Design and Testing of an Olfactory Stimulus Device for use in fMRI

By

Harjit Dhami

Electrical and Biomedical Engineering Design Project (4BI6)
Department of Electrical and Computer Engineering
McMaster University
Hamilton, Ontario, Canada

Design and Testing of an Olfactory Stimulus Device for use in fMRI

By

Harjit Dhami

0564254

Electrical and Biomedical Engineering
Faculty Advisors: Dr. A. Jeremic and Dr. M. Noseworthy

Electrical and Biomedical Engineering Project Report
submitted in partial fulfillment of the degree of
Bachelor of Engineering

McMaster University
Hamilton, Ontario, Canada
April 23, 2010

Abstract

This report outlines the design and testing of an olfactory stimulus in an fMRI setting. The goal of this project was to create a device that would be both cost effective and compatible with an extremely unique environment. The sense of smell provides a unique challenge for scientists. Because of most of the processing goes on in the deeper centers of the brain, it can be often hard to image. Another issue with the study of olfaction is the actual delivery of the odour. This problem is what our device was designed to solve. We went through many prototypes which had several drawbacks, whether they were price or compatibility. In the end we decided to go with a device that was pneumatically controlled and involved the use of a Laerdal mask. This device provided an air tight mechanism to deliver smell into the MRI environment, without having to worry about passing signals in and out, which can be challenging. The system was fairly simple but proved very effective. The overall result was activation seen in expected regions of the brain.

Keywords: fMRI, olfaction, Laerdal mask, pneumatically controlled

Acknowledgements

The author of this report would like to acknowledge the efforts of Dr. Noseworthy and Dr. Jeremic who served as faculty advisors on this project. They provided both guidance and resources without which this project would not been attainable. Also, to Shawn Keating, my partner in this project, who had some wonderful ideas and helped me a great deal. Also I would like to acknowledge Dr. Doyle who served as course coordinator for these projects and provided great insight into the work that goes into a final year project. Finally, to all my fellow students, who put in a great amount of effort and time to create some great projects.

Contents

List of Figures

Nomenclature

fMRI- Functional Magnetic Resonance Imaging

RF- Radio Frequency

BOLD- Blood Oxygen Level Dependence

CNS- Central Nervous System

Chapter 1

Introduction

1.1 Background

Smell is one of the most important senses that humans possess. It provides us with information that the other senses cannot. It gives us another parameter on which to base our decisions. Something can look appealing and feel nice, but if it smells bad people will often gravitate away from it. Smells can be good and bad and each one tends to elicit its own unique emotional response. Each individual interprets smells in their own fashion, and thus the study of smell is subjective and more qualitative than the study of other senses.

Our understanding of how smell works and what mechanisms in the brain are involved in processing of the stimulus is considerably less than the understanding that we have of vision and auditory. The challenge of studying smell lies with its difficulty to quantify. Thus when you're trying to create an experimental protocol that can be duplicated; these challenges have to be considered.

1.2 Objectives

The overall goal of the project is to study the effect of an olfactory stimulus on a functional magnetic resonance imaging system and compare the results with both theoretical and other research findings. The study of smell provides many different challenges. Smell is not an on off type of stimulus. There are considerable lingering effects that have caused the study of smell to take a back seat to the more immediate senses such as vision and hearing.

Our goal with this project was to set up an experimental procedure, which could be easily duplicated, to measure the response of an olfactory stimulus. This response can be measured on the fMRI to map out areas of the brain that respond to certain smells. A better understanding of the olfactory stimulus response of the brain can lead to many developments in several fields of study. The application to medicine is clear. Smells are

often indicators of neural dysfunction such as seizures. If one could map out which parts of the brain are active when a certain smell is delivered, they could discover that these areas are likely responsible for the medical issues that may be indicated by that smell. Smell also has a considerable emotional impact. Thus the applications in psychology are also clear. Studies of pleasant and unpleasant odours can be used in the study of neuropsychology. Furthermore, there are applications in marketing as well. Many attempts have been made to study the brain and use it in marketing purposes. Putting the person in a more pleasant state of mind makes them more willing to spend. This can be done by distributing smells which are shown to put people in more pleasant state of mind.

There are many applications which we may not have thought of, however our goal is just to provide a working apparatus. Basically we want to see some activation in areas which we believe should show activation.

1.3 Methodology

Our approach to this problem was to make an apparatus that would deliver the stimulus to the subject and then do data analysis on the data that we received from the fMRI scanner. To prove that the system works we have to consider that data we receive and do correlation analysis to show that what we saw was actually due to our stimulus. The basic idea of the device would be to deliver a stimulus for a predetermined period of time to the subject and then review that data recorded by the scanner to see if there was any activation during this on period. Also we want to see if this activation is in areas which we expect to see activation.

1.4 Scope

The focus of the device will be to deliver the stimulus under manual control. The control will have to be periodic. The fMRI data will be used to distinguish between on and off periods. Then data correlation is run between the periods and the expected response of the system. This project is a proof of fact experiment. Basically what we wanted to accomplish is to show that when some stimulus is applied that we can detect its corresponding effect on the brain in an fMRI system. Also a map of activation from the stimulus can be created. This map would show the activated areas that should coincide

with prior experiments. Overall, what we wanted to accomplish was a system that was effective in delivery of an olfactory stimulus in an fMRI system.

Chapter 2

Literature Review

2.1 Air Cannon

This system is used in virtual reality (VR) systems to provide an olfactory stimulus to the participant. The purpose of this device was to deliver a stimulus to the subject without them having to wear a mask or having to be attached to a tube. The system was to be used in conjunction with some other virtual reality device which would provide the other stimuli, mainly audio and video [1].

The device is composed of a nasal tracking system, air cannon platform, air cannon, and a scent generator. Figure 6 shows a sketch of the set-up of the system. The system works by using a camera to track the nose. The cannon then shoot's a vortex of air at the nasal cavity of the subject [1].
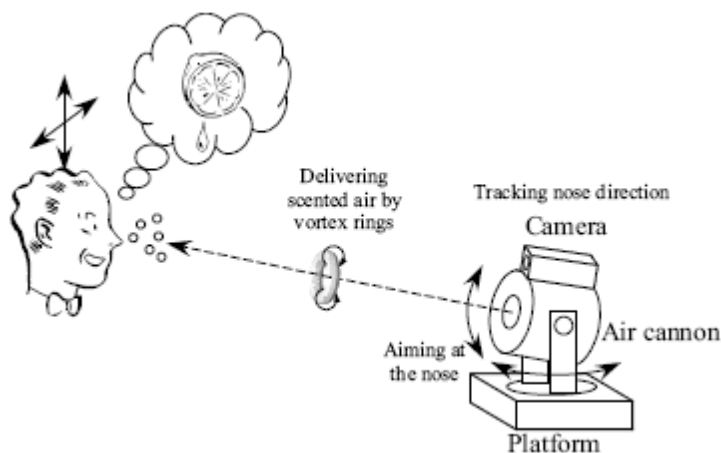
Figure 2.1- Basic Outline of Air Cannon system

The third prototype worked by using a scent switching mechanism. This basically takes 4 different scents into the scent injection system. Figure 7 shows the basic operations of the scent switching mechanism. Basically the scented is air is pushed out of the tube which is then shot out of the cannon. The overall device is mounted on a robot to provide is the ability to move with the person's nose [1].
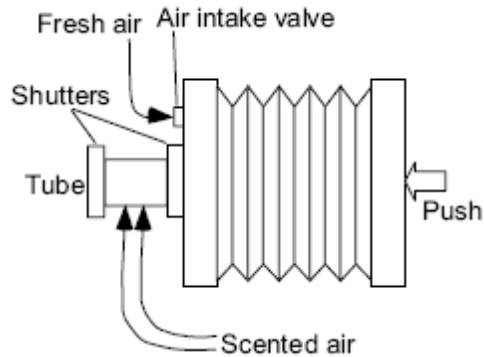
Figure 2.2- Scent Switching Mechanism

The overall procedure is as follows:

1. Close both ends of the shutters
2. Open the injection and evacuation valves
3. Drive the pumps
4. Intake scented air into the cylinder
5. Close the valves and shutters
6. Fire the air cannon
7. Close the shutters and open the valve at the body
8. Recover the condition of the bellows
9. Close the valve at the body

This system has the benefit of being completely isolated from the subject. Thus, there will be no need for any tubes or masks to be connected to the subject. However, there are some aspects of this device that won't work in our settings. Shooting air vortexes into a MRI is not something that is practical for us. Also this system requires robotic control, which is very difficult to achieve inside of a MRI setting and would not be feasible for the scope of this project. The total cost of this system makes it not practical for our purposes.

2.2 Inkjet System

This system uses an inkjet to deliver scents to the subject. The basic operation of the device involves the use of inkjet which has 3 large tanks and 9 small tanks, thus giving it

the ability to deliver 12 different scents [2]. Figure 8 shows how the inkjet system is used to disperse the smell.
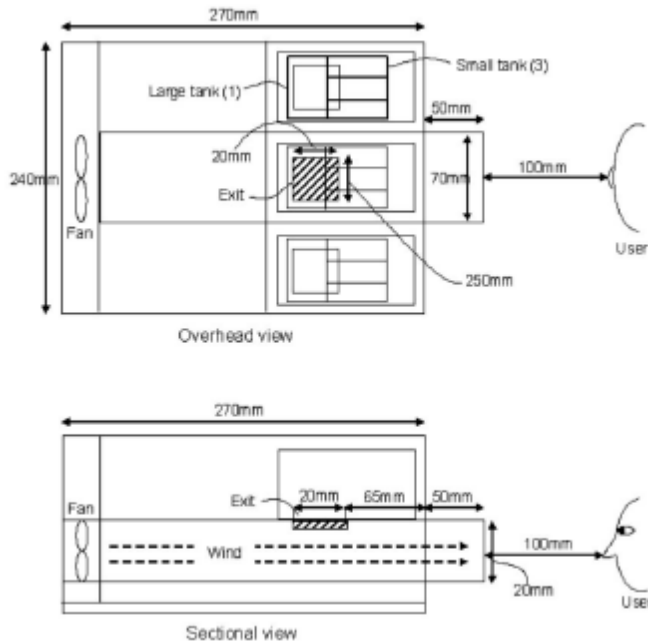
Figure 2.3- Inkjet Olfactory Delivery Device

A fan is equipped to allow for control of the wind velocity. This can be used to create control over how much stimulus is being delivered in each pulse. This device also is synchronized with the breathing rate of the subject. This is done to maximize the amount of scent that person is taking in [2]. The entire system is mounted close to the subject as shown in figure 9.

Figure 2.4- Inkjet Delivery System

The system has some clear benefits such as providing a pulse like injection that is synchronized with the respiration rate of the subject. This system also provides the use of a control system which has the ability to alter the amount of stimulus and since there are multiple smells present is provides the ability to change scents without much alterations. There is one clear drawback in this design, which is the proximity to the subject. The person that is undergoing the experiment has to be fairly close to the delivery device. This problem is easily remedied by using a tubing system that would extend the delivery of the scent.

This system was a promising design that we initially considered employing. The biggest issue here again was cost. In order to implement a system such as this one we would have required a sponsorship from a printer manufacturer. This system would have to also be made completely MRI compatible, which would require additional costs.

2.3 Sub-smell Delivery

The main purpose of the sub-smell system was to be used in conjunction with a movie. The system would provide an olfactory stimulus that would provide the scents of the scene depicted in the film. This system uses the classical method of delivering smells. Basically they have the scents placed in canisters that are equipped with a fan. Then when they need the release of the stimulus they just turn on the fan to disperse the scent [3]. The system that was used is shown in figure 10.

Overall, the device would have a controller that would have a predetermined release protocol associated with a specific movie. The controller will then release the appropriate stimulus for the pre-determined duration. The scent canister's and fans would be place in front of the subject resulting in the scent hitting the directly in the face [3]. Figure 11 shows the overall system when connected in the environment.

This system is simple and relatively cheap. But for our needs this system is completely impractical. This is because the scanner that we are using is a clinical scanner. Thus this type of design would leave odours which would continue to linger. Thus, there is a big issue involving the clean up that would be required after we would run our experiments. Another, big issue is creating a pulse like system with this type of system. There is no

control over when the stimulus is received and when it is removed. Our experiment requires a fairly well modelled pulse for analysis on the fMRI. If we have activation occurring at random times we will not be able to make any predictions from the fMRI data.

Figure 2.5- Sub-smell Delivery System
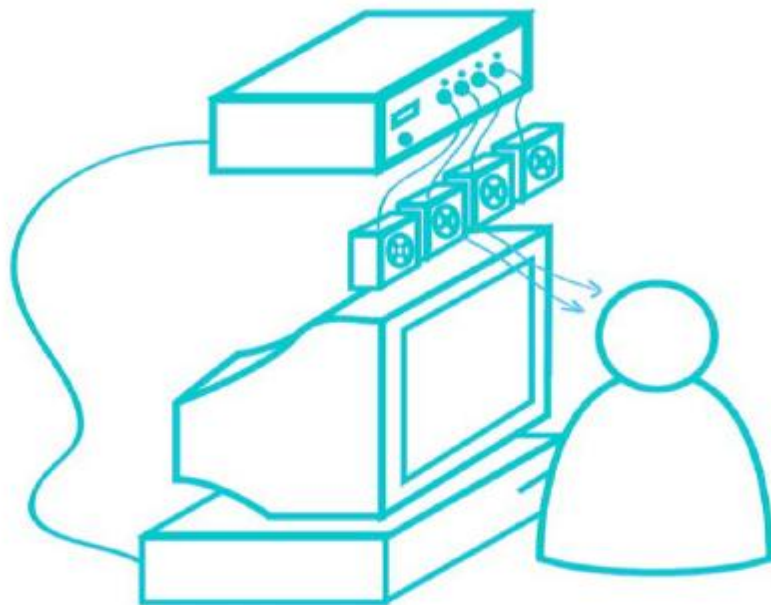
Figure 2.6- Sub-smell Delivery System Overview

Chapter 3

Statement of Problem and Methodology of Solution

3.1 Olfactory System

The sense of smell is one of the most primitive senses that humans possess. Over the years humans the sense of smell has taken a back seat to some or our more dynamic senses. However, the sense of smell remains a key in our emotional and physical well-being. A smell can elicit responses that bring back bad memories, or make you feel sick to your stomach. The internal mechanism that is used to record and process smells is referred to as the olfactory system. Figure 1 shows the overview of the olfactory system.

Figure 3.1- Overview of the Olfactory System

When the nose intakes a smell, the olfactory epithelium where the detection process begins. The epithelium consists of olfactory receptor cells, supporting cells, and regenerative basal cells. As the figure shows the receptor cells extend all the way from

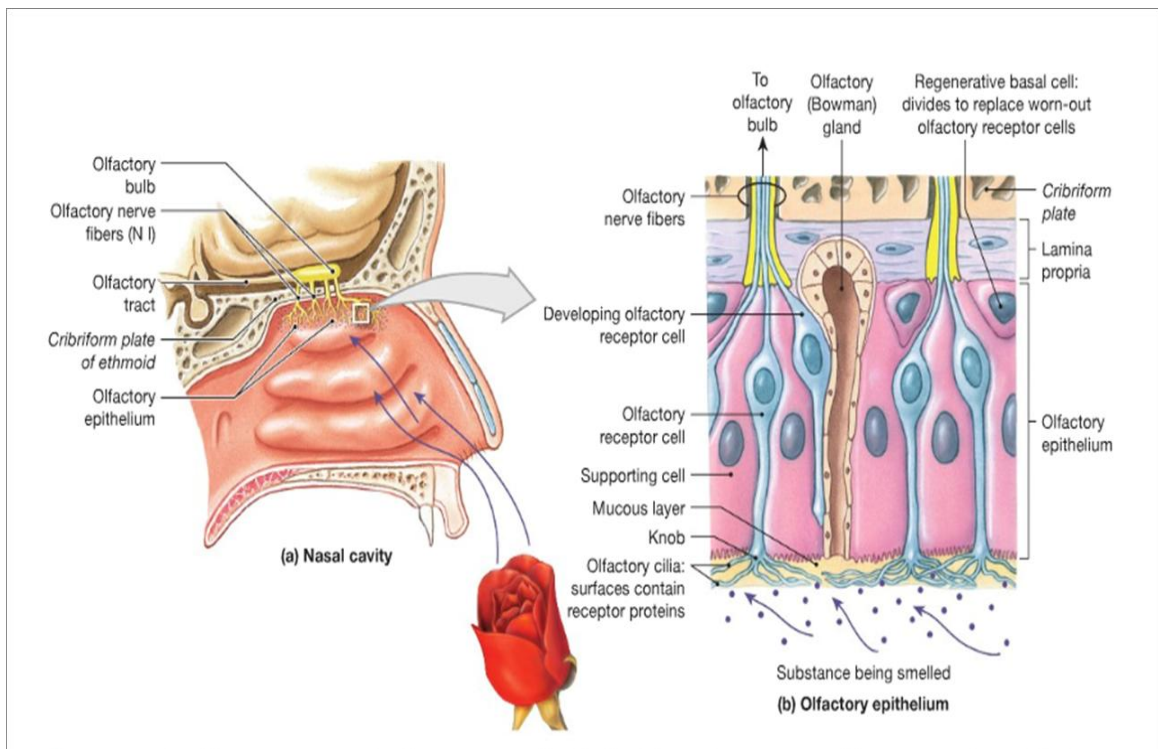the surface of the nasal cavity to the cribriform plate, where they will connect to the olfactory bulb. The tips of these cells have cilia which extend onto the surface of the nasal cavity. The reception of the stimulus occurs on the cilia where the smell reacts with the receptors, which are called odorant-binding proteins. Binding these receptors causes activation of the enzyme adenylate cyclase, which converts ATP to cyclic-AMP (cAMP). This cAMP then causes sodium channels to open which causes depolarization of the membrane. If this activation is sufficient to cause an action potential, this information of the stimulus will be passed to the central nervous system (CNS). These receptors appear in great abundance over a small surface area. Approximately 10-20 million receptors appear on a 5 cm^2, which is approaching the surface area of the entire body. Overall, the system does have regeneration of receptors, but these receptors tend to lose their effectiveness overtime. This is why older people tend to have a weaker sense of smell. Once the axons leave the olfactory epithelium they collect into 20 or more bundles which then reach the olfactory bulbs of the cerebellum. Axons which leave the olfactory bulbs then travel along the olfactory tract to the olfactory cortex, the hypothalamus, and the limbic system [4].

Although the olfactory system is very sensitive, this doesn't mean that the stimulus will elicit a response. There are several synapses that converge along the way which causes inhibition which can prevent the sensation from reaching the olfactory cortex. Also, the receptors tend to remain very persistent to stimulus, but there is central adaptation which causes the loss of stimulus from a new smell. The fact the limbic system and the hypothalamus are involved provides the basis for emotional responses elicited by smell. These areas of the brain are typically associated with establishing emotional states and the storage and retrieval of memories [4].

Overall there is considerable differentiability in the olfactory system. The system is able to make subtle distinctions between 2-4 thousand chemical stimuli. This is done by no apparent structural difference between the receptors. However, the epithelium contains cluster which tend to more receptive to certain stimuli. It is likely that the CNS interprets these smells on the overall pattern of receptor activity. The ability to distinguish a smell depends not only on the receptors but on the type of smell as well. Some scents tend to

require a smaller concentration to elicit responses. The reason for this could be evolutionary. Some smells can be harmful and need to be detected at a lower concentration in order to provide the body with enough time to react [4].

3.2 Functional Magnetic Resonance Imaging

Functional MRI uses a typical MRI system to map out changes in blood volume, flow, or oxidation in response to a stimulus or some other task activation [5]. Typical MRI systems employ the use of a large magnetic field, referred to as B_o, which is applied to a specific area of the body. This field causes the alignment of a small amount of spins with the field. Then a radio frequency pulse is applied, which causes these parallel spins to become perpendicular. Once, the RF pulse is turned off these spins return to their equilibrium states, causing the release of RF energy. This RF energy that is released is recorded and stored as data. This raw-data is converted into k-space which is the frequency representation of the image. The return to equilibrium is controlled by two time constants T1 and T2. T1 is the spin-lattice (longitudinal) relaxation while T2 is the spin-spin (transverse) relaxation. These RF pulses are generated and received by RF coils which must be placed around the region of the body that is being imaged [6]. Figure 2 shows the RF coil that was used in our experiments.

Figure 3.2- MRI head coil

The basic fMRI uses the blood oxygenation level dependent contrast to determine the functional activity of the brain. This signal basically relies on the iron in hemoglobin. A hemoglobin molecule is centered by an iron molecule which bonds to four molecules of oxygen. When this oxygen is removed the molecule becomes deoxyhemoglobin, which has four unpaired electrons [4]. These unpaired electrons cause the molecule to become paramagnetic and thus affecting the signal of the MRI. The result of this causes a decrease in the time constants. Thus when the brain is has increased neural activity there is increased blood flow in the brain. This new blood has an increases in the amount of hemoglobin which causes an increase in the T2* (gradient-echo equivalent of T2) and thus causing an overall increase in the MR signal [6]. Figure 3 shows the increase in hemoglobin caused by this increase in neural activity.
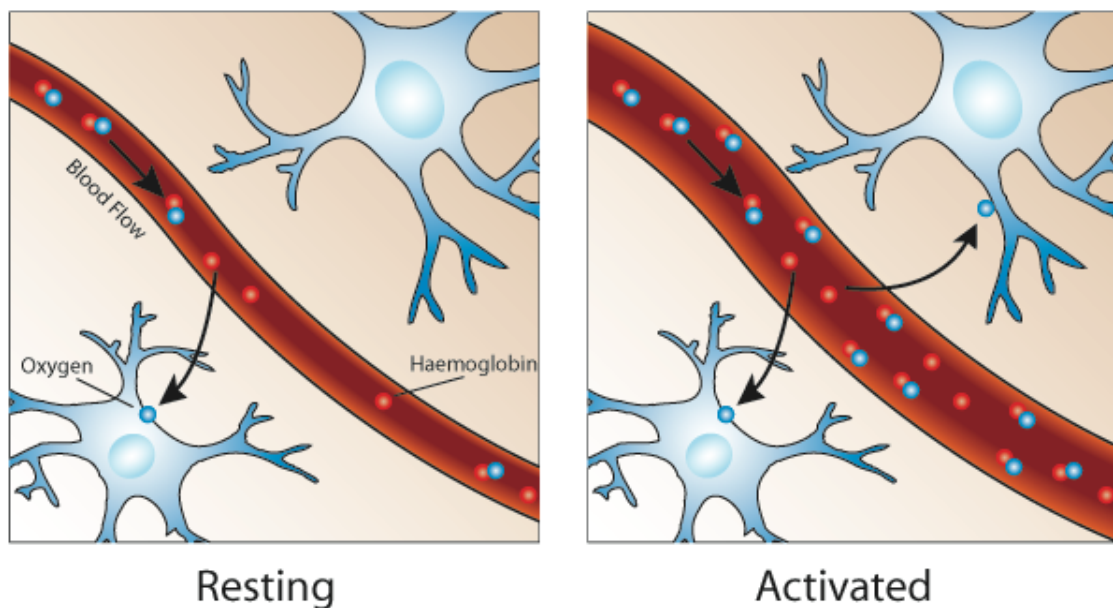
Figure 3.3- Increase in neural activity causing increase in blood flow

Initially when the neural activity increases the amount of oxygen in the blood initially decreases. This decrease is referred to as the initial dip [7]. This is due to the fact that the amount of blood present isn't able to accommodate the demand. There is then an increase in blood flow which actually overcompensates for the blood oxygen demand. This remains for the duration of the stimulus. After the stimulus is removed there will be undershoot which is quickly corrected to the baseline. This overall effect is known as the

hemodynamic response function (HRF). Figure 4 shows an example hemodynamic response function.

Figure 3.4- Hemodynamic Response Function

The imaging sequence that fMRI systems use is the echo-planar imaging (EPI) sequence. This sequence acquires the entire k-space in one repetition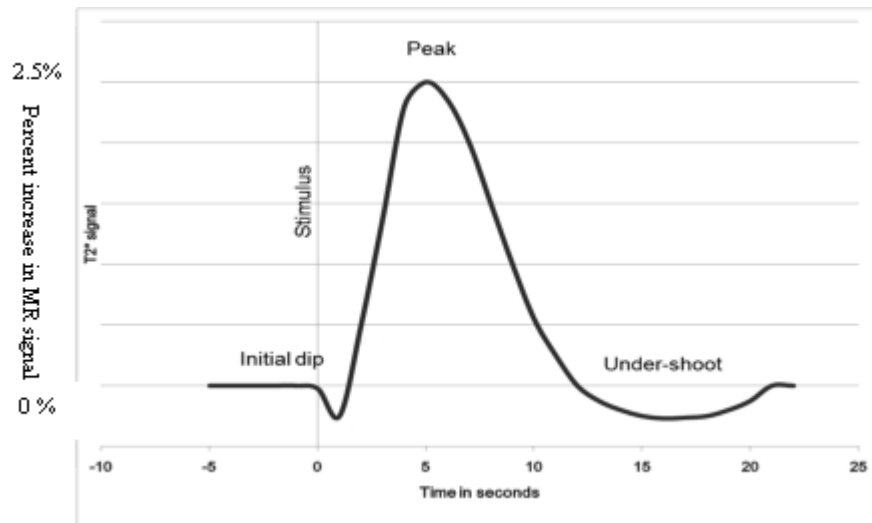 time, thus making it a very fast technique. There are several reconstruction strategies that are used for EPI. However, all of them acquire the k-space data in different directions. For this reason and others the EPI imaging sequence is prone to more artifacts in the final image [6].

3.3 Analysis Software

The software that we used in analysis was SPM, which is freeware developed by the Institute of Neurology at the University College of London. This software just requires you to input the data and set your experimental parameters. It basically takes the input images and compares them to the experimental setup. This program is very useful and user friendly. The overall analysis of fMRI data can be quite tricky and thus for us to write code that did this would be outside the scope of the project. This program allows you to input your experimental procedure; it then takes this procedure convolves it with a built in HRF. This is then correlated with the fMRI data to create an activation map.

Chapter 4

Design Procedures

4.1 Design Progression

When we started this project our goal was to develop a fully automated system. This system would ideally be push button from the fMRI control room and would have required minimal human control. However we quickly realized that this project was out of the scope of this project. Most of the equipment would have to be MRI compatible and these products can be fairly expensive. However a look at how we arrived at the device will be presented here.

4.1.1 FLAP OPENING DEVICE

The initial design that we had was to develop a plastic dispersal device that could be mounted onto the headset, shown in figure 8. A rough sketch of this design is shown in figure 11. This design works by having two different air lines coming into the device. Positive air pressure will cause the flap to open and the scent to be released. Then to close the device negative (vacuum) will be applied. This will create the desired control over the dispersal of the scents
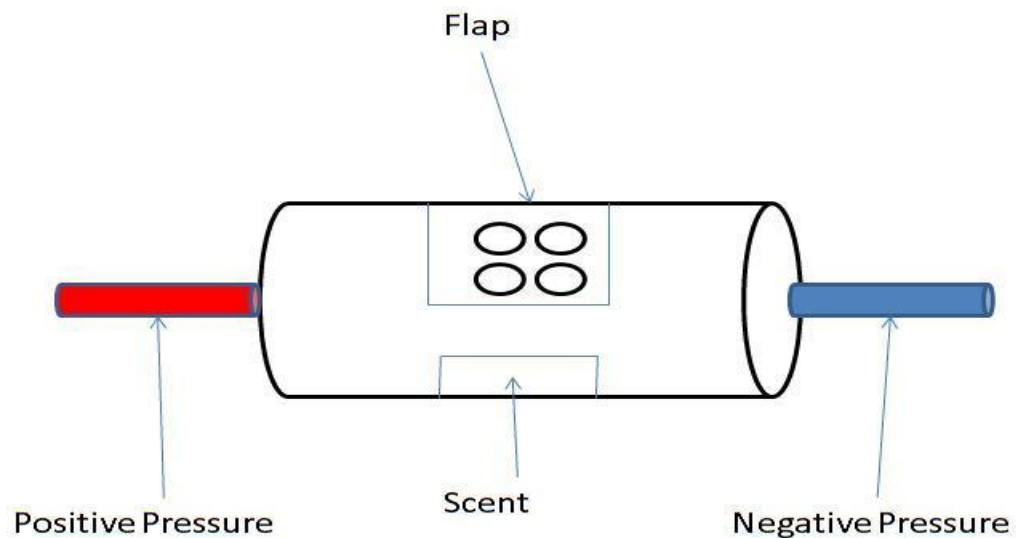

Figure 4.1- Original Design

This device will be regulated using a controller. This controller will have two lines feeding into it. One would be the negative pressure, and the other would be the positive pressure. Thus when the scent needs to be turned on the positive pressure would be applied and the controller will open that valve. To close the flap the controller will close the positive pressure valve and open the negative pressure valve. Doing this would create the scent pulse that we need.

The major drawback of this design was the mounted of the device on the headset and keeping the scent contained to the subject. Since there is no mask to provide a seal there would be considerable lose of scent into the air that surrounds that space. Also, since we don't have access to the MRI headset all the time, it would be difficult for us to find enough time to fabricate the device to fit the headset. There were also considerable issues involved in quantizing the scent. Since the air pressure was driving the opening of the flap and not the actual dispersal of the scent; there was not a constant amount of scent that was released. For these reasons we moved onto the next design.

4.1.2 VAPOURIZER WITH LAERDAL MASK

This design employed the use of an anaesthetic vapourizer that is MRI compatible. This vapourizer would quantify the scent and disperse equal amounts every time. The whole device would be controlled pneumatically and there would be control valve that would drive the air into this vapourizer. This valve would be controlled by the microcontroller and the microcontroller would also send a TTL pulse to the MRI to sync the acquisition. The scent that would be emitted would go the Laerdal mask, which is a clinical mask used in resuscitation. This mask provides us with an air-tight seal which would eliminate the issue with the scent getting out. Finally there would be a second line that would clear out the scent from the mask. Figure 12 shows the overall design of the system. The control valve would have to be designed by us, and we had not figured out an automated valve that would MRI compatible.

However, this valve was not the only issue with this design. The key component of this system would be the vapourizer. This component was very expensive and we could not find one that we could use for a reasonable price. Other than the cost of this system, this

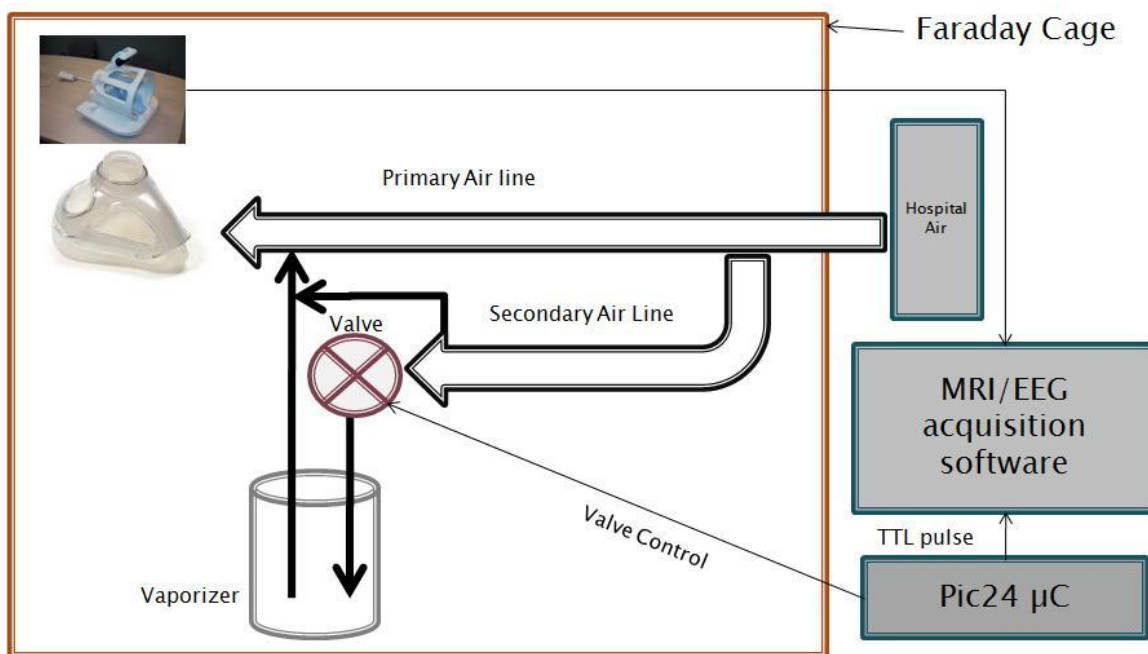design provided us with several good building blocks which we chose to incorporate in our final design.

Figure 4.2- Design with Vapourizer

4.2 Final Design

For our final design we decided to remove the automation feature. We felt that to automate this device would be fairly costly and something that we could not afford. We decided to go with a design that would be completely manual in its control. This does have its drawbacks, such as human error, but we felt this was the most feasible option. This device has three components to it: the mask, the control valve, and the vapourizer.

4.2.1 THE MASK

The mask that we used was the Laerdal resuscitation mask. This mask provides an air tight seal so we have no worries about any air coming in or going out. Figure 13 shows the mask that we used. This mask has one input that is shown in the left hand side of the figure. This input comes from the vapourizer and either inputs scentless medical air or scented medical air depending on which is needed. The choice is controlled by the control valve. The squeeze bag is does not play any role in the operation of the device, however it

has been left there because removing it would damage air tight connections, and since it offers no hindrance we decided to leave it alone.

Figure 4.3- The Mask

The seal on the mask is provided by using a rubber strap that is design to fit on the mask. Figure 14 shows the mask applied to the subject, Shawn. The mask and the headset are quite a tight fit but since this device will only be used on test subjects, the comfort will be something that will have to be compromised. The straps wrap around the subjects head and attach to clips that are mounted on the front of the mask.

4.2.2 THE CONTROL VALVE

The control valve that we ended up using was manually controlled. Figure 15 shows the valve that we used. This valve is a typical valve that is used in hospital tubing system. It generally used for IV drips or for some other fluid or gas that may need to be controlled somehow. The entire valve is made out of plastic and it has two inputs and one output.

Figure 4.4- Mask inside MRI headset

Figure 4.5- Control Valve

The inputs two the valve are medical air and the scent. The valve is turned in the direction of the flow. That means that if you want the scent to go to the mask, we will turn the valve towards the tube that has the medical air in it. This means that tip of the valve will be pointing in the direction the air is flowing. When the valve is open, whether it be for medical air or scented air, it flows through the junction and out through the top into the mask. Figure 16 shows a sketch of the flow through the valve.
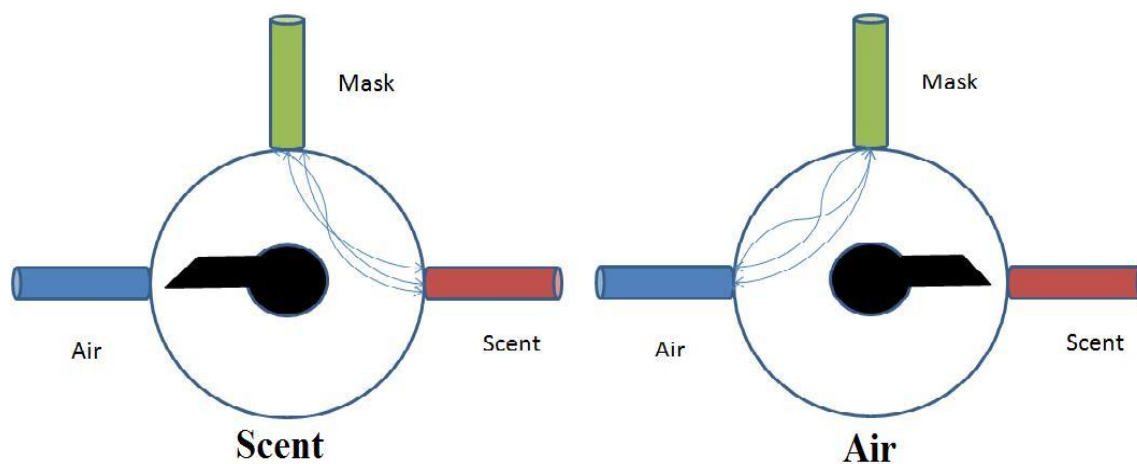

Figure 4.6- Flow Depiction

4.2.3 THE VAPOURIZER

For the vapourizer we decided to go with a fairly simple design involving an Erlenmeyer flask. The device is show in Figure 17. The basic function of the vapourizer is two push the scent out using medical air. This air comes in through the side and enters the flask. When the air enters the flask it pushes the scent towards the top. The top of the flask has a stopper that is used to keep the smell inside the flask and not allow it to flow out into the environment when under the pressure. There is a hole in the top of the stopper, which is connected to the tube line which goes to the control valve. The hole in the top of the flask and the tube are connected using a glass tube. This tube provides a sturdy yet reliable method to connect to the tube. It also allows us to get as close to the scent as possible so that it doesn't have to travel up the whole length of the tube. There is also a fat tube that is used to connect the skinny medical air tube to the flask. This tube was used because the flask side is bigger than a normal medical air tube. This fatter tube has

to be held in place using a clamp. This clamp provides not only a fixture method, but also keeps air from leaking out.

Figure 4.7- The Vapourizer

This vapourizer is cheap and effective and those are two of the main reasons why we chose to go with it. As mentioned earlier the other more robust vapourizers were too expensive and weren't feasible for this project. This also provided us with a very easy way to change the scent for different studies. All we had to do was remove the stopper, pour out the scent, wash out the flask and fill it with a new scent. Thus, because of its price, effectiveness, and flexibility this was the design that we went with.

4.2.4 DESIGN SUMMARY

The overall design requires there to be medical air lines present, which since we're in a hospital wasn't a big challenge. Another important aspect of the design was the use of tape to keep all the joints air tight and prevent and leakage from occurring. There is an initial junction point which is used to split the incoming medical air into two lines. This is

done so that one line can go straight to the control valve and the other can be used to drive the vapourizer. Doing this means that scent is always being delivered to the control valve and thus we don't have to worry about any delays in the tubing. The only place a delay could occur would be the line going from the control valve to the mask. We cut this line as short as possible to minimize this delay. However, we could not make it too short because it had to reach all the way inside the MRI machine which was about a foot and a half. Thus there is some delay in when the control valve is turned and the stimulus is received. This delay was also minimized by increasing the pressure of the air line which will be discussed later in the report.

Chapter 5

Experimental Procedures

5.1 Subject Preparation

When conducting an experiment in an MRI setting the subject has to be prepared according to certain regulations. First there can be no metallic objects present anywhere on the subject's body. For this reason the subject has to change clothes into hospitals gowns. We used typical hospital gowns that were readily available. After changing into the hospital gowns the subject must be place in the MRI bed. This bed is equipped with clamps that are used to connect to the headset. Figure 18 shows Shawn strapped into the bed before entering the MRI room.

Figure 5.1- Subject in MRI bed

Along with MRI protocols, the subject also has to be connected to the mask. This is a tight fit with the MRI headset. The method to do this is a bit tricky and it really depends

on the shape of the head you are dealing with. To begin with the rubber strap that connects the mask to the subject is laid down in the headset before the subject is place in. In Shawn's case we had to put his head in first then squeeze the mask in. To get the mask through the holes in the headset we had to tilt his head to the side. After tilting his head we had to squeeze the mask through the space in the headset and press the mask up against his face. Then by keeping the mask pressed against his face we strapped it into place. After the subject is strapped into place the bed it wheeled into the MRI room and connected to the MRI machine.

5.2 Device Preparation

Once the subject is connected to the MRI you can then set up the device. The first thing to do is to connect to the medical air line in the hospital. The connection was similar to the one shown in figure 19. Basically this is designed to connect to the tubes that we used. Then the pressure for the air line has to be set. This required a bit of trial and error on our part. We initially started off with 3 Lpm in our first trial. This didn't give us much data so we decided to go up to 5 Lpm. The second trial went a lot better and we got some data. However this was still not good enough to get good data. In our third trial we went up to 10 Lpm which gave us the best results we had.

Figure 5.2- Medical Air Regulator

After the air pressure is set, you have to connect the bag to the mask. The bag connects the output from the control valve to the mask and effectively to the subject. To do this the subject has to be passed all the way through the MRI and out on the other end. The bag is now connected to the subject and then the subject is positioned back into the MRI in position to be imaged. The mask has to be connected on the other end because of the person that is controlling the device. This person has to be in a position in which they can both see the clock mounted on the front of the MRI (but seen in the window) yet be close enough to the subject to minimize the length of the tube required from the control valve to the mask. Figure 5.3 shows the MRI room.

Figure 5.3- MRI room

The medical air lines that we used are situated on the right side of the MRI room. The timer can be seen on the front of the machine. The experiment time is set from the control room and this timer counts down from that time. In our case it was set to 10:20, where the extra 20 seconds were just to get the MRI ready to do the scans. I stood at the back of the room on the left hand side. This allowed me to see the timer in the window of the MRI

control room. Also Dr. Jeremic stood in the room while the scan was going on. This was to also give me a signal when I was to turn the stimulus on and off.

5.3 Experimental Protocol

To begin with the fMRI system has to be set up to acquire data in a correct fashion. Someone with knowledge of MRI's is needed to operate the MRI since it is expensive technology and can't be handled by anybody. Dr. Noseworthy was present for all experiments that we conducted and he set up all the parameters in the MRI. The min parameters that we care about here are the TE=2.1ms and TR=7.7ms. Also this was an fMRI scan which used echo-planar imaging. The pulse sequence that was run was one that was designed previously.

Along with the MRI parameters one must also control the experimental parameters. This is mainly the on/off times of the stimulus. Figure 21 shows the experimental model for our experiment. This model basically consisted of a 90 second rest period before a 30 second on period. The 90 second rest period gives enough time for the stimulus to clear and to create a nice baseline to compare the stimulus portion too. The 30 second on period provides the stimulus enough time to be effective without having the subject being exposed to the stimulus for too long a period. Over exposure to the stimulus can lead to many repercussions such as habituation. Over time the subject will become less affected by the stimulus and this will lead to drops in the data. This is why we decided to keep the experiment time to 10 minutes. This gave a long enough time to acquire the data that we needed while not being overly consuming of MRI time. As noted before this was a clinical scanner and thus we had to budget our time accordingly.
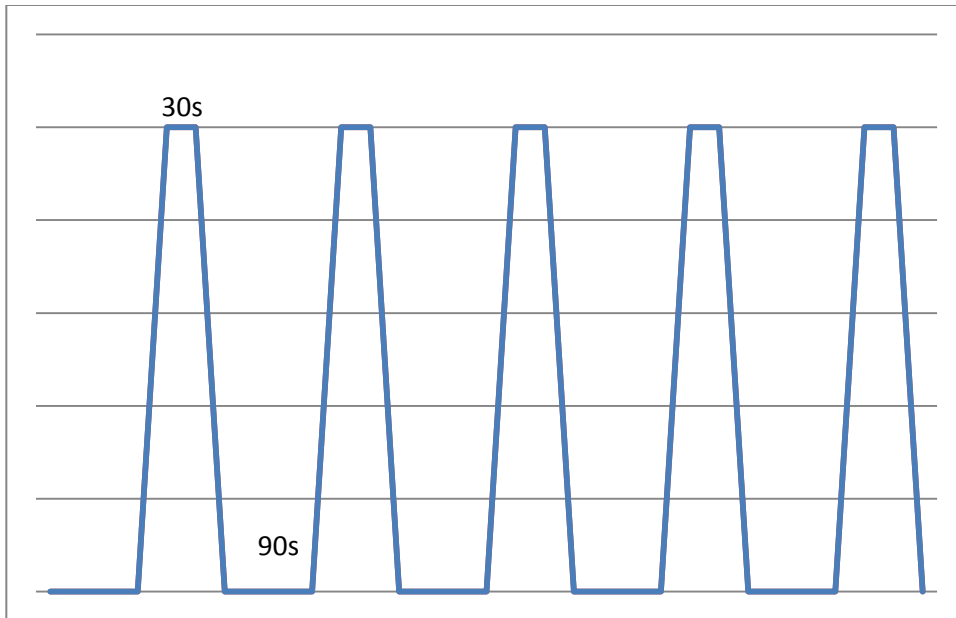
Figure 5.4- Estimated Experimental Procedure

This experimental procedure does have some errors associated with it. The main error would have to be the control valve. I had to sit in the machine and watch the timer in the mirror and change the direction of the valve according to the procedure. Although I tried to be as efficient as possible there are inevitable human errors which I could not get pass.

5.4 Procedures Summary

The overall procedure is a simple one. Turn the scent on for 30 and leave it off for 90. Other than that the preparation is important. The subject must be placed in a manner that is in accordance with MRI standards. Also making sure that the device is hooked up properly and everything is set up and working is essential to being both effective and efficient with valuable MRI time.

Chapter 6

Results and Discussion

6.1 Results

The results of the device are hard to measure. One can only acknowledge that the device is delivering a stimulus by being there and smelling the output from the mask. However, from personal experience I can say that the mask operated very well and was surprisingly effective in delivering the stimuli. The use of the fMRI indicated successful operation of the device. The correlated data that we had showed activation deep centers of the brain.

6.2 Discussion

Our results showed activation in and around the insular cortex region of the brain. This is an area with a link to the emotional response in humans [4]. This was to be expected. As noted before some of the strongest responses that humans exhibit from smell can be emotional ones. Thus an area that is responsible for processing these emotions should be one that is activated.

The device did perform very well considering its overall cost and the restrictions that we were under. Working in an MRI environment caused all the equipment that would make this device more advanced and efficient to be way out of our price range. Considering this is only an undergraduate project and to see actual data appear on the scanner was a big accomplishment for us. The overall goal for this project was to apply a stimulus and see if we get some sort of result. This goal I believe was accomplished to complete success. We had a device that was very successful in doing its job.

This device did a lot of things well, one of which being the deliverance of the scent was almost immediate. The delay through the tubes was a few seconds at the most and because MRI data works over averages this did not really matter. Furthermore, it was very easy to control. Since the device was under manual control, there were no electronic problems that we incurred. This may not seem like a big deal because someone can just debug them and that is a part of any design project. However, our project was unique

because of the environment that we had to do this in. The MRI was not available to us for prolonged periods of time, thus we could not spend hours in the lab trying to debug all the little issues that may have arisen along the way. We needed a device that was portable and allowed for quick set up. This device was both of those things. Another benefit of this device was its leak free operation. Throughout the device there are many tubes and connections, thus giving air many areas to escape. This device has air tight seals, made by using tape or glue, which air almost impossible to escape. Also the mask has an air tight seal which means that when the scent is delivered it remains there until it is ready to be flushed out.

Although this device did have many positive there is room for improvement. For instance it would be nice to have a device that would be fully automated. Something which would sync completely with the MRI system and be able to trigger both activation of the scanner and control the release of the stimulant would be ideal. This however, would have a great deal of costs and would likely require some external funding. Another aspect of the device that could be improved would be the vapourizer. Although this design provided a constant scent every time there was no way of quantifying it. A mechanism which would allow the disbursement of different amounts that could be quantified exactly would be helpful especially when trying to do the analysis.

Even though this device has its drawbacks it performs very well for a first prototype using a very limited budget. Improvements can be made to almost any device and this one is no different. Considering this, all devices have to start somewhere and I believe this to be a very good starting point for the study of olfaction.

Chapter 7

Conclusion and Recommendations

In summary that device provides a very effective method for the delivery of the stimulus in the fMRI environment. Having limited time, resources, and funds limited the extent to which we could take this project. We needed a solution that was both cheap and effective. This device worked by using pneumatics and using air pressures to drive smell. The overall design of the device was simple and involved no electronic control. This was not desirable but in the end helped us keep the device simple and made it a bit easier to control. Overall, this device ended up being the most feasible solution to a very complicated problem.

My recommendations for this project would be to perhaps continue it as a graduate level project. There is a definite need for the study of olfaction and this device provides a good basis for that kind of study. However, with the additional funding that would be provided to someone that is doing graduate level work this device could be made more robust and provide the additional aspects that would make the experiment more precise. Automation, quantization, and synchronization are all additional perks that could be added to this device to give optimal experimental conditions.

This device does not really have any drawbacks. It has aspects that can be improved upon. However, for an undergraduate level project this device has done a great job at achieving the goal that we set out too.

Bibliography

[1] Yanagida Y, Kawato S, Noma H, Tomono A, Tetsutani N. Projection-Based Olfactory Display with Nose Tracking. IEEE Virtual Reality. 2004 March 27; 04:43-50.

[2] Sato J, Ohtsu K, Bannai Y, Okada K. Effective Presentation Technique of Scent Using Small Ejection Quantities of Odor. IEEE Virtual Reality. 2009 March 14; 09: 151-8.

[3] Pornpanomchai C, Threekhunprapa A, Pongrasamiroj K, Sukklay P. SUBSMELL: Multimedia with a Simple Olfactory Display. PSIVT. 2009; 5414: 462-472.

[4] Martini FH, Nath JL. Fundamentals of Anatomy & Physiology. 8th ed. San Francisco: Pearson Education; 2009.

[5] Noll DC, Vazquez A. Contrast Mechanisms and Acquisition Methods in Functional MRI. IEEE EMBS. 2004 September 1; 26: 5219-22.

[6] Noseworthy M. 4BF3 Lecture Notes. Hamilton, ON. Available from: http://physics.stjosham.on.ca/~mikenose/ECE-4BF3/ece4bf3.html

[7] University of Oxford FMRIB Center. Introduction to FMRI. Oxford, England: Department of Clinical Neurology; c 2005-2010 [cited 2010 April 16]. Available from: http://www.fmrib.ox.ac.uk/education/fmri/introduction-to-fmri/introduction/

VITA

NAME:	Harjit Dhami
PLACE OF BIRTH:	Etobicoke, Ontario
YEAR OF BIRTH:	1987
SECONDARY EDUCATION:	Chinguacousy Secondary School (2001-2005)
POST-SECONDARY EDUCATION:	McMaster University (2005-2010)
HONOURS and AWARDS:	Excellence in Math Award 2002
	Ontario Scholar 2003, 2004, 2005