inward by 2.5 centimeters to avoid contact with the sliding door of the cage. The device will be mounted so that the two reward doors will be located directly in front of the far right and left large, 4.67-cm mesh holes of the cage. The holes reserved for stimulus presentation will be located directly above the reward doors. These stimulus-doors will be placed high enough so that they rest above the sliding door tract, and between the thin 2.5-cm mesh holes directly above the door tract.

For the locking mechanism, we chose to incorporate the gravity-operated locking pins. The locking pins will be two brass pins, each about twelve centimeters in length. Their size is too large for them to be accommodated completely within the housing of the device, so holes will cut in the top of the device to allow their passage. These holes also function as guides, in addition to the guides located inside the device. For our prototype, we have chosen to make all the components of the locking mechanism – doors, pins, hinges, and supports – out of brass.

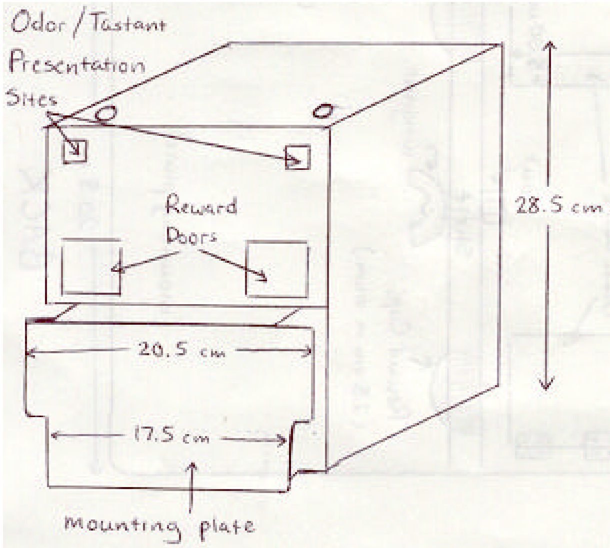

Figure 4: Schematic drawing of the basic shape of our selected design showing the relative location of the reward doors, stimuli, and the mounting plate.

Figure 5: Photograph of "new" cage with a feeding tray mounted directly below large, 4.67-cm. mesh holes (Campbell and Potter, 2002).

Specifics of Prototype

The casing of the prototype, shown in figure 5, consists of five 16-guage aluminum sheets, two sides, back, front-bottom-shelf, and front-top. The front-top portion (above the recessed middle), is a single piece of aluminum that includes the testing interface (stimulant administration and reward doors), and the top of the box. The front-bottom-shelf portion (below recessed middle), is also a single bent piece of aluminum that makes up the bottom side, the mounting plate (front side), and the inside shelf that supports the rewards. The doors, rods, rod guides, and hinges are all brass to reduce the corrosion and difficulties of soldering that are found with aluminum. The fluid delivery vessels are 15ml centrifuge tubes.

The pieces are fastened with steel screws and nuts, which facilitates quick dismantling and assembly. The locking mechanism (Figure 6) shows the soldered brass pieces that comprise the locking Mechanism. Each door consists of three brass pieces: the hinged door, one vertical, and two horizontal pieces soldered perpendicularly so that the second piece can support the brass rod. The first brass horizontal piece on the right door of Figure 6 is bent around the rod to ensure successful operation. The hinges are soldered onto the brass doors and are screwed to the aluminum casing.

The rods are wrapped with rubber “stoppers that prevent the rods from falling completely into the device. They also stop the falling rod directly in front of the door, thus inactivating it.

The rewards are placed in small cups (Figure 7) that fit into the holes directly behind the door. The cups are sandwiched between the shelf and an aluminum strip that spans the distance between holes; the cups are mounted to the shelf with a bolt and a wingnut.

Figure 6: Front view of prototype.

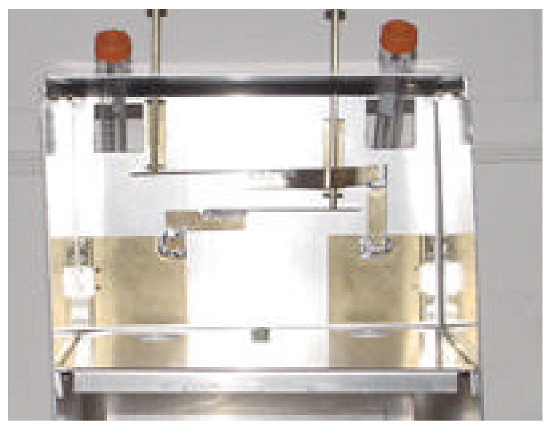

Figure 7: Inside of device, showing the locking mechanism in the top portion of the device.

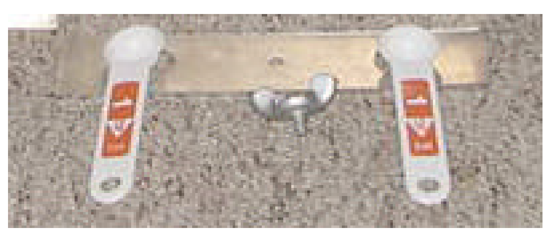

Figure 8: Reward cups and fastening strip.

Conclusions and Future Work:

In the future, we hope to make improvements to our basic design, to make it better serve the needs of the client. One such improvement that we are planning to make is the incorporation of a blinking indicator light. The presence of the light, a visual signal, helps facilitate the monkey's learning process of mentally associating a particular stimulus with a reward. Experiments have shown that monkeys, like humans, are highly visually-oriented animals; they rely most heavily on their vision to provide them with information about the environment. Thus, the presence of a blinking light may drastically shorten the time period necessary to train the monkeys how to perform the test. The light would serve only to indicate that the monkey made a correct choice; the experimental results themselves would not be affected.

Either one or two indicator lights could be incorporated into our current design or prototype. A design incorporating one light would place the light directly between the two reward doors, and would light up only when the monkey has made a correct choice. A design incorporating two indicator lights would place one light next to or above each door. When a correct choice has been made, the light above the correctly chosen door will illuminate. If an incorrect choice has been made, either the light above the (still closed, now locked) correct door could illuminate, or both lights could simply remain unlit. The choice between these two designs, as well the dimensional and logistical specifics of either design, are choices than can be made later after further discussion with the client and advisors. As of now, either of the two possible designs would probably fulfill their desired function. Furthermore, our current design and prototype appear to have the dimensions necessary to employ an indicator light feature, including its necessary electrical components. This feature would likely be best incorporated into a second-generation prototype, once the basic structure of the apparatus has already been constructed and tested.

Another possible improvement to our design could be a closing door on the back of the device. Right now there is a prototype door and hinges that could easily be attached to our prototype; however, a closed back panel would obstruct the front reward doors from opening entirely. The locking pin support of the opening door would the hit rear panel before the door is completely open. The monkey being tested may not have access to the reward or see the reward as easily. This could affect the results of any tests done with the device and is unacceptable. In order to add a door to the back of the device, either the depth of the device must be enlarged or the pin support extensions must be shortened.

The largest portion of future work for this project will consist of testing the device and modifying our design based on the test results. There are several possible alterations in our design that could result from testing. As soon as we try to place the device on the cage we will see if our mounting plate designs are correct, and if the testing interface fits as close as possible to the cage.

Currently, our design is made mostly from aluminum with some brass components. Though our current design seems to function fine with these materials, there is always the possibility that or materials could better suit our clients needs. Because we have two types of metals in contact with each other, there is the possibility of galvanic corrosion. This could affect the devices performance and may need to be modified if so. Also, the metals in our prototype were chosen because of their bendable properties. Perhaps after testing we will find a stronger material, such as stainless steal, may better suit our needs.

After testing our prototype we may also find that the reward cups are too deep or located improperly. If that is the case we could revise our design of the reward cups in order to more easily facilitate monkey reward for correct choice and to speed up the training process. Another goal of ours is adjust the tastant delivery dimensions. Currently, we are not sure the delivery device will fit snuggly into the cage. Once we test the device we will know if the tastant delivery devices fit into the cage and if the monkey is able to bat them out of the cage. The delivery tubes may need to be secured better to our device. There may also be several unforeseen flaws with our design now that will become exposed once the device is in the testing process.

Lastly, our prototype had several components and surfaces that were either partially or entirely hand made or prepared. If our device ever needs to be produced in larger quantities, it will be helpful to have a design that is more easily reproducible and requires less inaccurate, hand made components. We should be able to revise our design in order to more easily facilitate increased production if necessary.

One must always consider ethical issues when conducting experiments with non-human primates. Our device must not cause physical harm to the monkey, such as lost fingers. Another ethical concern is how the monkeys are treated during the experiments. In the experiments that this device is designed to run, a correct choice is rewarded with a treat (such as a raisin or fruit loop), while an incorrect choice receives merely a lack of a reward. It would be seriously unethical to actively punish a monkey for making an incorrect choice; while the animal might learn faster, punishment is not acceptable. The device is designed to provide a safe and kind environment for the testing of non-human primates.

Appendix A:

Product Design Specifications
(May 9, 2002)

Title: BME 301 - Olfactory Stimulation of Monkeys

Group Members: Sarah Kolpin (leader), Kevin Campbell (communications), Heather Shaner (BSAC), Wyatt Potter (BWIG).

Clients: Goran Hellekant, Vicktoria Danilova, Thomas Roberts

Advisor: Professor John Webster

Function: Apparatus should provide quickly interchangeable pairs of stimuli to a caged monkey. It should then allow the monkey to choose between two possible solutions, each corresponding with one of the stimuli. The device must then provide a reward for the correct solution.

Client Requirements:

a. The device should allow for the presentation of both tastants and scents to the monkey (not necessarily simultaneously).
b. The tastants will most likely be provided by either standard water bottles or through centrifuge tubes, and the scent will come from saturated filter paper.
c. The device should present the monkey with exactly two options for actions that will allow the monkey indicate its choice in tastant/scent.
d. These two options must clearly separate from one another, and must clearly correspond to a specific stimuli.
e. After monkey has chosen one smell/tastant, choice should be final, and the choice not chosen should be locked out.
f. A reward should be provided for the correct solution; an incorrect solution will earn no such reward.
g. A light should also indicate that the correct choice has been made. It must be possible to turn off this light mechanism for the duration of testing.
h. Apparatus should be readily moveable from cage to cage.
i. The apparatus should work at two height levels: about 1 foot from the ground, and about 5 feet from the ground – on the two levels of cages at the Primate Center.
j. The device must easily accommodate an operator who is responsible for switching stimuli and moving the device from cage to cage.
k. The replacement of stimuli between tests must be out of sight and smell range of ALL monkeys within the immediate vicinity (i.e. testing room).

Design Requirements:

1. **Physical and Operational Characteristics**
   a. ***Performance requirements:*** Device should operate continuously, and should handle extreme forces from angry monkeys. (i.e. cage-shaking). It should not break or fail if dropped or knocked off of the cage. The *locking mechanism*

must operate for at least one thousand trials without replacement parts. The device should withstand moisture, fecal matter, and urine. It should be durable enough to withstand frequent cleaning and sterilization.

b. ***Safety:*** Product should not cause harm to monkeys. There should be no risk of monkeys to electrocution, shock, extreme heat or cold, fast-moving blunt objects, or pinching of fingers.
c. ***Shelf Life:*** Device should be functional indefinitely, stored in temperatures ranging from 0° C - 37° C.
d. ***Operating Environment:*** Temperature range should ideally be around standard room temperature and pressure; the device should handle large amounts of dust, humidity, vibration, resist all corrosion (due to water and/or monkey urine), should be easily handled by people and monkeys.
e. ***Size:*** The device should have a mounting plate with dimensions that will allow it to slide into the available feeding bin slot on the front of cage (20.5 cm by 12.8 cm). The device will attach to the outside of the cage and be a size that is easily manipulated by both the caged monkey and the operator. It should be no more than 30 cm high, 25 cm wide, and 20 cm deep. The monkey should not have to strain his reach to either operate the device or receive its reward.
f. ***Weight:*** Should not weigh more than eight kilograms; optimum weight should be around four kilograms or less.
g. ***Materials:*** The device should consist mostly of metal. This metal could be either stainless steel or aluminum. It is feasible to use high-density plastics as guides for the locking pins. **Any** material that is either subject to corrosion or extensive wear, has a high friction coefficient, or is easily breakable should not be used.
h. ***Aesthetics, Appearance, and Finish:*** The device should not be colorful, highly reflective, or distracting in any way to the monkey. One or two indicator lights may be attached to the cage-facing side of the device to indicate to the monkey when a correct choice has been made. Another light or indication device should be on the back of the device to inform the operator if monkey has or has not made a choice yet. No particular finish is required.

2. Production Characteristics

a. ***Quantity:*** Begin with one prototypic device. After that, design should be refined and perfected so that many devices could be easily and cheaply mass-produced.

3. Miscellaneous

a. ***Customer:*** All recommendations from client will be incorporated into design.

b. ***Patient-Related Concerns:*** The device would need to be regularly cleaned and periodically sterilized. All components of the device must withstand such processes.
c. ***Competition:*** To our knowledge there are no other devices offering the same characteristics as our device.

Appendix B: Sources

Campbell, Kevin and **Potter, Wyatt**: Digital images of monkey cages, taken on February 15, 2002

Danilova, Vicktoria (Vika): Personal conversation held on January 28, 2002

Danilova, Vicktoria (Vika): Visits to the UW Primate Center on February 15, 2002; March 4, 2002; and March 12, 2002.

Hellekant, Göran: Personal conversations held on January 28, 2002 and March 1, 2002.

Hubener, Fabienne and **Laska, Matthias:** "Assessing Olfactory Performance in an Old World Primate, *Macaca nemestrina*" Physiology and Behavior, Vol. 64, No. 4, pp. 521-527. © 1998 Elsevier Science, Inc.

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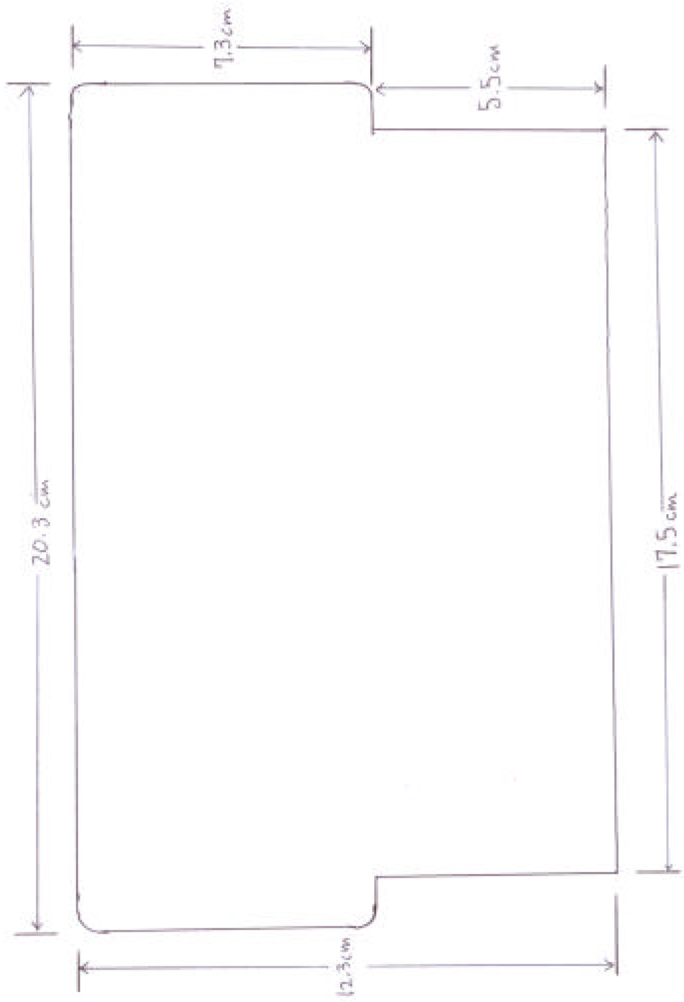
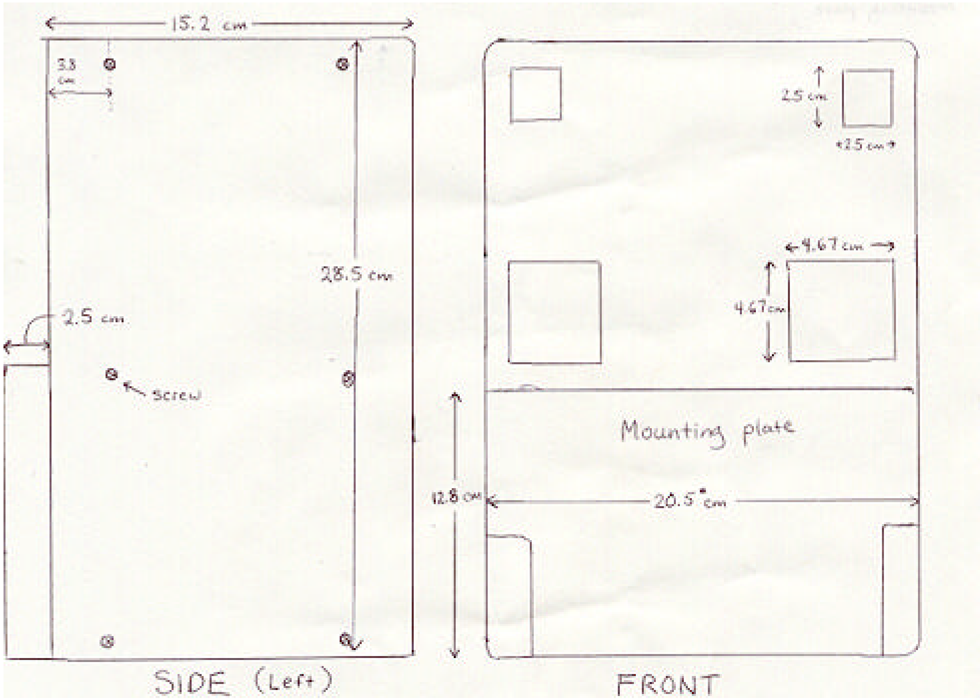
Kolpin, Sarah: Drawings of locking mechanism and of Alternative Design Three; Digital images of the prototype; Schematic drawings of the prototype.

Potter, Wyatt: Schematic drawings of selected design and of mounting plate (see Appendix C), Digital Images of the primate cages (with Kevin Campbell)

Appendix C: Schematic of the mounting plate:





Schematic of the prototype, showing dimensions.