DESIGNING POLYSENSORY EXPERIENCES TO IMPROVE MOTORCYCLE SAFETY

BY

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THESIS

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ABSTRACT

Since motorcyclists figure disproportionately in accident statistics, safety feedback devices can be important life saving measures. Motorcycles also face a woefully underdeveloped set of tools to help them navigate the road. This scenario offers a unique set of challenges as well as a rich opportunity to improve. This thesis describes the design process used to develop a polysensory haptic system, built into a motorcycle helmet that could effectively warn drivers when they are in imminent danger of collision, and help them to keep their eyes on the road when navigating.
For Kalina
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CHAPTER 1 - IDENTIFYING A NEED

"Don't just extrapolate yesterday's technology and then cram people into it... Why aim for anything less than a dynamic medium that we can see, feel, and manipulate?"

Victor Brent, 2011, Apple UIUX design

1.1 INTRODUCTION

Far too often, in a world increasingly dominated by screen-based interaction, products and services are becoming two dimensional, leveraging only our senses of sight and sound. Our bodies have extraordinary sensory capabilities; we have evolved a sophisticated set of tools for exploring the world, yet we are totally underleveraging these assets. Taking advantage of these facilities will enable designers to create products and experiences that are not only more delightful and memorable, but make the tools we use more safe and effective.

Why are sensory and polysensory experiences so vital to modern design? For one thing, a sensory touch point can confirm the experience, and make it more real. Sensory interaction is also often linked with deeper engagement of the user. In this project, a multi-sensory touch point approach is used to act as the point of transmission for a motorcycle system that both warns of impending danger and aids navigation.
1.2 MOTORCYCLE SAFETY AND NAVIGATION

Driving a motorcycle requires constant monitoring of the traffic environment. However, the combination of visual and auditory blind spots and the high level of ambient auditory noise from surrounding traffic and the motorcycle are factors that contribute to poor rider awareness and the incidence of serious motorcycle accidents. Because simply adding more visual alerts may contribute to visual overload, haptic alerts merit further exploration as a means of conveying directional information to the driver, and giving him or her a chance to execute any necessary crash avoidance maneuvers in a timely and appropriate manner.

European research data shows that the majority of accidents involving motorcycles are caused by perception failures or improper use of helmets. According to an article in *Accident Analysis and Prevention* titled: “Evaluation of motorcycle safety strategies using the severity of injuries (p.358)”, the authors (Jung, S., Xiaio, Q. & Yoon, Y., 2013) noted that U.S. fatalities involving motorcycle crashes have increased from 1997 to 2007. In some states like California, the motorcycle fatalities have been greater than the national average. These researchers found that “...lack of or improper use of helmets ... was likely to result in fatal injuries regardless of age group” (p. 357), meaning that if helmets becomes more desirable, useful and seamlessly integrated into the motorcycle riding experience, lives will be saved.

While they can protect the rider from severe head injuries, the use of helmets has a downfall - a helmet also muffles sounds and limits vision. The motorcycle helmet can be improved by building in haptic interfaces that could help with navigation, and also alert riders to vehicles that are approaching at a dangerously close distance. When riders are busy paying attention to the road and other cars, a haptic system with sufficient warning could allow them to feel the need to execute a turn. One of the challenges of designing a helmet with haptic interfaces for the motorcycle rider is that in this environment, there are already many ambient vibrations from
the actual motorcycle (Siegel, 2011).

This project involved a polysensory design for the helmet that could both alert the rider to danger and assist in navigation. By utilizing haptics to alert motorcycle riders of information as opposed to visual or auditory signals, the helmet will free the rider up to pay attention to the road. Since motorcyclists figure disproportionately in accident statistics, safety feedback devices can be important life saving measures.

In the beginning of this project, some basic assumptions needed to be made about the overall system of which this helmet is a part. In the context of design and experience design, a metaphorical line was drawn around the project, so that the only elements designed were those that were critical to the expression of this designed experience. For example, there already is technology for identifying a hazard, and because this part of the ecosystem exists, it doesn’t need to be designed again for the purposes of this project. Moreover, the existence of Bluetooth communications is already present in helmets, and so the ability to get voice guided navigation from phone applications are already given.

In the process of researching polysensory design, it makes sense to start with the goal of simple navigation. This leads to looking at car navigation and finally motorcycle navigation, which leads to the idea of augmenting the riding experience with blind spot hazard warnings. There are a number of reasons this project focused on improving the motorcycle experience.

Firstly, the motorcycle riding experience offers a surprisingly isolated and controllable environment. A number of factors play into this. The rider’s helmet muffles the sound around the rider as well as decreasing peripheral vision. The sound and vibration of the motorcycle, as well as the wind, coupled with the rider’s
protective clothing, have a numbing effect over the body, and make manipulating fine controls difficult.

These are just some of the parameters that make the motorcycle-riding environment difficult to design for and may be the reason that there does not seem to be a lot of technological advances with any regularity. This does not mean that motorcyclists are not willing to pay for increased safety and functionality, in fact the motorcycle market is a large one, and most riders are willing to spend a fair bit of money on their helmets. So the motorcycle-riding scenario is a rich and under-explored design opportunity.

Lastly, by designing new and useful features into the riding environment, two things can be done: the helmet can be made a more critical accessory, and the overall safety of the riding experience can be improved. If the helmet can become so useful and so critical to safety, and ultimately an essential part of a seamless system, riders will be more inclined to wear it in places where it is not mandated by law.

1.3 DESIGN APPROACH

The goal of this thesis paper and accompanying project is to accomplish two things - first to explore a unique design methodology, and secondly to execute a design process that champions design-by-doing. My committee very much encouraged me to get started early, to plan less and try more, wisely in the end, as it brought to light directions that made more sense and I had not considered at the outset.

Over the past 10 years of my design career, I have had the unique opportunity to work with some of the best design minds in some of the more innovative design consultancies, and it was in this space that I first encountered the concept of sensorial design: trying to design products and services that appeal to the five human senses and make experiences more delightful, impactful, and memorable.
Whether it was approaching a fairly unusual problem of cardboard packaging at IDEO, or understanding how sense memory can improve in-store purchases at Design Bridge, I have worked in this space on many and vastly varied projects.

This helmet project added a new layer in that I was looking at the senses in a fairly extreme, highly sensorial environment. It also gave me a chance to become more familiar with what I saw as an under explored sense: the sense of touch. Designing with haptics is unlike designing for the other senses as it involves the space where physically tangible design meets a more ephemeral space or experience. Design in this area often moves beyond the two-dimensional space of screen based interaction design.

This project also gave me a chance to dwell on the best approach to polysensory design, to understand how to apply it, and where it might best make sense.

Urged by my committee, my approach to the design process was very much, "just try things, explore by doing, fail early, and fail often". At the beginning of the project, with very little engineering background, I resorted to using modified toys and dissembled electronics to explore haptics. Later, with the help of engineers, I was able to prototype three different haptic experiences in the span of just over a year. This style of iterative design proved to be crucial, in that I was able to start with a fairly broad goal and let the findings guide me. Often in design consultancies, we might let the research speak for itself, and let it guide the direction of the project. Similarly, in this design project, I was able to try things out, play with various options, and let the successful aspects guide the next prototypes. This not only helped me to make design decisions, but also brought new unexpected directions to the surface.
CHAPTER 2 – POLYSENSORY APPROACH

2.1 INTRODUCTION

Polysensory design can be simply defined as the intentional use of multiple senses in order to deliver better, more impactful, and useful experiences or products. By considering the multiple senses while designing products and experiences, the designer can tap into a very powerful set of tools that connect with users on emotional, physical and even primal levels.

In order to understand how we might do this, we must first understand the five senses, what are the limitations and parameters, as well as understand how they are being used currently and finally, when it is appropriate to leverage the senses.

2.2 OUR FIVE SENSES

As far back as Aristotle, humans have appreciated that there were at least five senses (sight, sound, taste, touch and smell) that we use to navigate the world. We can think about these senses as being near to far, where our sense of sight is our furthest reaching, followed by our senses of hearing and smell, and our closest senses being touch and taste. We can also classify our senses into two categories, wherein sight, hearing, and touch are considered to be our mechanical senses, and tastes and smells are referred to as our chemical senses.
However, the sense of touch has been complex to understand by researchers because it is not merely that which is sensed on the skin’s surface, but also includes pressure on muscles, tendons, and joints, as well as awareness of a limb in space, and motion, vibration, texture, pain, heat, cold, tickle, itch, and so on. Thus, touch is not a “simple sense” (Boring, 1950, p. 110).

2.3 SENSE CATEGORIZATION

While the five senses are fairly well established, some would argue that some of the sensations we experience might best be classified as separate senses. Proprioception and kinaesthesia (joint motion & and acceleration) as a well as thermoception (temperature differences) and interoceptive senses (our ability to feel our insides) are typically categorized as sub-sets of our sense of touch. Some believe we should re-establish more difficult-to-define things like nociception (pain) and equilibrioception (balance) as senses on their own. And lastly, things like emotion as well as our sense of time passing could be argued to be sensations
that do not fit into our strict definitions of a “sense”, yet these are just as real and tangible as many of our other experiences (Gourishankar & Wallace, 2011).

For the purpose of this project, this paper will focus on the five main senses, as they are traditionally and widely accepted.

2.4 SENSES WORKING IN TANDEM

While scientists tend to classify senses as singular, and we treat them as separate siloed experiences like sight, smell, and hearing, in fact, the senses often work in tandem and are inexplicably linked. "Flavor" for example, is actually the sense of smell and taste combined and working together. Our brains process the senses in an integrated, seamless way. In The Design of Everyday Things, author Donald Norman (1998) notes, "The word perceived is critical: the causal relationship does not have to exist; the person simply has to think it is there. Sometimes we attribute the cause to things that had nothing to do with the action. And sometimes we ignore the real culprit" (p. 40). This cognitive overlapping is a key concept and one of the few polysensory experiences being used in modern mobile technology.

Consider a user pressing a key button on a keyboard. They can simultaneously see the button move, hear it click, and feel the button engage, telling the user that the task was successful. In screen-based interactions, it is nearly impossible to give that kind of immediate haptic, auditory, and visual feedback. Often though, designers will use graphics to show a button's state change and use auditory cues to reinforce the success of the task.

With this widely leveraged “see-hear” style feedback, we lose the important haptic dimension, a design asset that, on a cognitive level, enriches and reinforces our experiences.
The definition of flavor and the concept of cognitive overlapping are just two examples of experiences which show that use of multiple senses is both highly necessary, and in the end can help to deliver better user experiences.

A Canadian-based company, Molecule-R, created the Aroma fork, which uses smell to add additional tastes to our favorite dishes. Because so much of taste is based on our sense of smell (which is why food tastes different when we are congested), using smell gives this illusion of taste, despite the fact that you are not ingesting any food. The fork comes with 21 different aromas, including smoke, vanilla, wasabi, cilantro, and coffee.

![Figure 2.2: The Aroma fork](image)

So we start to see the benefit of the polysensory design approach, and in a world of increasingly screen-based interactions, we can see we are leaving behind, ignoring, and losing a wonderful and powerful design tool -- haptics.
2.5 HAPTICS

Haptic / tactile feedback (or haptics) is the use of advanced vibration patterns and waveforms to convey information to a user or operator. The word "haptics" is derived from the Greek meaning “to come in contact with” (Sheridan, 2002). As a scientific term, it is traced to the German word *haptik*, meaning “the study of touch and tactile sensations, especially as a means of communication” (Oxford English Dictionary). Today, the term has expanded in scientific use beyond touch, and now includes anything having to do with contact forces generally. Thus, haptics includes not only cutaneous senses of force, which are distributed in time and space on the skin’s surface, but also contact forces applied to the muscles, tendons, and joints, sensed by different receptors in these structures (Sheridan, 2002).

In recent years, significant progress has been made in understanding how to use haptics in design. One of the first engineering uses of haptic systems was in hand controls — power operated controls for automobiles and aircraft. During World War II, aircraft engineers recorded many instances of pilots confusing hand controls because the knobs were similar in shape, and their eyes were too busy to watch their own hands. Experiments were performed to find sets of knob shapes, which are most quickly and correctly discriminated by haptic senses alone (Sheridan, 2002).

Haptics are also used to assist the blind. The idea of sensory substitution (displaying to a human sense information that is normally mediated by a different human sense) was first applied in a major way in an effort to helping the blind to read. Louis Braille (1809-1852), blinded at the age of three, invented the haptic reading system, which bears his name. Various combinations of six raised dots represent individual letters, numbers, or common combinations of letters (Sheridan, 2002).
Beginning in the 1970s, "touch sensors" became a commonly known use of haptics. In 1977, The Siemens Corporation financed an effort to produce the first curved glass touch sensor interface, which became the first device to be called a "touch screen". Towards the end of the 20th century, the computer manufacturers Hewlett-Packard came up with a home computer that used the touch technology. This computer had infrared beams that detected finger movements on the screen. Subsequently, electronic devices like ATM’s, computers, phones and handhelds began incorporating the touch screen technology in the 1990s. Today, the term haptics has come to encompass “the study of touch and the human interaction with the external environment through touch” (Minogue, 2010, p. 2). This shows that the definitions of touch devices and haptic feedback have been recently blurred. There needs to be a line drawn between touch devices and the haptic feedback. The fact that people use their fingers to manipulate the content does not necessarily mean that they are receiving haptic feedback.

The touch screen, widely utilized in online gaming, technical gadgets, training, and simulation is often referred to as a haptic application when in fact, this is slightly misleading. While touch screens are widely used in airports, malls, museums, offices etc. to display information or to create a user interface (Paterson, 2007) they are in fact, numb technologies, because while they do engage the user’s sense of touch, they do not provide haptic feedback.

Touch screen tablets and smart phones have been widely adopted, with staggering speed. Aided by mobile data availability, people have begun using their phones not just to make occasional calls, but for almost every conceivable use. Social media are a constant distraction, and people can too often be found staring into their screen rather than observing their environment or enjoying their surroundings. We as humans have such a wonderful, powerful set of sensory tools, and yet we are letting them atrophy, as modern touch screen interactions are so devoid of haptic feedback. This “numb” experience is beginning to be the norm, and yet, by leveraging a
polysensory approach, we might be able to create experiences that do not take up so much of our attention bandwidth, and leave us freer to experience the beauty of the world (Lewin, 2010).

Figure 2.3: Social Media are Distracting

Take the example of a book: you can feel it without looking if you are nearing the end. Or, you can pick up your Starbuck's to-go cup and you simply know if you are nearly finished. These are, on the face of things, very simple interactions, but below the surface, they are incredible, physiological miracles of the body and brain. So what we are offered by modern screen-based technology and our devices in general, is underwhelming.

Rather than going through six or more steps to check our email, might we rather pick up our phone and without even looking “feel” how urgently we are needed by others? Or, feel how many unread emails we have piling up by feeling our phone getting heavier? Perhaps even feel the time or how close we are to a meeting? These
are the kinds of things that might free us from the screen and allow us to enjoy the world around us more.

Figure 2.4: Improving the Haptic Experience

Gaming is an area where designers have successfully taken advantage of the visceral nature of haptic experience design. Gaming controllers have haptic motors integrated in order to simulate the real world haptic feedback you might feel from, for example, bumping your car into a wall, or jumping from place to place. This example of haptic design is successfully making electronic, simulated experiences more immersive and enjoyable (Vance, 2011).

From another angle, game designers are using our sense of body position to make games more immersive. We see this with the adoption of gestural gaming like in the Nintendo Wii system or with the XBOX Kinect, which use either an accelerometer in a hand held controller to sense the position of the player or a camera to identify
body position, respectively, and allow for users to use hand and body movements to play the game.

Studies prove (Banter, 2010) that haptic experiences increase the speed and accuracy of information transmission, thereby reducing the time taken to retrieve information, and improving a user's overall experience. With the spread of the latest state of the art technologies geared towards utilization of the human senses, haptic technologies have been introduced as a way of utilizing the sense of touch to either solve real world problems, or to enhance present experiences.

2.6 POLYSENSORY DESIGN

Haptics can tangibly reinforce physical experiences, by enhancing smells and tastes. It doesn't need to be argued that richer sensory experiences are desirable and more enjoyable. How do we approach the intentional designing of our products and services to appeal to more senses?

The California-based industrial design group, IDEO, uses sociologists and anthropologists paired with designers to help it drive a product design process that is characterized by a rapid sequencing of observation, prototyping, and fast implementation. Its design philosophy is underpinned by what founder Bill Moggridge called "designing verbs not nouns" (Rodriguez, 2010).

At the heart of this type of design process is the goal of improving product experiences, a process that involves designing products which can be described in polysensory terms. Touch, smell, taste, feel, appearance, and sound all have become essential to modern product design, because it is through the senses that consumers become engaged with a product (Hickson, Stacks, & Moore, 2004).
There are many ways designer might go about leveraging the senses. Take sense memory as an example. Designers might use scents to access users’ sense memory and associate themselves with something positive. A great example of this being widely adopted more recently is with banks. More and more often, when you walk into a bank lobby, you will encounter the smell of fresh coffee. This is done intentionally, not only because they want to offer you a free cup of coffee, but also because the smell of coffee covers up other smells while suggesting a feeling of alertness and welcome.

A British chain of grocery stores, Waitrose, used a similar tactic to sell more food per visit. The grocery stores would roast chickens in the back of the store and rather than exhaust the fumes outside, they piped the smells to the front door. Customers arriving would step through the door and find themselves becoming immediately hungry. Today, many other grocery stores have begun to use this strategy (Hulten, Broweus & Van Dijk, 2009).

In these examples, experience designers are leveraging our sense of smell to affect the customer’s mindset, tapping into deep-seated positive memories and associating their products with them. This is a powerful technique, and just one of many ways a designer can leverage the senses using a polysensory approach.

Singapore Air (SIA) is another example of polysensory experience design, and probably one of the most influential. As early as 1972, Singapore Air identified that having a consistently unified sensory experience would improve the customer experience. SIA was the first to introduce hot meals, free alcoholic and non-alcoholic beverages, and hot towels with a unique and patented scent, personal entertainment systems, and video-on-demand in all cabins. They also reinforced the brand message in their advertising, setting them apart, and helping them become The Best Airline in the World ten years in a row (Roll, 2014).
Singapore Air would control the look of the stewardesses -- their exact hairstyle, nail polish color, and the design of their uniforms, even standardizing the perfume they wear. Moreover, they dialed in the customer's sensory experience on the plane, by playing soothing pre-chosen music, handing the female passengers a fresh orchid, and as the passengers settled down, they would be handed a hot lemongrass towel to refresh themselves.

This all sounds like standard practice nowadays, because it was so effective and well received that it has been copied by many other airlines. Singapore Air designed a polysensory brand experience that would not easily be forgotten, and for many customers, every time they smelled lemongrass they would remember that refreshing Singapore Air towel.

What Singapore Air was doing was designing a very unique and sensorial experience, and while they were one of the first companies to use this approach, they are not alone. Harley-Davidson motorcycles trademarked the iconic sound of their rumbling motors, and they have paid close attention to delivering a "Harley-Davison experience" with even their brand new, more efficient motorcycles (Baskin, 2013).

Other companies have come much further -- one Japanese tire company actually trademarked the smell of their tires. So these carefully planned and executed polysensory experiences are not only impactful, but also very much ownable.

Designers must take many things into consideration when designing a product, service, or experience. How will it be used? Will it be understandable and easy to use? Will it communicate the desired message? Is realizing the product feasible from a manufacturing, engineering, and business sense? These and many, many more questions need to be considered.
These are examples of questions that a good designer will start to integrate and answer effortlessly as he or she gains experience. But if the designer starts to ask regularly, "How am I leveraging the senses?" then this will become second nature, and will ultimately result in richer user experiences.

When beginning to integrate polysensory design, the designer must carry out a sensorial review. The first step is to evaluate the user’s experience step-by-step, similar to a cognitive walk through, and identify which of the senses are being used.

At this point the designer must ask themselves these things:

1. Can I leverage the sense being used in a more effective way?
2. Can the leveraged sense be used differently or in new ways?
3. Which senses are not being used and why?
4. Could these unused senses be used in a meaningful way?

By reviewing their design through this polysensory lens, a designer can start to find new ways to improve the designs. However, as mentioned earlier, in the context of app design or software design, the designer is very limited by the manufacture of the device. Yet, in previous generations of software, and in some legacy examples, we could see companies like Apple and Disney trying to design their software to simulate real world textures and familiar experiences that consumers could relate to (Israr, 2011). This kind of design, that references or even tries to mimic real world textures is often called skeuomorphism, and while largely considered passé, it fills the need to cognitively link these digital and real-world experiences.
Designers might also take another approach, asking themselves questions like, "If I could touch my interface, would it be soft or hard? If my brand had taste what would it be? If my app made a sound what would I like it to sound like?" These are the kinds of questions that lead car manufactures to carefully design the sound of their car doors to make a very specific sound when they open or close, in hopes of communicating a sense of quality or strength, hence strengthening their product experience and improving brand loyalty (Woodyard, 2009).

Through practical, real world examples, and examples of carefully branded examples of polysensory design, we can start to see that it is not only a valid and powerful methodology, but that it is already being used with a high level of success.
It is easy to conclude that any product can benefit from a polysensorial makeover, and this methodology can lead to both exciting new designs and more valuable marketable products.
CHAPTER 3 – DESIGN PROCESS

3.1 FIRST PROTOTYPE (WRISTBANDS)

Going into the design phase, I was much more interested in exploring navigation, specifically navigation using haptics. As I have mentioned, the use of haptics is grossly under leveraged and I was interested to see where I could take it.

The first prototype I built explored a simple left/right signal, by trying to steer a blindfolded person through a maze using only haptics. The goal was to learn about the limits of haptic direction and hopefully inform the next stage of design iteration.

I approached this project with the idea of developing a minimum viable product (MVP). An MVP is a product that is designed to have the minimum core values. This type of product involves an iterative process of idea generation, prototyping, presentation, data collecting analysis, and learning, and it can be deployed to a subset of possible customers for feedback. It is used to grasp a product vision (Ries, 2011).

3.1.1 Design

As you will see, coming from an arts background, one of the major challenges with this thesis project was overcoming a lack of electronic engineering knowledge.

For this first prototype and test, I decided to try and stay as simple as possible, aiming to build a pair of wristbands with a small haptic motor on each side.
Haptic motors (sometimes called pancake motors or coin motors) are really motors with an unbalanced load (eccentric mass) that vibrates when activated. There are a number of ways to deliver a haptic signal, but coin motors are relatively cheap, safe, effective, and easy to work with.
3.1.2 Making

While researching ways to build these haptic wristbands, I came across LittleBits. LittleBits is a modular system of electronic modules that snap together with magnets. While positioned as a learning aid for young adults, LittleBits proved very useful for me, as it enabled me to rapidly build the prototype with little to no understanding of circuitry.

LittleBits is a collection of magnetically connected circuit boards that essentially provide input, output, and some controls and a power source. After ordering a number of LittleBits, I was able to piece together a simple circuit with a left and right button that, when pressed, would make one of two coin-motors vibrate.

Next, I stripped down two cheap wristwatches, taking out the contents of the body, and embedded one coin-motor on the surface where it would normally contact the skin.

![Figure 3.3: LittleBits Integrated into Wrist Bands](image)
While this prototype would have been better as a wireless system, I decided that it would still work with wires. For the purpose of testing the concept, I felt that this was useful because I could get an idea how this haptic interface would work. The idea was that given enough slack, I could stand behind or near the person who was being steered, and assess whether the interface was successful.

3.1.3 Testing

Finding or building a full-size maze would have been ideal, but for this simple test it proved unnecessary. Instead, I masked out a maze on the ground. This seemed a simple enough way to test whether the researcher (designer) was able to give haptic signals to the subject, yet be complex enough that the "subject" would not be able to memorize the pattern.

![Halloween Maze](image)

Figure 3.4: Using Haptics to Navigate a Maze
Having set up the maze, I asked the first subject to put on the haptic wristbands and wear a blindfold and earplugs, in order to isolate the other senses. Giving the signal of a tap on the back, the subject gingerly started forward into the maze. The subject was asked to keep a slow and steady pace forward. This would remove the need for the driver to give the subject any feedback such as "forward, slower, faster, back up", allowing the driver to focus on purely steering the subject.

I tested four people in the maze including myself, and we quickly learned it was, in fact, possible to complete the maze with nothing but haptics. However, we also found that there were a number of techniques that improved signaling left and right.
3.1.4 Learnings

Test One

As I mentioned, for the first test the user was told to only to keep a steady pace, and respond to the left and right signal to navigate the maze.

At first, the subject would start gingerly shuffling forward in small steps, the driver would tap the left or right button and the subject would turn accordingly. Problems arose when the subject would make too much of a turn, or they would be walking down a straight part of the maze at an angle on a collision course with the maze's walls. In either of these scenarios the driver needed to let the subject know so they could correct their path, but they didn't have a way of communicating the difference between a "turn" and a "correction" which led to both the driver and the subject doing a lot of over correcting.

In this first case, the subject had to guess what the haptic signals meant, while the driver was learning to control the subject. In this transaction, we started to learn that there were really only two ways to communicate with this prototype. Because the prototype did not have frequency/strength control, there was really only an analog on/off signal. Thus, we could either send a burst, a series of bursts, or a burst of a certain length.

The driver was learning to steer the person, and learning how the subject would respond to a signal and then try to build on that. But as soon as the driver tried a different signal (e.g. a series of burst vs. a long burst) the subject would have to guess what that meant.
This led to some confusion, but still resulted in a completed maze. What we needed was to establish a haptic language, so the driver and the subject were on the same page, speaking the same language.

Test Two

For the second test, the subject was asked to respond to the length of the bursts (see signal v1 in Figure 3.6) where they should adjust the amount of turn to the length of the signal so a single burst would result in a fine adjustment and a longer more sustained signal might signal a complete 180 degree turn.

While this sounds straightforward, we realized immediately that the subject could interpret this in two ways: first, keep turning until the signal stops, or secondly, turn X degrees for every Y amount of time.

While setting this perimeter vastly improved the ability for the driver to control the subject, we found that subjects had a hard time perceiving the difference between medium length signals. In other words, people had a hard time discerning the fine differences in the length of the signal.

Short bursts were easy to understand and would result in a small adjustment (e.g. a ten degree turn) and long sustained bursts did, in fact, result in more drastic turns (e.g. a full 180 degree turn). However, it was difficult for both the driver to communicate more subtle turns, and for the subject to perceive the signal length and turn to a consistently appropriate degree.

In the future, it would be interesting to conduct some research into people's ability to perceive time in relation to a haptic stimulus. I found that subjects had trouble perceiving how long a stimulus was, and had trouble remembering the length of stimuli after some period of time.
Test Three

Having identified some of the learning issues from the previous test, I decided to try to simplify the language even more. I instructed the subject to make a fine adjustment for each burst, so a single tap on the controller would result in a fine adjustment (about 10 degrees) and a repetitive burst would signal a 45 degree turn.

This vastly improved the ability of the subject to navigate the maze, yet still left one parameter unchecked: the severity of the bursts. In fact, we developed a language to communicate through haptic signals. For example, a series of three slow bursts would get the subject through a simple turn, but if the driver sent the same three signals in fast succession, the subject would interpret that as more urgent or more acute and make a bigger correction in their turn.

Upon finding that this style of short bursts worked well, we reran the maze test two or three more times, and found that both the driver and subject were communicating well through the language of bursts, and that the subject could now perfectly complete the maze. So once the language or interface was learned, both driver and subject could very efficiently steer through the maze without hitting any walls.
Post Test

At the end of these tests, we tried one different kind of test. One of the subjects who did not know her way around town was asked to wear the haptic wrist bands, and to attempt to drive home, while someone who knew their way around town would give haptic prompts before each turn.

While we found varying levels of success with the three initial blind maze tests, this unplanned test was really the breakthrough of the day. With virtually no learning curve, the subject was not only able to navigate home, she was delighted by the experience.

"I've used GPS navigation units, and I've used my phone's maps functions, but the subtle and non-invasive prompts on the wrist bands were really nice. There was no jarring loud voice, and the haptic signal was pleasant yet unmistakable. The best part was that is gave me a warning of an upcoming turn without interrupting our conversation or the radio".

In summary, coming into this experiment I really didn't know where I was going to take this project, but as a part of a "learning by doing" process, I suspended
judgment. Thus, I learned that with haptics alone, I could steer people through a complex maze, and now seeing the seemingly perfect integration of the haptic stimuli into the driving experience really made it clear that I was onto something useful and interesting.

3.2 SECOND PROTOTYPE (HAPTIC ARRAY)

With the relative success of the wristband navigation, and after some discussion and thought with my advisors, I began the process of translating what I had learned to a motorcycle helmet. The first test was also an exploration into higher resolution direction giving.

3.2.1 Design

The goal of this next prototype was to use a line of motors to create a haptic array. Lined up from right to left, the motors would fire one at a time to signal "go right" or "go left" with a movement.

At this point, I needed help, since I had reached the limit of my engineering capabilities. I started by asking the ACM (a student-run club for computer science engineers) if they could point me in the right direction or suggest someone to help. They recommended I attend a SIGbeded meeting. SIGbeded is a Special Interest Group for Embedded technology; this group works closely with an emerging technology called single-board microcontrollers, or SBM.

One of the most popular SBMs is called Arduino, which is intended to make the application of interactive objects or environments more accessible. I found a fellow student that had a shared interest in exploring this kind of technology, and together we planned a circuit, bought supplies, and wired up the prototype.
3.2.2 Making

The prototype consists of a control box with a simple left/right button, a power source, a controller, and at the end of a long cable, ten coin motors arranged in a line.

Figure 3.7: The Second Prototype

When, for example, the left button is pressed, the motors vibrate in a right-to-left direction, one at a time.
I had read about a system called “Surround Haptics” technology that Disney Research is working on, which is similar to my research. Disney's system is integrated with a wide variety of entertainment and media contents, so that the contents are not only seen and heard but also felt, simultaneously. The tactile contents are carefully created and synchronized with visual and auditory cues to create effective and immersive experiences, and increase the interest of users while they are playing video games, watching movies, etc. The technology is integrated into theater seats, gaming chairs and vests, rides, gloves, shoes, hand-held devices and controllers, and even clothes, to create another dimension of sensory feedback. For example, while playing an intense driving simulation game, users feel road
conditions, gravel, traction, acceleration, brake, explosions and collisions (Israr & Poupyrey, 2011).

Disney researchers describe what they called "haptic blur" where they used a grid of haptic motors to send signals to the person's chair in tandem with video game data. They called this "blurry" because of the inherently inaccurate nature of your sense of touch, particularly on less sensitive parts of your body like your back. Disney found that with a fairly spread out grid of motors, they could define a single "point" on the body, the body "blurs" the various motors and perceives the sensation as one point.

3.2.3 Testing

For this round of testing, I didn't formally test the device, as I wasn't really interested in its effectiveness as a directional prompt, or at least I was not interested in the accuracy of that prompt. I was more interested in how people would interpret the signal, if it communicated a "go left" or "go right" message.

To do this, I tried two things:

1. I asked a number of friends to stop by my studio and they put on the helmet. Then I directed people through our office and I would walk behind them and steer them this way and that.

2. I brought the prototype helmet to a classroom and asked the students to try on the helmet and describe the feeling.

Before testing this on any respondents, I tested the prototype on myself to discern the most appropriate placement of the haptic array. I found that for this case, it was easier to feel it on the center of the forehead rather than on the center of the nape of the neck. The nape of the neck was so un-sensitive that I found that subjects were
not able to accurately feel the middle of the array. We could only feel the array's start and finish.

![Figure 3.9: Integrating the Technology into a Helmet](image)

Based on self-testing with a single haptic motor and then asking three or four friends to confirm the test, I created a map of the head's sensitivity. In the map below, you can see the darker red areas are the more sensitive areas. Based on this, I placed the array on the inside front of a helmet, so I could get the most accurate reading from respondents.
In Test One, I asked people who were not familiar with my research to put on the helmet, and then describe what the feeling was like. The respondents with no background were apprehensive to even putting the helmet on, and those with no background could only describe it as "feeling something move across my forehead". It was only when I told respondents that I was trying to indicate "go left" that they understood what was happening and they agreed that this was an effect they could feel.

3.2.4 Learnings

There were a number of limitations and drawbacks to the prototype. For example, I realized that I was unable to vary the strength of the signal as it moved across the forehead. In other words, the signal was the same strength from right to left and visa versa. This caused a cognitive disconnect in that: for a "turn left" signal, the first sensation the respondent encountered originated on the right side of their forehead (the signal for "go left" would start on the right side of the forehead and move left).

One of the ways to potentially fix this problem would be to ramp up the signal as it move across the array. In effect, you might not even feel the signal until it was half
way across your forehead. Unfortunately, with the time and resources given, I was unable to build a revised prototype to test this.

For Test Two, I used a classroom of students. I learned that two things are key. First, was that people need to experience the haptic array a number of times before it makes sense to them. Second, was that despite my best attempts to describe the array and what it would feel like, people were still very surprised by it. Most people also really enjoyed the sensations, as they had never felt anything like it before. The vibrations were repeatedly described as "pleasant."

People also remarked on the noise the array would make. Here I must point out that the human head is very resonating, and that the motors are sometimes easier to hear than to feel. However, it was in my finding that while people could very clearly hear the motors, they were less able to discern the direction of the vibrational noise, in that the vibrations were resonating throughout the skull.

3.2.5 Conclusion

It was clear at this point that the haptic array, while interesting, fun, and pleasant, didn't necessarily add anything significant to the goal of direction giving. A simple left signal/right signal was easier to implement, and from a manufacturing standpoint, ultimately cheaper to produce.

One of the most important learnings from this was not really based on the haptic array, but rather on an idea that came from playing with it. I had an idea that perhaps, if there were a series of infrared cameras on the back of the helmet, each attached to a corresponding motor on the inside of the helmet, that you might able to wave your hand behind a subject’s helmeted head, and the person might be able to "sense" where your hand would be.
This was an interesting idea and led to the breakthrough idea of using haptics to alert motorcyclists of dangers in their blind spot. Unfortunately, due to time and funding constraints, this "sixth sense" prototype was never built. After talking to my community, the feeling was that the prototype would lead to a fun new experience, but that we wouldn’t learn anything new. The decision was that maybe the two points on the back of the head would be enough to signal if a car was in your left or right blind spot.

What we did was identify that there was a need for a deeper understanding of what the various (possible) haptic signals might mean, to start to build a haptic language for this haptic interface.

3.3 THIRD PROTOTYPE (SIGN WAVES)

The goal of this stage was to start to begin to write a "haptic language" that might be applicable here in the context of navigation and blind spot warnings. We asked ourselves, what might the most appropriate "turn signal" feel like? Or what would a warning feel like, and how would you communicate severity? What are the different parameters for a haptic signal?

In order to do that, I needed to learn about signaling, and I needed a prototype that would allow for a higher level of control over the signal length and strength.

3.3.1 Design

Working with my student engineer, I was able to design a prototype that would have a left and right "on", as well as a dial for each channel that would increase or decrease the strength of the signal to the haptic motors.
With this prototype, we also experimented with using two motors on each side in an attempt to make the haptic signal stronger, since in a motorcycle environment, there are a lot of ambient vibrations to start with.

During this design phase, I started to look into the waveforms of signals in hopes of being able to articulate and describe the "haptic language" I hoped to design.

By playing with the motors, I was able to discern two basic signals: a wave and a pulse. A wave is created by a slower ramp up (sometimes described as pitch) of the coin motor from its resting zero state to your desired maximum, and then controlling the ramp down/loss of the coin motor's RPM to its resting zero point again.

Going from zero to maximum and back to zero as fast as possible creates pulse. It must be noted that the coin motors have a relatively slow ramp up, and the motor does continue to spin briefly after the signal stops.

This slow response time can be mitigated by using a different kind of motor that uses Piezo actuators to move a weight linearly, rather than spin an eccentric weight.
However, the linear actuators that are of a comparable size with the coin motor offer a much weaker signal, so we decided to look for stronger eccentric weight motors.

![Wave and Pulse](image)

**Figure 3.12: A Wave and A Pulse**

Going further, we can start to describe more details of the signal. The maximum vibration could be described as the strength of the signal. When using a pulse signal, you might describe a slow pulse as having a large break duration or pulse duration.
Lastly, when we gain more control over the signal, we can see that there are some established wave forms that we might take advantage of (See figure 3.14).
3.3.2 Making

The following are some of the challenges I faced while trying to make fast iterations with this kind of design:

1. I was limited by what my engineer could build in his free time (and in between his coveted online games of something called DOTA2 which is apparently a black hole of time).

2. In order to test one of these prototypes, you need to:
   1. Design or specify what you want the prototype to do
   2. Source, purchase and receive parts
   3. Assemble and program the prototype hardware
   4. Install the hardware into the helmet and the control housing.
Ultimately, by the time you have a prototype ready, you might have been waiting two or even three months to even try it out, and if there are any changes needed, you will need to accept a delay of at least two to three weeks. This left me with very little wiggle room for a design or time to try to improve style with iterations.

![The Controls for Testing Haptic Sensations](image)

**Figure 3.15: The Controls for Testing Haptic Sensations**

### 3.3.3 Testing

When we had the prototype assembled, we made two big discoveries. The first was that two motors next to each other behaved in an unexpected and not-optimal way. The second was that while we had vastly more control over the motors, we were still very limited by the manual nature of the controls and our inability to physically move the controls fast enough, or with enough control, to try out many of the wave forms we had hoped to play with.
When placing two coin motors next to each other, we found that they interacted with each other's resonance and this caused unpredictable results. We deduced that the small differences in how the motors were made, or even where the motors' eccentric weight came to rest, would sometimes cause the two motors vibration to interact in inconsistent ways.

Sometimes, each motor would actually be vibrating in a way that would cancel the other motor's vibrations out, or in other cases they might just be out of sync and make a kind of undulating vibration, when we were trying to get a constant vibration signal.

We found that trying to manually input the pattern of a wave (for example the saw tooth wave form) was impossible, given that:

A. The motors had a fairly slow ramping up and ramping down time, meaning that a rapid pulse might be perceived as either an undulating wave, or blurred together into a constant signal.

B. Because we were manually ramping up and down the motors, we weren't able to test more finessed waves and variances of wave, so we could only test simple signals, and they were difficult to reproduce.

C. Because we bought control knobs designed for audio equipment (like a volume control), they were designed in such a way as to physically dampen the speed in which you could turn them. The knobs were designed to move slowly so as to give the intended user a smoother control over a finer range control. What we needed was a faster way of controlling these variables.

Lastly, with these "volume controllers" we found that while they had a large range of control, when trying to control the motors from zero through to maximum, the
ranges didn't match (see Figure 3.16). This meant that while the control was hard to use in the first place, it was compounded by the fact that only 15-20% of its range could actually control the motors. In other words, the first part of the control range did not result in a perceptible (or any) kind of vibration, while the last 3/5 of the range was all "maximum", leaving this prototype to have a limited number of signals we could produce.

![Figure 3.16: Range of Perceptible Haptic Output](image)

Despite the limitation of the prototype, we were able to at least start to understand the limitations of the motor and begin to understand what we would need from the next prototype.

We also found that when people were familiar with the haptic feedback, they could describe what they would image the ideal signals might be for the helmet. Often when prompted interviewees would describe the turn signal, as a "tick tack" sound similar to that of a car's turning signal.
Lastly, while installing the motors, I tried playing with them directly. I put them against the compressed foam core of the helmet, underneath the liner. This had an unexpected result, as helmets are designed to absorb energy, thus placing the motors directly against the foam actually cancelled the vibration. The foam inside the helmet was so efficient at absorbing energy; it was actually rendering the motor useless.

### 3.3.4 Learnings

Ultimately, this prototype convinced us that we need to change strategy, and start designing the final prototype that would be programmable, processor-controlled, and provide consistent and reproducible signals.

We also learned that in the end, one well-placed strong motor for each location would be enough. The haptic display showed us that an array would be confusing, and that the use of two motors did not produce the desired doubling effect. We also learned that a simple right/left signal was enough to give direction in the first prototype. Now we were starting to get a picture of what worked and didn’t work in the helmet.

From talking to motorcyclist friends and regular users, I was starting to learn a few things about what people wanted from the haptic feedback. People were universally concerned about adding further distractions to a motorcycle driver. People also had described their worry that a vibration might startle the driver, and cause more negative than positive effects.

### 3.3.5 Conclusion

While trying to design a haptic language, I discovered that, while we designed the prototype to be "played with", in reality this low-fi, manual approach ended up
being unsuccessful. This was because the kinds of signals we wanted to play with were impossible to produce manually, and we needed to be able to reproduce them reliably for testing.

I also learned that when prototyping hardware, the iterative loop needs to be lengthened. Another possible solution to this might be to have multiple projects running in staggered succession, so that while you are waiting for one prototype to get finished, you might be able to be testing and evaluating another.

Lastly, I learned through interviews that people desire two things from the feedback: first, that the feedback must be non-invasive, not jarring or startling; and second, that the feedback, where possible, should be mapped to existing experiences that users can reference.

In the end, while we were not able to test a lot of variations of signals, what we found was that for the "turn" signal, people wanted it to mimic a car's turn signal because that is a familiar experience. Also, for the blind spot warning, the only relevant parameters are that it should not be too jarring and it should vary in strength to signal distance or severity. When designing the real warning, as we saw with the many models from the beginning, since people have no frame of reference for this effect, we could really design the waves in any way that make rational sense. People will, as with anything, learn to use and interpret the interface.

3.4 FOURTH PROTOTYPE (FINAL)

For this final prototype, we changed engineers and set out in one semester, starting from scratch, to build a wireless, more programmable final version of the helmet. In order to complete the system, I would also need a basic mobile application (app) to communicate with the helmet and to act as the main interface for the end use
3.4.1 Design

The bulk of this final design phase was focused on overcoming the technological hurdles that were in store. This involved moving from low fidelity prototypes, designed to explore haptics, to a final resolved product that could demonstrate that the concept was sound and ready for production or further development.

This final design would be the culmination of all the research, testing, and learning from the previous prototypes, and would prove that a polysensory approach could lead to viable and innovative products and solutions.

![Figure 3.17: The Fourth and Final Prototype](image)

One of the most pressing problems I wanted to address was the relative weakness of the haptic motors I had observed, in this application, the motorcycle was already creating a lot for ambient vibrations and weak signals might not be noticeable. Turning to the Internet, I started looking deeper into haptic motor technology, and discovered a great resource in a British company specializing in haptics and haptic motors: Precision Microdrives Ltd. After consulting with my new engineer and
calling the British firm, I ordered a completely new motor that would triple the amount of haptic vibrations and improve the response of the motors.

I also laid out the framework for the accompanying app, which would control the system, help the user connect the system, and set up his preferences for the system. This framework would be the start of an app that would function as a platform for testing the helmet’s capability, as well as showcase how the app would work for the end users.

3.4.2 Make

For this build, we first got the system working outside of the helmet. Then we embedded the system, and finally, through testing, we refined the vibration signals and app to get it to a high level of resolution.

As mentioned, we wiped the slate clean for this final phase of the design. My new engineer had to learn everything anew, as we couldn’t rely on the engineering learnings of the previous engineer, and so there were many hiccups along the way that cost us time. The Arduino was wired to a board, with a Bluetooth shield, and connected to two LEDS and four motors (two for the front left and right and two for the rear left and right). It took a great deal of trial and error to get the system working. By the time we got the system working to the point where it was responding to the commands sent from the phone via Bluetooth, we ended up burning out two Bluetooth shields and two Arduinos.

I also sourced a completely new helmet. I chose a helmet that had two key features: a replaceable liner, and space for the electronics to be housed.

Removable liners are a common feature in helmets, as they allow the user to wash the inner liner every season or so. This removable liner would prove instrumental,
as it allowed me to seamlessly embed the motors in the zones previously identified as the most sensitive to vibrations in prototypes two and three.

The first step was embedding the motors in the liner. Initially, I had planned to sew in soft felt pockets to house the motors, since the previous motors were relatively weak, and it made sense to keep them as close as possible to the skin of the user. But with the new motors being much stronger, I found I could actually embed them behind the liner, allowing for a much neater and cleaner final product.

Figure 3.18: The Internal Mechanics of the Helmet

I also chose a helmet that, while it did not have a Bluetooth communication system installed, had been designed to have one installed post-purchase by the user. This meant that the helmet was designed to be taken apart, and had extra space to accommodate the additional hardware. After the liner was removed, there were two pieces of high-density foam on the inside left and right of the helmet that could be removed to install the communication earpiece speakers. These two panels would untimely house my system, and made installation easier in the long run.
Next, I set out to prepare the helmet to accept the hardware of the system. As the helmet was designed to have a Bluetooth speaker installed post-purchase, it proved relatively easy to do this. After pulling out the liner, I pulled out the left and right side panels. On the right side, I used a Dremel to mill out space for the battery pack. On the left side, the helmet the manufacturer designed a small removable exterior panel that was an affordance for the communication system’s controls, a simple on/off switch and volume control. Taking advantage of this, I Dremeled out the support braces that served as backing for the communication system. This meant that after the system was completely installed, we would have some basic access to the Arduino and electronics we embedded, without having to pull everything out each time we needed to reprogram the Arduino.
Once the hardware was installed with the Arduino still accessible, we could begin work on the app, and dialing in the vibration patterns. The Arduino would need to be connected to the computer and reprogrammed every time we upgraded the app or designed a new vibration pattern.

### 3.4.3 Test

The test phase of this was more of a confirmation of what was learned from the first phases of the project, and while I learned much from it, the learning could quickly be integrated into the system. Because of the architecture of the stock helmet, we were able to make changes to the app and the system in much quick iteration.

When we first tried out the system, we found that it was lagging and the response was slow, which was easily fixed. Following that, we had a system that was, in effect, a more elaborate version of the third prototype. We could turn up the power and control the on/off for each motor, but as I learned in the third phase, we were still limited by the dexterity of our hands.
We needed to try out and design patterns that we could control and that could be reliably repeated for testing. We designed a simple interface that would allow us to select one of six patterns, control the volume, and then apply it to any of the four areas in the helmet.

Figure 3.21: Designing the Five Signals
Through trial and error, and quick iterations, we came up with five signals that we could use to help test on the road, and that showed a good spectrum of haptic signals:

1. "Fast Pulse" would send a steady on/off pulse at a fast rate, faster than we could produce with just pressing the buttons rapidly. This proved to be an effective warning signal and could be implemented as a kind of “severe” warning if a hazard was imminent.

2. "Sinusoid" was programmed to allow us to experiment with custom waveforms. As the user pressed the controls for a motor, the vibrations would ramp up slowly until they reached 100%, and then stay that way until the button was let go. This allowed us to confirm that a soft ramping wave, which increased in power, would be a subtle enough signal to be distinguishable as a warning, yet not too jarring as to startle the rider.

3. "Sawtooth" was programmed so that we could simply feel if it would make sense as a warning, but test users found it was just too scary. The saw-tooth (see previous figure) was impossible to produce manually, and while it proved effective as a potential extreme warning, but is potentially too intense to be used for everyday purposes. For this reason, to show the extreme end of things, it was left in for demonstration purposes.

4. "Default" would reset the system to an on/off state. When tapping this, the motor control would just turn the motor to 100% and stay that way until unpressed.

5. "Pulse" was a simple constant undulating waveform, and was only used to determine weather or not the ramping up/down of the motor in between rapid signals was useful.

As we learned previously, the turn signal should simply mimic the sound and visual cues that we are used to in cars, but we found that in mapping this to a vibration, it needed to be carefully dialed in. We designed the turn signal as a set of rapid double pulses, where the first pulse would be full power, then a shorted half powered pulse,
followed by a relatively long break. This gave a very discernible “tick tack” sensation which, when tested on various subjects, was perceived clearly.

For the final (and most fun) step of the testing process, I donned the helmet and took to the roads with a friend riding pillion position on the back of my motorcycle. The first thing I noticed was that the helmet’s upgraded motors were a great improvement and that even at low settings the motors were very detectable. Yet, while on the road, during the tests, despite the volume of the surrounding traffic, the
motors were still fairly loud when activated. While the motors that we used were effective, they were also potentially too powerful, leading us to think that in a final production model, a quieter motor should be sourced.

During the ride, we tested out all of the haptic patterns we designed and found that because of the strong motors, the response was similar to that of when we tried the patterns in a lab environment.

I asked my friend to watch the road around me and to send signals to my helmet, acting as my sensor every time a vehicle was in my blind spot, either passing me or being passed.

We needed to stop and discuss the signals a number of times, effectively dialing in the system further and discussing how the system felt, and what could be better.

3.4.4 Learn

While the system functioned incredibly well as a navigation and blind spot warning, it was clear from the testing phase that there would need to be a more responsive set of controls, both physically on the helmet, as well as on the app on the phone.

These new sets of controls would allow the user to turn off parts of the system that were either unnecessary or interfering with their ride, or customize the settings. An example could be that the user might want to change the navigation signals LED color depending on the time of day, or if the user preferred a pulse signal rather than a wave signal for a blind spot warning.
Beyond this, it occurred to us that there should also be a set of physical controls on the helmet itself. The reason for this is that, as a user’s riding environment changes, he might need to turn off parts or turn down parts of the system. For example, the user might want a more powerful long-distance blind spot warning while on a long stretch of road, but in the city as he moves through traffic, without needing to interface with his phone, he might prefer to turn the system off.

Furthermore, as this is part of a system that would co-exist with existing technology like Bluetooth phones, stereos, and passenger-to-passenger communications systems, it would need affordances for each of these technologies.
During our test, we also learned that despite our assumption, even the turn signal should start quite softly and ramp up in its power, as it has the potential to startle users with such powerful motors.

Lastly, we also found the LEDs we embedded in the helmet to act as visual cues in tandem with the motors were not always visible, and that in a final production model, the visual feedback should be very customizable and movable to suit people’s facial structures and preferences.
CHAPTER 4 – DESIGN CONCLUSION

4.1 FINAL DESIGN

In its final manifestation, the helmet described here would be part of a system involving hardware for the motorcycle, the helmet, and accompanying software on a mobile phone. Ultimately, the goal of the helmet is to two-fold: to leverage haptics and our powerful sense of touch to free up the driver to pay attention to the road; and to help alert the rider to potential blind spot hazards. These features, if adopted, will help save motorcyclists' lives and make the roads safer.

The system would require some onboard hardware to be either installed by the motorcycle manufacturer or by the user post-purchase. In order to identify the presence of potential hazards, there would need to be a number of rear-mounted infrared proximity sensors, similar to proximity sensors used on many cars for back-up assistance. These sensors are widely available, and tried and true.

The infrared proximity sensors would be rear-facing, discreetly attached to the rear of the bike, and would connect to a control box that would connect via Bluetooth to the phone. If the vehicle manufacturer installs the system, then the sensors would probably connect directly to the bike's CPU. In the case where the sensor is user installed, the control box would also need to be powered by the bike and installed in an accessible spot.

The sensors would not only need to be able to tell the distance of the hazard, but also differentiate between hazards that are approaching versus being passed by. In this way, the sensor would be able to discern between a hazard that is being passed and does not pose a threat, as opposed to a car in the blind spot that the motorcyclist might not be able to see. The sensors would also need to be fairly long
range, so in the case of a car approaching at a high speed, the system should be able to warn the rider to avoid being caught off guard.

At the center of the system is the phone, communicating with the sensors and the helmet via Bluetooth. The phone would be capable of controlling all the parts of the system, potentially handling the necessary processing of the infrared data, connecting via GPS to pull information about the route ahead, and even handling the audio demands of the rider.

Optimally, the phone would be able to communicate with the motorcycle directly, so that it would be able to detect if the rider was indicating a turn signal. If the rider turn on the their turn signal (or indicates), the system could assume the rider was making the recommended turn and would not need to send any more signals. In the case of blind spot hazards, if the rider was signaling a turn and the system identified a car in the rider’s blind spot, it could give a strong warning to alert the rider.

The app would have an initial setup to connect to the bike, to the helmet, and to GPS. In doing so, the app would have all the information needed to provide a safer ride. Often with modern helmets, Bluetooth is used to connect with a phone to support rider-to-rider communications and to allow the rider to listen to music, directions or phone calls. The polysensorial helmet works within this paradigm and only adds minimal hardware to the helmet.

The helmet would have visual, haptic, and auditory capabilities, Bluetooth connectivity, and a basic physical interface on the outside of the helmet. The phone would be simultaneously monitoring the road, supplying audio, and tracking GPS location, then sending the appropriate signals to the helmet.

Motorcycle navigation needs are slightly different than that of cars, whereas in a car, the driver is freer to monitor the navigation screen, the motorcyclist needs to pay
closer attention to the road. Motorcycles are inherently more exposed, and the
driver needs to be more careful about changing lanes, and therefore may need more
time to do so carefully. In light of this, the app can act as an intermediary between
the navigation system (like Google Maps) and the rider, interpreting the signals and,
if necessary, optimizing them for motorcycle-specific needs.

Signals might be sent to the rider as only haptic prompts or a combination of haptic,
audio, or visual signals, all controllable and changeable in the apps settings.
The application would have a number of preferences built in for the riders to
change, giving them control of the strength of the haptic signals, the kinds of signals,
and the behavior of the system. If the rider prefers not to have the LED active at
night, or prefers less bright colors at night, they should be able to manipulate that in
the app. Furthermore, if the rider would like to adjust the sensitivity of the sensor,
as they might on a long open road trip versus a city ride, the app should make
affordances for that.

The helmet would also need to have a physical interface, to enable on-the-fly
changes or the turning off of all parts of the system. While voice activated controls
for this kind of application, might be used where the hands of the user are busy, the
relatively loud environment could prove to be a major challenge.

As the rider is typically wearing gloves, it is important that any physical interface is
easy to manipulate. Large buttons with audible and haptic feedback for on/off and
changing the strength of the signals will be necessary. Beyond this, the system will
also need to have standard feedback for connectivity and phone answering and
volume.

By default, the haptic signals for the navigation and blind spot hazard warnings will
start with a subtler signal and increase in strength until either the turn is missed,
complete, or the hazard is no longer present. This will be the default, because we want to avoid the signals startling the rider or getting annoying.

In the case of overlapping signals, the system response will favor the collision warning system. The app will know if the rider is about to execute a turn based on either data being sent to it by the navigation system, or data sent to it from the motorcycle’s onboard computer (which tell if the turn signal is on or, based on electrometer data if the bike is moving to one side). These signals will be fed into the system and if there is a threat in the blind spot during a turn, the helmet will warn the rider with a high level of vibration like the “sawtooth” pattern.

As part of a seamless system, this helmet and its haptic signals would become second nature to the rider, and a critical part of the riding experience.

4.2 IMPROVEMENTS AND NEXT STEPS (TECHNOLOGY)

The next step, having completed the helmet design, would be to test the helmet on the road with an enabled system. In order to test the helmet, it would need the data sources for the system to function properly, and it would need navigational data and information about the riders’ surroundings from the infrared sensors.

Connecting the system up with GPS is relatively straightforward as the system can call on easily and freely available information like the Google Maps API to get its information. Tailoring the system for the motorcyclist is slightly more complex and would need to be tested. Based on these tests it may be found that the motorcyclist needs more time to change lanes, or needs a series of prompts leading up to a turn, or just a single prompt to glance at the phone’s screen.

Getting infrared information is also relatively straightforward as this kind of hardware is readily available. However, the processing needs to actually identify
threats on the road and differentiate a car approaching from a distance as opposed to a car being passed. This is a much more complex demand. This might require machine learning to process the data or in the case where simple infrared proximity sensors are insufficient (or need to be assisted by cameras) it would require fairly complex digital signal processing to identify threats.

Setting up the system to identify the threats would be a major hurdle, and a key step toward testing the system's accuracy and proving its roadworthiness. This part of the system is not novel, as mentioned cars use them to assist drivers with backing up and are being utilized to help make using cruise control safer. These systems are not far away from being rolled out on a consumer level, but at this stage, as seen in the autonomous Google Streetview Cars, they are still relatively costly (Markoff, 2010).

4.3 MOVING FORWARD (MANUFACTURE)

This system has obvious safety benefits and its merits are clear. For the project to move forward it would require not only the right organization to help develop it, but also the financial support from key stakeholders. As the most critical next step is to test the system, progress may be limited by the available technology, however, companies like Google or larger car manufactures would have proprietary technology that could be utilized to work with the system. Companies that have an interest in motorcycle safety might also be interested in helping develop this kind of warning system, as keeping riders alive and safe will ultimately sell more motorcycles.

Moving towards manufacturing the helmets would mean finalization of the hardware, and physical interface for the helmet. For the sake of prototyping, the technology used to develop the helmet, Arduino controllers, were necessary as they
offered versatility and flexibility, however for a production model of the helmet this level of sophistication would not be necessary and would be cost prohibitive.

The requirement for the helmet is:

1. A battery pack with external access for replacement and charging
2. An internal control board with Bluetooth capabilities
3. A physical interface with controls for power navigation, volume, sensitivity
4. Four high-end eccentric motors optimized to reduce noise and ramp up time
5. Two RGB LEDs with custom defuse lenses
6. Left and right earpiece speakers and microphone

In order to develop a helmet with these contents that conforms to DOT safety standards it would require both specialized engineering know how, access to specialized manufacturing, as well as extensive safety testing. Almost all of the technology going into the helmet is not new to helmets, and is no more space consuming than existing communications systems. Any new helmet that goes to market requires this kind of quality and safety assurance.

While it is highly unlike that this combination of haptic/auditory/ visual signaling has been patented, it would be prudent to do a patent search. While there is nothing like this on the market, parts of this may have been used or invented in the past, knowing this would be critical to know before making the concept public (Tomohiko, 1996).

4.4 CONCLUSIONS

The goal of this project was two fold: to prove that a polysensory approach was a viable framework for developing new innovative products; and to develop a viable,
useful product that could convey and exemplify the power of polysensoy design in practice.

Polysensorial design is not as formulaic as many other design methodologies, it is more of a way for designers to gain new perspectives and help develop products that leverage as much of our bodies capabilities as possible so that their designs will ultimately be more holistic, useable, and memorable.

Whether designing a new product, experience or service, or trying to improve existing ones, designers should consider the senses, one-by-one. Think of the product as the user interacts with it in a polysensorial timeline with sensory touch points along the way.

The designer should consider both the senses that are intentionally used and the ones that are serendipitous, and craft those to be as beneficial as possible. Then the designer should consider the senses that have been excluded, as these are often the senses that can bring a design from good to great. By considering these underleveraged senses, like how a computer app would taste, or how a logo would smell, may very well lead to the kind of innovative ideas that change the world for the better.

One of the best ways to leverage polysensoral design is to consider the power of sensory memory. User-experience designers are able to tap into positive memories to align their brands with, as well as use cognitive mapping to help make experiences more understandable by referencing parallel experiences. Consider the haptic turning signal used in this helmets design, by referencing the sound of a car blinker it became instantly understandable as a turn signal.

Far too often in this increasingly two dimensional, screen based world, designers are ignoring the incredible gifts our bodies are capable of. It is my hope that by
considering all the senses as an integral part of the design process, we will fill the world with not only more delightful products, but also experiences that will free us from the screen and allow us to experience each other and the beauty of the world around us. It is a beautiful world out there. Enjoy it.
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