Sensory Helmet:

Haptics, lights and sound for bicycle navigation

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To Vero.
For making our dream possible.

Acknowledgements

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Thank you to all of my friends who help me test the prototypes. I literally could not have done this with out you. I hope you had as much fun as I did.

I would specially like to thank all of those who offered their invaluable support after my unfortunate bicycle accident. You made that unpleasant situation a lot easier.

Most importantly and with deep gratitude, I acknowledge my family for their unconditional love and support.

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The Big Day

It’s 8:14 in the morning. Jason can’t stop thinking about today’s big appointment.

He’s in his apartment, finishing up the scrambled eggs that his girlfriend Emma made for him while he took a shower.

The week before, Jason received an email from an upcoming startup inviting him to their offices for a job interview. He had recently graduated from graduate school, and this job was exactly what he needed if he wanted to stay in the city.

After Jason brushed his teeth, he finished tucking in his white button-down shirt that he hadn’t worn since his sister’s wedding two years ago. This was a big day, and he was determined to get everything right, down to the last detail. He blew Emma a kiss as he headed downstairs to the building’s storage unit where he kept his bicycle.

Jason had the address where he was headed, but he didn’t know exactly how to get there. He knew the office was in a part of town where he hadn’t been to before; not because he didn’t like going there, but because he never had the time. Jason removed his smartphone out of his pocket so he could set his destination on his phone before he had to put on his gloves, which he wore during the cold season to prevent the bone-chilling sensation as he rode swiftly down the hills of San Francisco. He unlocked the screen, and went straight to the app that was going to help him get safely and on time to his destination.

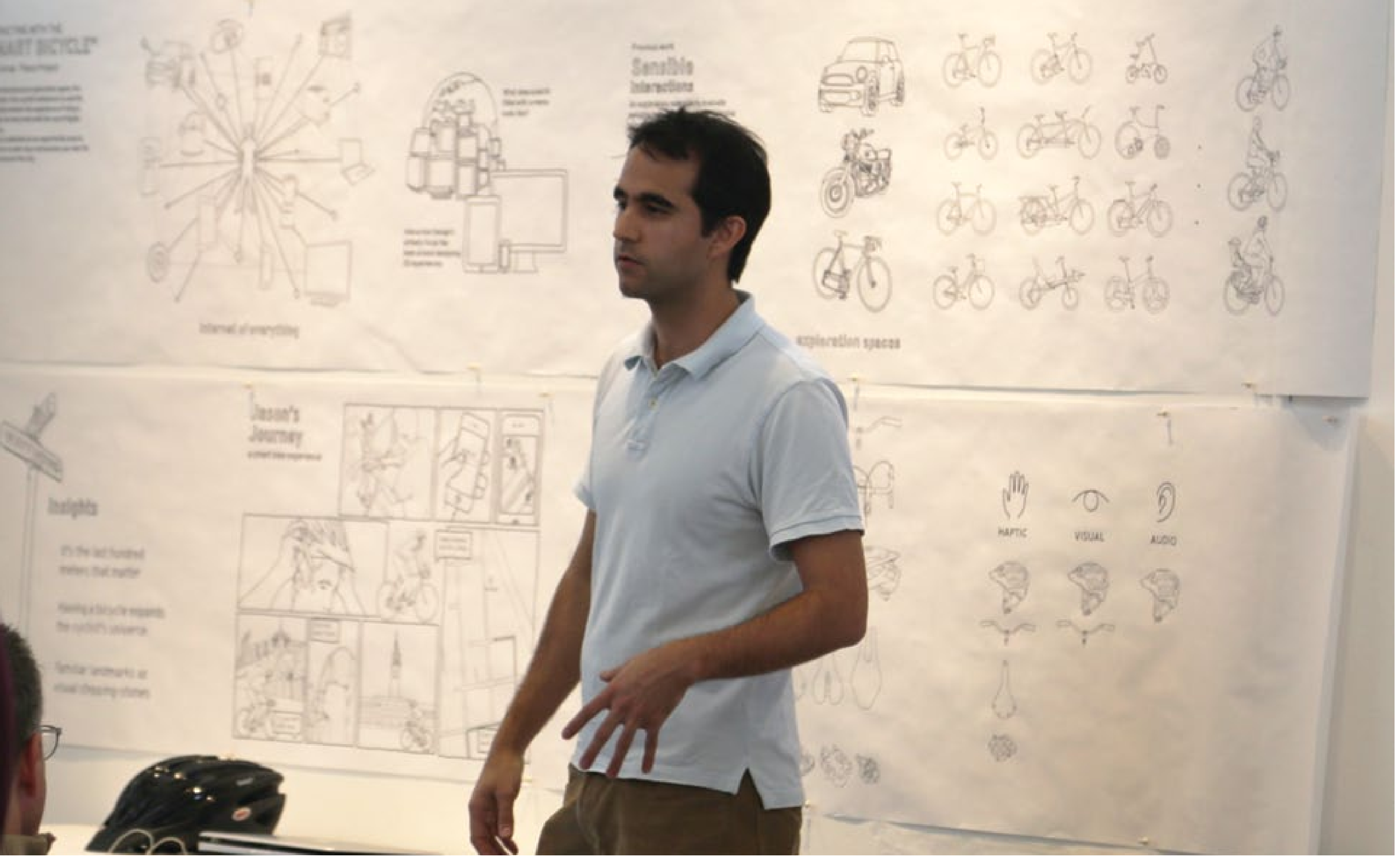
As he finished entering the address, a marker appeared on the map showing the precise location of where he was headed. Along with the marker, a few landmarks were called out, and Jason was prompted to select one or two that he knew how to get to. The app traced a trajectory: a straight line from his apartment to Civic Center, the first landmark he had settled on, followed by another straight line from Civic Center down to the second landmark, the Caltrain Station. After those two steps, the trajectory became a path that zig-zagged around buildings and obstacles that led to Jason's final destination. He didn't pay too much attention to the meandering trail, and tucked his smartphone away back in his pocket. He put on his gloves, followed by his helmet, and proceeded to get on his bike.

"Head towards Civic Center", a voice reminded him as he began pedaling. Jason had no problems getting there. He'd been cycling by that place every day for the past year as he headed towards school. He knew the best route - the one with the gentlest slopes and fewest stop signs. As he crossed a bike lane that aimed for what seemed to be a vertical hill, he wondered if the person responsible for laying down those paths had ever ridden a bike.

As Jason reached Civic Center he felt a tingling sensation in his hands that reminded him to pay attention to the voice that told him to "Head towards Caltrain Station". He moved on, taking 8th Street, and heading south towards the roundabout where that company with a dog for a logo was located.

All that Jason could think of was what he was going to say. He replayed an imaginary dialogue where he would provide his interviewer with the brightest answers he had ever heard. There was no way that he wasn't getting hired after such clever comments. In no time, Jason arrived at his second landmark. He took streets he had never seen, or heard of before. Everything looked so strange, yet he was taking turns confidently, as if he knew where he was going. After a few blocks and a couple of left and right turns, he learned that the building to his right was the AT&T Stadium, a San Francisco landmark that he thought it might be useful to remember for future journeys. Jason kept pedaling while he enjoyed the view of the East Bay, and the sound of the seagulls that flew over the sailboats. He didn't have to worry too much about where to turn next; he knew the bike would let him know in advance, and in case a dangerous obstacle like the Muni tracks were about to get in his way, he would receive a welcome nudge. Jason could relax the rest of the way, and enjoy the last moments of his trip before he reached his journey's end, and his future job.

Bicycle commuter.



Midterm review

Statement of Purpose

I began this project trying to understand how we could interact with all the digital devices that we incorporate in our lives. Preoccupied with the promise that soon the "Internet of Things" will revamp our mundane objects into smart widgets, I set out to explore new ways to communicate with products – without staring at their screens. The thought of a future inundated with displays seems more dystopian than idyllic; this motivated me to investigate new forms of interaction with future products.

Screens are just one of the many ways we can interact with digital devices. The way we interact with the current world, with the everyday things, is through the use of our five senses, why then should we only use sight and sound to interact with our digital devices?

In no way am I stating that screens are inappropriate, on the contrary, they provide us with rich content that we could only get through our sense of sight. However, there are situations where some of the other senses are better suited for the job. And if we think about it, in the long run, screens might only be a transitional technology into something way more meaningful than visual elements behind a display.

As engineers and designers work together to improve our relationships with computers, the latter are becoming more and more immersed in our lives. In developed countries, the amount of people that have a computer on them at all times has been growing rapidly, and there is no sign of slowing down. With new categories of devices like wearable technology and interconnected products, we are entering what some call the "Internet of Things". Objects are being embedded with sensors, microprocessors, and actuators, enabling them to take information from their surroundings, make decisions and take actions that fit their owner's needs. These interconnected objects are not only interacting with themselves, but also with their users, and with this new digital layer being incorporated into our everyday objects, alternative ways of interacting with them are required.

Since we interact with the physical world around us through the use of all of our senses, I believe that the relationships that we have with future technology should be mediated with interactions that make use of all our senses. Such interactions should implement the use of our human physical capabilities and employ new metaphors that will make the use of computers more suitable and advantageous. I intend to understand how and if these interactions are pertinent in the design of future digital devices.

Taking on a topic like this offered me numerous possibilities for exploration: household smart appliances, wearable technology, smart modes of transportation, just to name a few. However, my explorations ultimately focused on a specific use case: bicycle riding.

My work explores a new language for way finding for cyclists. More specifically the work interrogates how cyclists move across cities. I have come across insights and discovered opportunities to use several of our senses to improve the way one navigates in urban settings, and I have come to understand the complexity of direction giving and, most importantly, the effect it has on the journey. I intend to offer a new method for cyclists to navigate urban areas in such a way that they can focus less on the destination, and better enjoy the ride.

The Current State

This work started by trying to understand urban cyclists and their motivation for using a bicycle as their mode of transportation. My design research began by interviewing more than a dozen cyclists across the spectrum of use. These individuals represented the many subgroups of the urban cyclist. These groups included hardcore no-brake “fixie” cyclists, environmentally motivated cyclists who wouldn’t be caught dead driving a car, and inexperienced cyclists using an electric bike to help conquer San Francisco’s steep hills. I learned that for many, particularly avid cyclists, bicycle riding wasn’t just about getting from point A to point B. The experience was more profound: the freedom made it meaningful. Freedom from traffic, freedom from the nightmares of parking, freedom from the delays of public transportation, and the freedom they felt as the wind blew across their hair as they cruised across town. There are others who ride because they can’t afford other means of transportation, and those who simply must get from point A to point B in complete control. Though each is unique, they do share common, basic goals, apart from riding a bicycle of course: They move from one place to another, and they have a starting point and an end point. And how they reach that end point, when it is not part of their routine, is very similar across every type of cyclist.

All the cyclists claimed they know their way around the city, and are certain they can get anywhere they need to. If they are familiar with the location of their destination, cyclists navigate the city using the routes they feel are the most appropriate. Others are not as cognizant of the streets, and must refer to maps or apps on their smartphones. But I saw that regardless of expertise, when presented with an unfamiliar destination cyclists use the same method to figure out how to get from here to there.

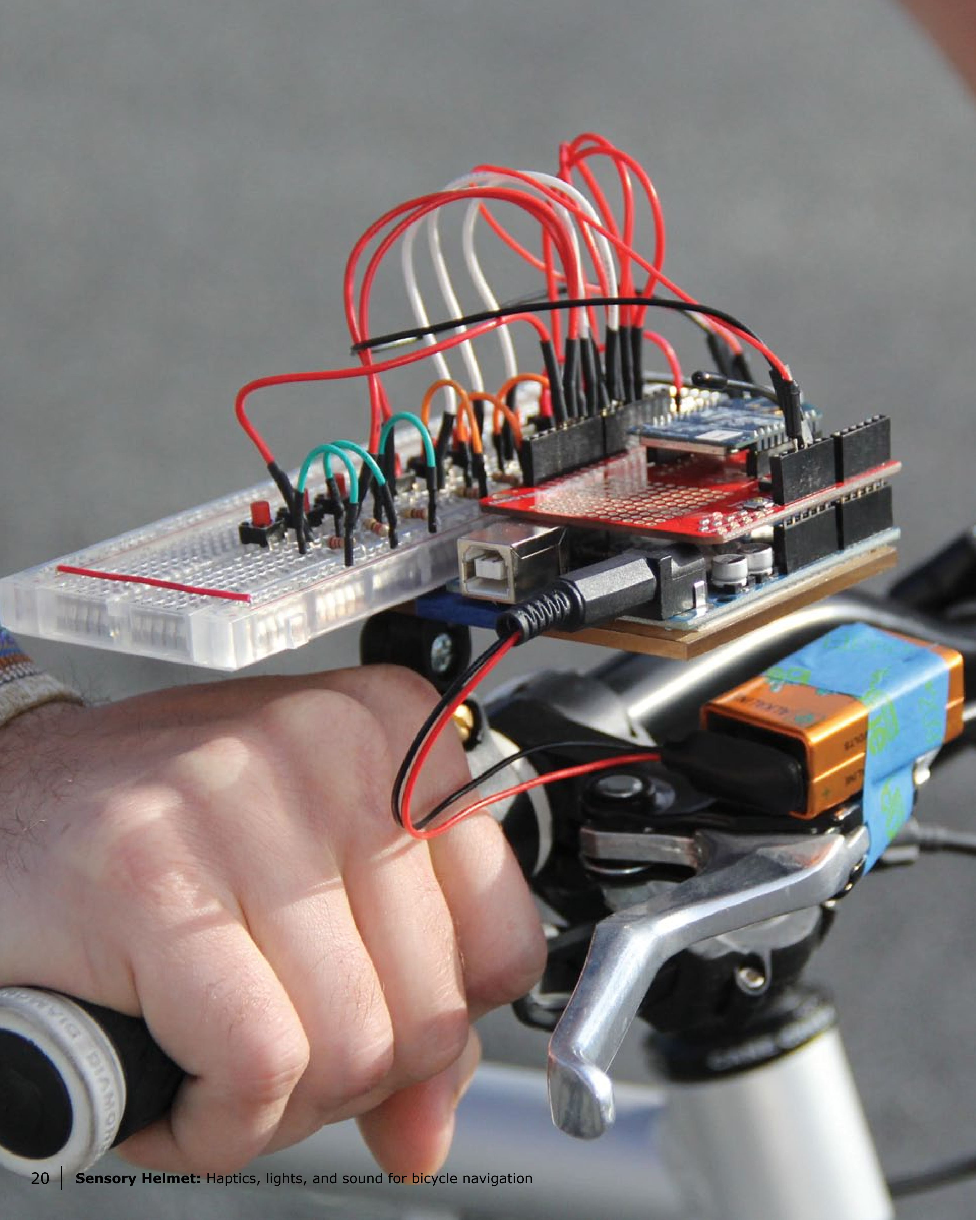
The first step these cyclists take is to identify their target location. Instead of relying on the app or the map to follow a specific route, cyclists identify reference points that they feel comfortable getting to. Mentally, a route is traced between those reference points, and is later used to navigate from point to point until they reach an area near their destination. Until this step, the experience feels natural and cyclists do not have any concerns. Relying on previous experiences to navigate to new places is a natural behavior that we all do with ease. But it is the following step that breaks the experience. Cyclists must now come back to the app, or the map, or the note with written directions they had previously prepared before leaving their house. They are forced to stop, and reach into their pockets – to look up a precise way to navigate that last kilometer to reach their final spot.

So no matter how well cyclists know the streets, there comes a point in the process that comes with a cost to an otherwise seamless experience. I learned that navigation does not happen like many people think it happens for cyclists. Cyclists do not follow a map, because it is difficult to access one while riding. Instead, they identify familiar landmarks and use them as visual stepping-stones to reach a destination.

Opportunity

This initial research helped me get a better understanding of cyclists, their motivations for riding, and their behaviors around way finding. I discovered an opportunity to create new ways to deliver directions, and facilitate a frictionless way finding and riding experience. Sophisticated technologies are being developed and implemented in the transportation space; cars are becoming "smart," they are connecting to each other and making decisions without the drivers even noticing, while bicycles are merely getting sophisticated lighting systems. I believe there is an opportunity to explore digital technologies, and design new interactions to deliver a more pleasant, meaningful, and importantly, safe, bicycle riding experience.

Ramune Rastonis testing the first iteration of interactions.



Explorations

I began this project concerned with interaction design, and its focus on screen-based interactions. I asked myself: How can I deliver directions to cyclists using means other than screens? To answer this question it becomes evident that I must make use of other senses like sound and touch to communicate with cyclists. With a series of probes, I set out to explore different ways to deliver directions, and understand the effects these have on the bicycle ride.

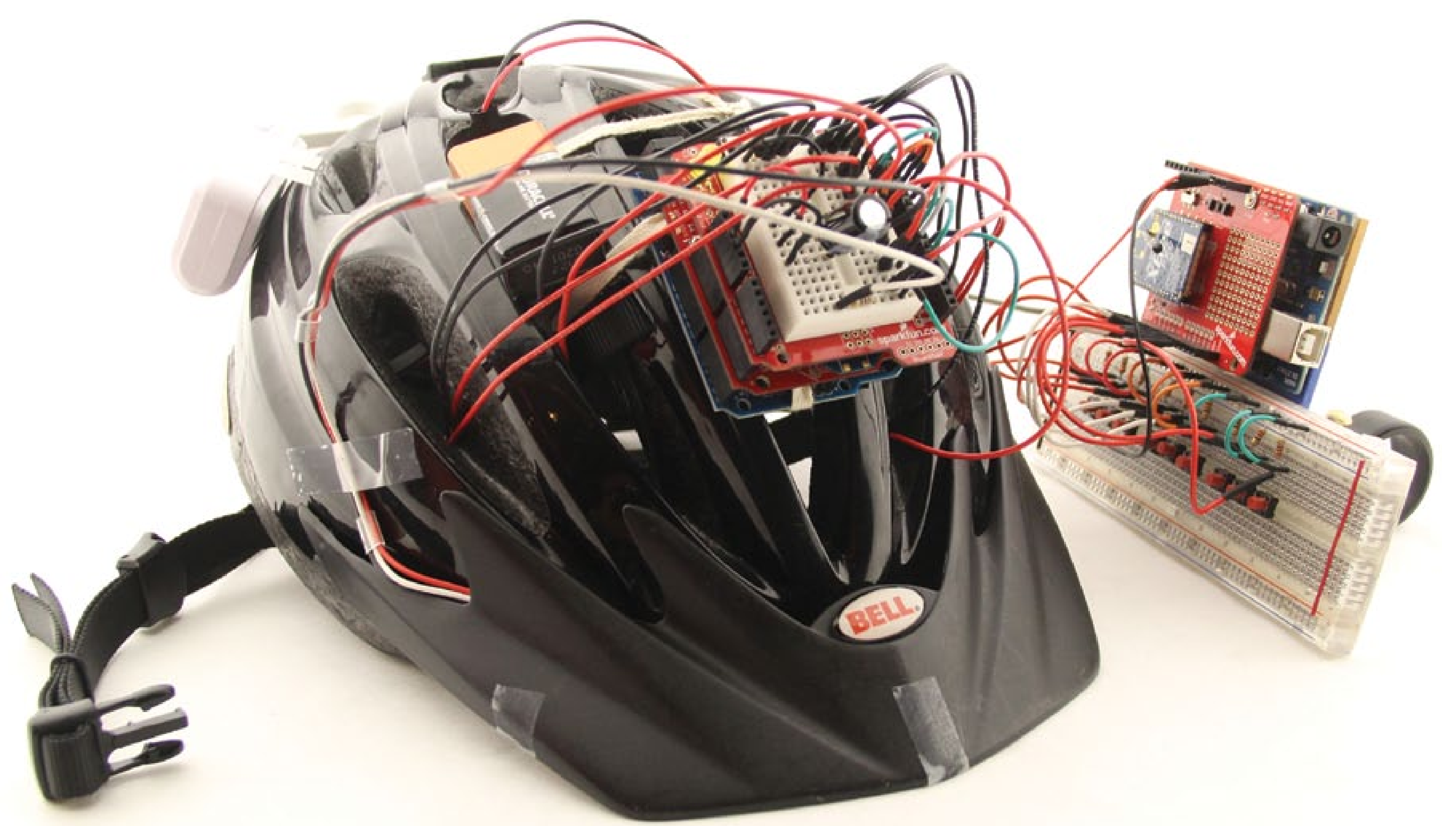
To this end, I first determined which part of the bicycle itself to leverage for these explorations. I defined several parts of the bicycle as the cockpit. To expand the possibilities, I did not restrict the cockpit as just the parts that were inside the immediate visual range of the cyclist. I also included all elements that are in contact with the cyclist: the handlebars, the pedals, the seat, and the helmet. Though all of these elements are available for interesting interventions, I selected the helmet as the primary medium for my tests. The helmet offers other qualities like its closeness to the eyes and the ears, which opens up possibilities to communicate via visuals or sounds. The other elements already transmit information: vibrations carried from the wheels, through the frame and onto these elements, inform the cyclist about the conditions of the road. Adding a flow of information to these channels would probably limit the clarity of the message.

Currently, there are several solutions that try to solve the problem of way finding for cyclists. These range from straight-forward options like map sleeves located on the handlebars, GPS or smartphone mounts for holding a device in full view, and novel devices like the Hammerhead, which uses light patterns to direct the cyclist. Although some of them might have implicit problems, my intention is not to

Wireless control. For prototyping purposes, directions were sent from a trailing bicycle using Xbee modules.

criticize those existing solutions, but to explore other alternatives that could be as good or even better for communicating with the cyclist.

The following pages describe a series of explorations that examine different ways of communicating directions by using various stimuli from the senses. They are presented in the order in which they were executed. The first exploration examines an existing solution to set a baseline for further explorations and constrains for future designs. The rest are explorations that consider sound, touch and visual elements, both independently and combined, to get an understanding of what they communicate and help create the building blocks of a simple language for indicating directions to cyclists.



Helmet prototype and wireless control. Setup used to test the different interactions.

Exploration 1

iOS version of Google Maps - Turn-by-turn Voice Navigation

Google Maps has a setting for returning bicycle-friendly routes when looking for directions. Under this setting, the user is able to use turn-by-turn navigation just as in-car navigation. This experiment consisted of testing this setting in Google Maps on my cellphone for a period of two weeks every time I rode my bicycle, even in situations when I already knew how to reach my destination. The idea behind this exploration was to get a general feel of turn-by-turn navigation while riding a bicycle, validate its effectiveness as a navigation system, and identify where it was strong and weak. All of these interactions would help me set a baseline for my own design intervention.

What worked

This interface was simple, and had been in my pocket all along. All I had to do was set the destination, put on my earphones and pedal away. The first steps of the interaction felt familiar. It works just as turn-by-turn navigation on a car: the user sets a destination, picks an option, and follows voice directions.

By constraining myself to pick a different route every day, I came across an interesting insight: traveling unfamiliar paths led me to discover parts of the city I had never seen. I learned about a nice and apparently very popular French café in Cole Valley. I got to cross Golden Gate Park through a trail I didn't know existed. I rode on top of a street where I thought my bicycle would fall apart from the intense vibration caused by the lamentable state of the tarmac. All of which were very valuable discoveries, and none of which I would have learned if I took my regular route.

What didn't work

What struck me as compelling were the options given for routes. None of them corresponded to the routes I usually took. Every day those options would vary, but none of them ever matched my own. The way these routes were differentiated was by time and distance, and though as valuable as these criteria might be, I was hoping to get information on difficulty (terrain/hill steepness), and safety – what cyclists usually use for route selection. Unfortunately this was nowhere to be found.

For testing purposes, I ended up selecting a different route every day on my commute to and from school.

"Turn left in 1,000 feet," I would hear clearly coming from my earphones as I tried to determine what that meant. The system provided directions of what to do next, and the timing of these prompts were apparently assigned to my location on the map. I would keep riding without really knowing what or how far 1,000 feet meant.

When driving a car, 1,000 feet is a distance traveled in a short time. This number seems to be intended as an alert to let car drivers know that an action is required soon, instead of a specific distance for when to turn. But when riding a bicycle these words take on a different meaning. A thousand feet are not traveled in just a few seconds; on the contrary, they might take a couple of minutes, especially if riding up hill.

As time passed, I tended to forget in which direction I had to turn. I would focus on the four-year-old child who seemed determined to cross the street, the brand new Tesla Model S parked on the other side of the road or the line of Segways being ridden by out-of-towners. Directions were no longer my center of attention.

Learnings

A better selection of directives can be drawn from what we naturally use when navigating in urban settings to make directions more clear, and the experience more enjoyable.

"Prepare to turn left in two blocks." This phrase sends a clear message that leaves no room for interpretation.

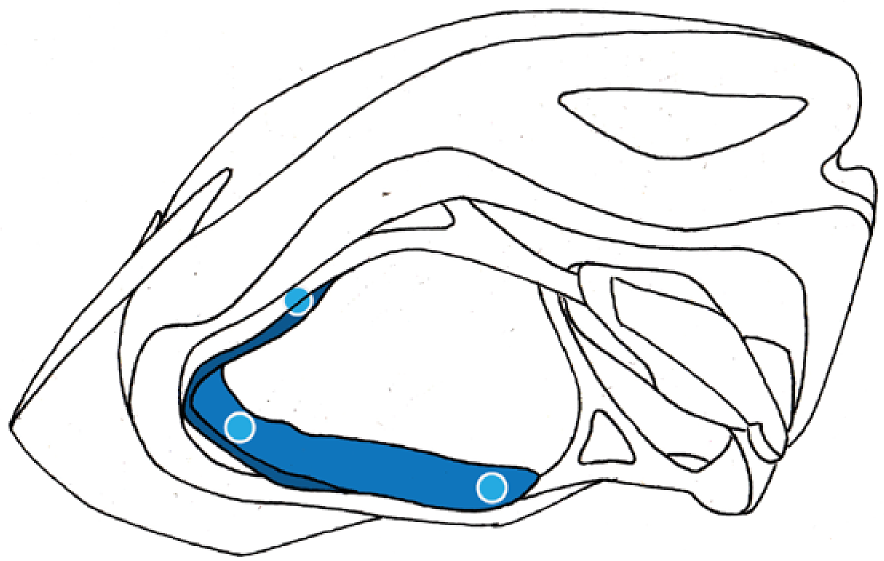
I talked to people about this system. No one had tried it before while riding a bike. They prefer not to have something obstructing their senses, especially in the city where they must be alert and cautious. Though I found this solution to be non-obstructive; most of the time the system remains silent.

Using this system was surprisingly helpful. I was able to reach my destinations every time; got to discover places and routes that I have incorporated into my routine, and I only needed to take my phone out of my pocket to type in the destination.

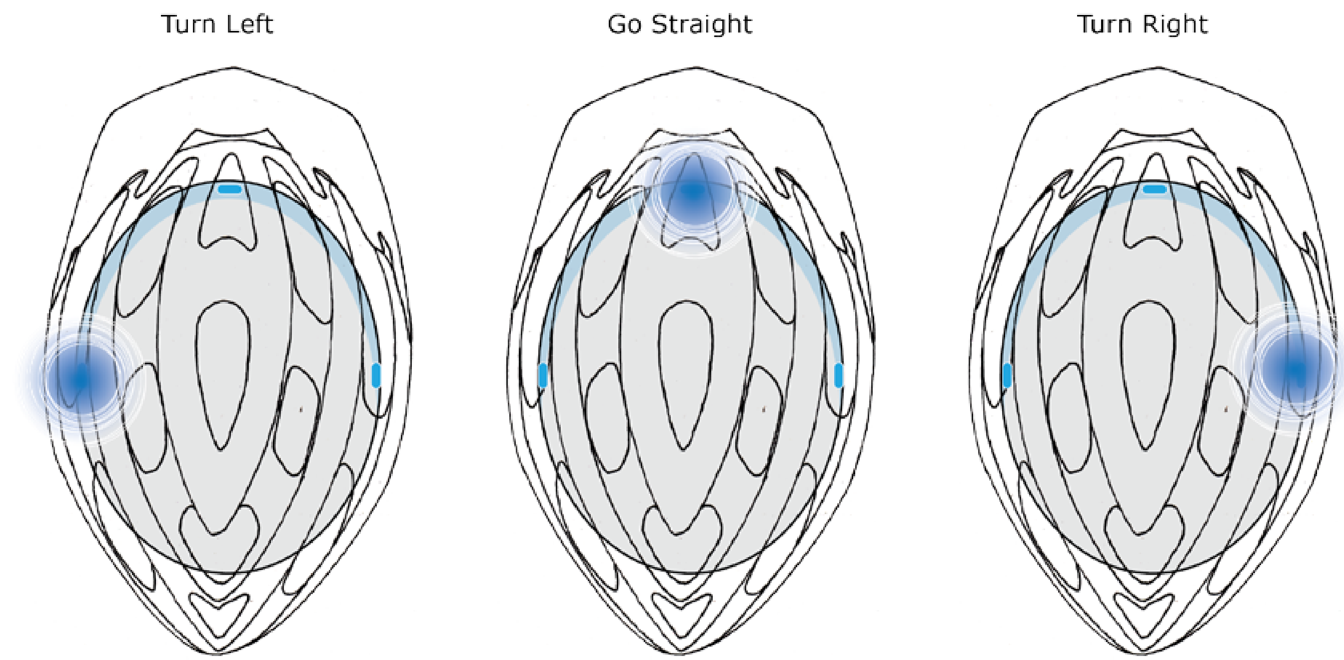
Screen-less insights

Voice feels and seems like the natural progression of human-computer interaction. Instead of us trying to learn new methods to interact with technology, we are teaching computers to communicate with us the same way that we do with each other. The advancement of this technology will greatly play a part in reducing the amount of time that we interact by touching a screen. However, spoken language is highly complex, and though there are great amounts of resources being assigned to improve this type of interaction, we still have some time before we are just speaking back and forth with our devices. Furthermore, we must not forget the importance of non-verbal communication and the role that our other senses play in understanding a message.

Google Maps for iOS set to bicycle routes.



Setup for the three vibrating motors located inside the helmet along the padding.



Vibrating cues for navigation.

Exploration 2

Haptics

I wanted to identify cyclist's reactions to haptic feedback while riding their bikes, and learn about the effectiveness of communicating directions with the use of vibrations. This prototype was built using the helmet as a canvas. The test consisted in placing three vibrating motors inside the bicycle helmet. The location of these motors were as follows: one at the front of the helmet, while the other two were placed on each side of the helmet; one for the left side and the other one for the right side.

For this prototype, a user wore the customized helmet while riding her bike as I followed behind (in this case I followed in a car). As we went around the city, I wirelessly controlled the signals that activated the three small vibrators. The idea was to communicate in which direction the user should head: right vibration for a right turn, left vibration for a left turn, and a front vibration for heading straight.

What worked

The general reaction from testers was positive. Initially some testers had anticipated that vibrating motors on their head would cause discomfort, and as a result they could lose focus. As they got on the bike and began to pedal, the vibrations were subtle, and did not distract them from their ride. Their experience contradicted their assumptions: they did not have to focus on where they were heading because the helmet would let them know; they could enjoy the ride and pay more attention to their surroundings.

Right and left signals worked without a glitch. They were sufficiently clear and presented no confusion.

What didn't work

The front vibrator was meant to signify "go straight," but users did not feel this message was clear enough. Some completely ignored it while others interpreted it as "stop." As a work around, I stopped sending this message to see what the testers would do. This resulted in confusion and anxiety; with a lack of a message, they did not know how to proceed. Many felt the system had failed, and stopped completely to wait for further instructions.

The use of only three signals is not enough. In one of the tests, a user came across a roundabout where she had 5 different options. In this situation the system was not equipped to provide information clearly enough to help the cyclist continue on her route, which resulted in confusion for the tester.

Learnings

Subtle vibrations have tremendous potential as part of a way-finding system for cyclists. They are easily felt and require little concentration from the cyclist. As a result, the cyclist can focus on other aspects of the ride; this makes the experience more enjoyable. Some testers claimed that their ride changed from merely traversing between point A and point B, to a pleasant ride that they could fully enjoy.

Though haptics show promise, they still have limitations that hinder the riding experience. When navigating a city, there are directions that require a higher complexity in the language being used; "turn left", "turn right", or "keep straight" are not enough. Using vibrations to communicate for all possible scenarios will prove to be difficult.

Moreover, cyclists do not like it when the system keeps quiet. Using haptics makes it difficult to give any other than immediate directions, which results in repeated periods of time without any feedback from the system.

This prototype is the first step in understanding haptic communication with the cyclists. Further investigations following this concept are further discussed in other explorations.

Screen-less insights

Haptic communication is a promising alternative to when visual interactions are not adequate, such as staring at a phone's screen while riding a bicycle. However, it has its limitations, like having the requirement of the device being in contact with the user, and the fact that it has not been explored that much by designers. Yet, there is a lot of potential in this type of interaction since it encompasses a variety of sensorial channels: thermal reception, tactile reception, pain reception, and kinesthetic reception. So far, a good amount of research in the haptic space has been conducted in the military industry and for the visually impaired. The findings from such research are slowly being implemented in our everyday lives, for instance car seats with haptic actuators that alert the driver when he is leaving a lane unintentionally. Soon, some visual interactions could be complemented or replaced altogether with haptic ones.

Sound transducer system.

Exploration 3

Sound

This prototype consisted in adding a transducer to the helmet, which transformed the whole helmet into a speaker. This transducer was connected to the user's cellphone via the headphone jack. The purpose of this exploration was to use voice turn-by-turn navigation without the use of earphones, and compare the results with those from the haptics probe.

Instead of using Google's turn-by-turn navigation, I called the user on their cellphone, which was connected to the transducer, and directed them where to go. I did this to be able to use my own choice of words and compare them with those presented by Google's system.

Like the previous exploration I followed the tester as they rode their bike.

What worked

Using words allows for clear directions in complex situations, for example when in a roundabout, or when there are more options than to turn right or left. The transducer worked well: the sound was clear enough and the users had no problems hearing it through the city's noise.

When I used directions like "turn left at the next intersection," the user found it to be much clearer than "turn left at Carolina Street;" looking for street names became difficult and distracted the cyclists. I tested messages that were not related to giving directions, but regarding information about their surroundings e.g. "To the right you will see Duboce Park". This was felt as a pleasant surprise for the testers, and it is something that can only be done with voice or text.

What didn't work

Though the messages were clear, users felt like they had to concentrate on the voice, which took away from the riding experience. Unlike the vibrations, which were quick and felt automatic the voice directions required greater effort on the part of the user.

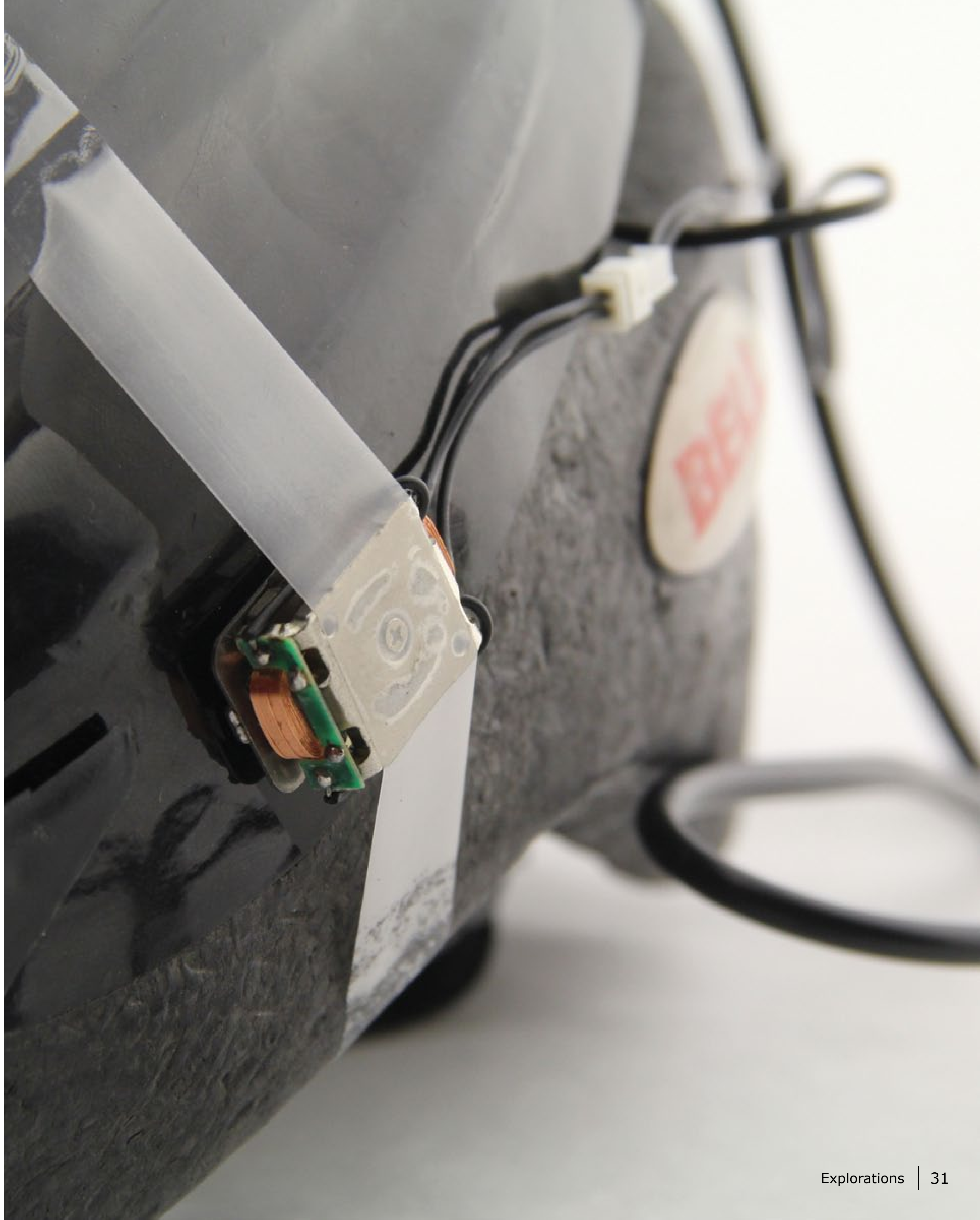
Learnings

Using voice allows not just for greater clarity in complex situations, but also for delivery of extra information that can make the ride more enjoyable. This method allows for a system that will help discover the city in a much richer way than by just riding across it. Data about events, history, weather, traffic conditions, time, etc., which can be crowd sourced, can later be delivered via voice to inform the cyclist; a system analog to augmented reality but using sound instead of visuals.

Yet, I also understood it is important not to overwhelm the cyclist with too much information. With simple directions, the users felt like they had to take away their full attention from the road to concentrate on the voice.

Screen-less insights

Voice and sound cues are great ways for a device to interact with the user. Nevertheless, just like the other types of interactions referred to in this project, there is a right time and right place for them. As mentioned before, voice feels like a natural way of communication, however, it demands attention from the user to ensure that the message is clearly transmitted and environmental conditions should be adequate to prevent noise from affecting the clarity of the message. We have been using sound interactions second to visual interactions, and have learned to identify meanings from different sounds; we are able to distinguish when we receive a text message alert from a calendar alert in our phones. The ability to differentiate these nuances in sound cues enable designers to explore new ways to combine sound with other types of interactions and deliver rich messages. However, the idea is not to embed each device with voice or sound interactions, this could be as unfitting as a world filled with screens.



Sound transducer attached to the helmet. Turns the whole helmet into a speaker.

Exploration 4

Lights

For some, the use of lights could be considered as a low-resolution display. In this case, I consider them to be simple visual aids. The difference between a screen and the use of lights is the complexity of the information being presented. Screens usually present the user with images or animations that require the cyclist to concentrate on the display taking away the focus from the road. This prototype presents simple directions by turning on or off LED's located on the visor of the helmet, which the user can understand by swiftly glancing at them.

Like the haptic prototype, I kept the messages as simple as possible: Two red LED's that glow for two seconds on the right side of the visor means "turn right", while two red LED's located to the left of the visor mean "turn left." Just as in the previous two probes, I followed the tester and sent wireless signals to the system to set directions.

What worked

Those who tested the system found the messages to be straight forward; as the right LED's turned on, they knew they had to turn right at the following corner. The same happened for turning left. The lights, though close to their faces, did not present any uncomfortable sensation or diminished overall visibility.

What didn't work

To get the message, users had to constantly look for signals. Concentrating on the road, they missed the signal, which only lasted a couple of seconds. This made the ride uncomfortable for the testers since they felt they had to constantly be on the look out for any changes on the visor. I believed the change of color in the periphery of their vision would be enough to inform the following instruction. However, the results show that the visor is not in the periphery at all times, which results in many missed messages.

Learnings

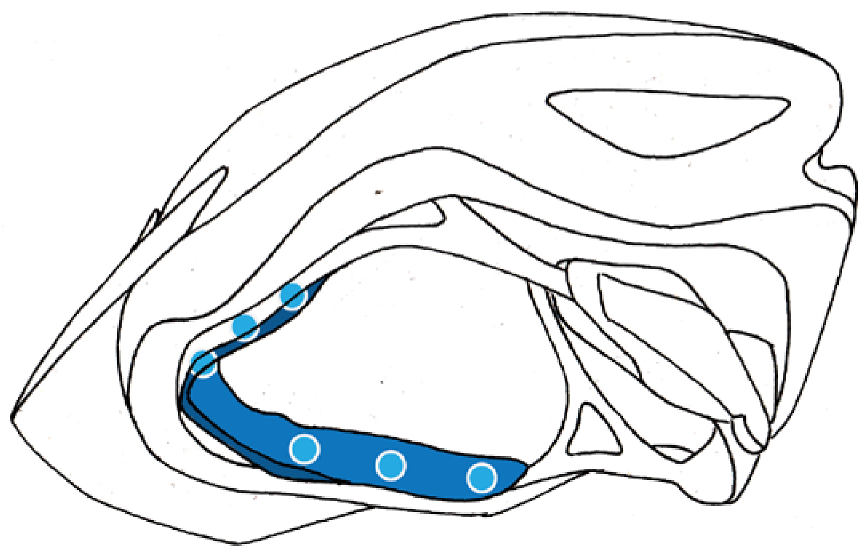
This type of signal is easy to understand and with RGB LED's it is possible to change colors to transmit different types of messages, for example the lights can gradually change color as the cyclist gets closer to the turn. But, lights alone are not sufficient to keep the cyclist informed. Even if the LED's are kept on until the following direction is sent, the cyclist will have to consciously look for it.

In further explorations I combine both haptics and lights to improve the awareness of the light message.

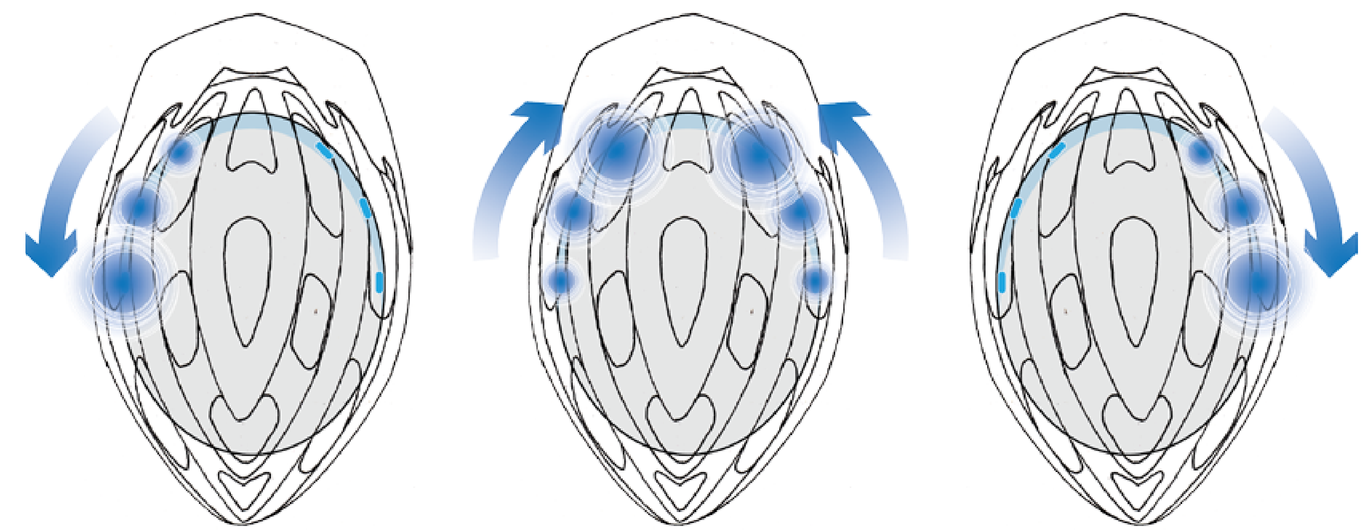
Screen-less insights

A few lights or simplified displays have been used on digital devices, included wearable computers, for some time now. The idea behind this means of communication is to bring across simple messages that require one single indicator. Signals can be as simple as on/off states to represent that something is happening, will happen soon, or that it has happened already. However, with the use of flashing patterns, light intensity, or color change, the cues gain complexity and add richness to the messages. In a future where screens are only used where essential, simple light cues become a suitable way for devices to make messages visible. It is important to make the distinction between visual and screen-based interactions: the former may consist of an object changing color or shape, while the latter requires a screen with a user interface to be able to interact with the user. I am in no way against visual interactions.

Two pairs of Neopixels (LED´s) are located on the bottom side of the helmet visor.



Setup for the six vibrating motors located on each side on the inside of the helmet.



Different sequences communicate the different directions the cyclist should take.

Exploration 5

Sequences

This prototype is an effort to further explore and improve upon the first haptic exploration. Its main focus is to consider other configurations of haptic feedback to better communicate directions. To do this, I arranged a total of six vibrators, three on each side of the helmet, separated by approximately 3cm each. With this configuration the vibrators are located to cover a good part of the sides of the cyclist's head. The intention is to send messages in the form of sequences, for example activating the left vibrators one after the other from front to back when communicating a left turn. This allows for more precise messages that could end up communicating complex directions. This test in particular intends to solve the problem encountered with the first haptic probe, where the front vibrator was interpreted as a "stop" signal instead of "go straight". A sequence of vibrators being activated from back to front on both sides at the same time tries to solve the problem.

What worked

Vibrators do a great job at communicating left and right turns. Signals feel intuitive, and users focus less on the directions and more on the joy of riding.

What didn't work

The users did not perceive the sequences. They would feel vibrations on the right side or left side of their head, but were not aware of the back-to-front sequence unless they were asked to try and feel them. This resulted in a confusing "go straight" message; if users were not told what each sequence meant, they found unclear the sequence for going straight.

Learnings

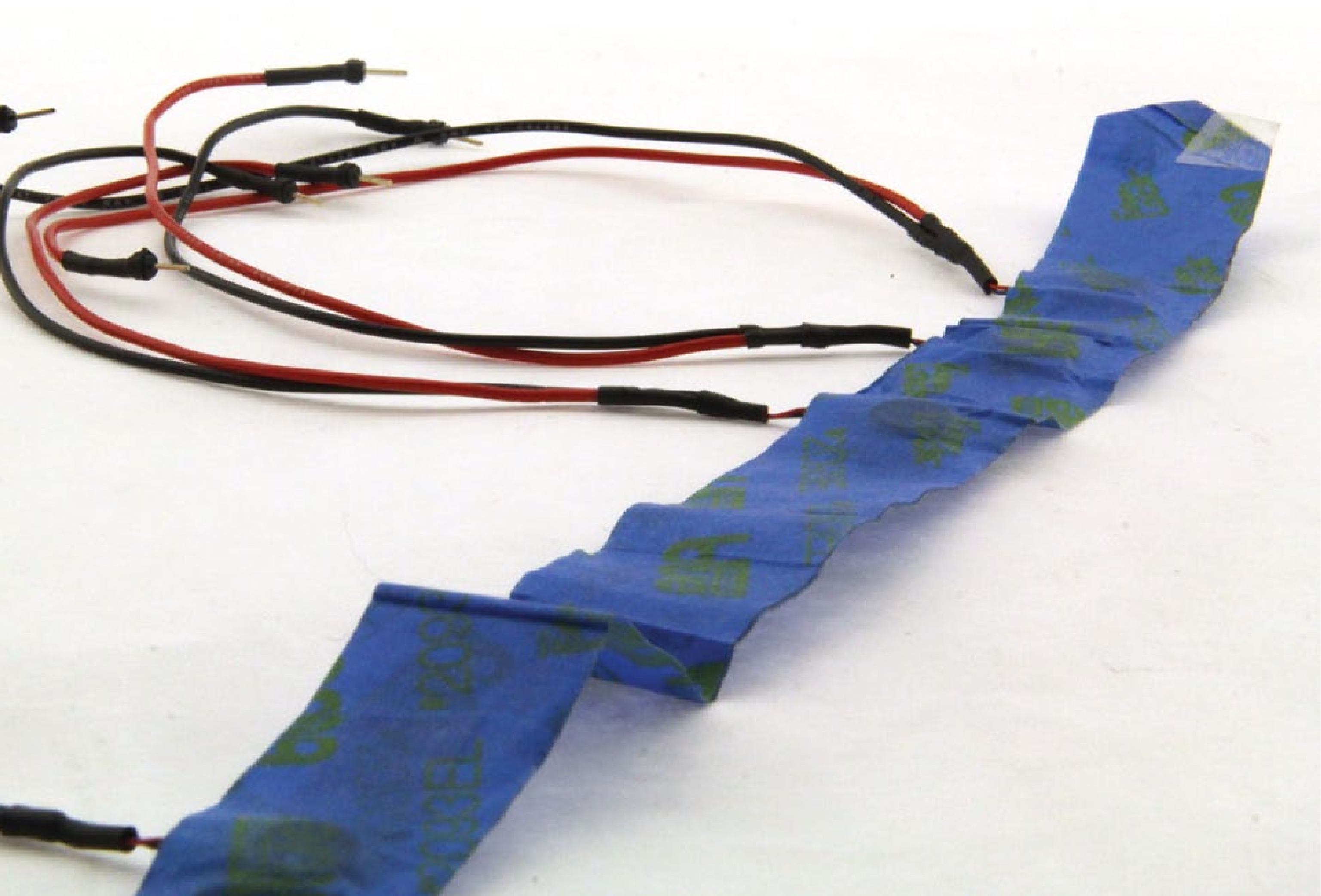
They way the vibrators are set up, and the sequence designed, are not appropriate for communicating more complex messages. The concept of using sequences is interesting and may have potential if implemented correctly. Further investigations continue to examine the possibility to convey other messages by implementing sequences.

After a brief explanation of what each sequence means, users have no problem interpreting the signals. Since there are only three sequences to learn, two of which feel intuitive and require no explanation, users have no problem interacting with the helmet. If more sequences are added to the repertoire, and they are not intuitive, there will likely be a higher possibility of users not understanding the system, and thus resulting in an unpleasant experience.

Screen-less insights

Haptic interactions, though present in virtually every smartphone in the market, have not gone beyond notifying alerts. This alternative channel is just beginning to draw the attention of designers, and so far it has been limited to simple tasks and the messages have been kept simple to avoid confusion. Yet, as users become accustomed to the use of haptics, the complexity of the interactions can and will increase to deliver richer experiences. In a few areas like the military or the health industry, haptic "screens" have become an alternative to visual interactions and have allowed users to accomplish tasks that were not possible before.

For prototyping purposes, the small vibrating motors were place on tape and later placed along the inside of the helmet.



Exploration 6

Combining for Clarity

Exploration No. 4 evaluated the effectiveness of lights for communicating directions. The results show that cyclists need to constantly look at the visor if they do not want to miss the message. With this prototype I try combining both vibrations and light at the same time. The vibrations are short, soft and come a few milliseconds before the light signals are turned on to alert the cyclist that a light signal will be displayed.

What worked

Vibrations were successful in alerting the cyclist about an upcoming signal. A few users suggested that combining both types of signals could be an optional feature that the cyclists select under a configuration mode. Using both signals at the same time did not feel overwhelming nor did it distract the users.

What didn't work

The vibrations themselves were considered as the message, and not as a way to inform about the upcoming light message.

Learnings

Vibrations are definitely effective in communicating immediate way finding instructions; even short vibrations were interpreted as clear directional signals. Lights, on the other hand, are useful for other types of messages. By leaving the light signal on, the cyclist can look for it when he feels the need for it. For example, the light signifier for "go straight" can be left on for as long as the cyclist is required to go straight. If at an intersection the cyclist is not sure of where he needs to go, he just needs to glance up at the visor to know what to do.

Vibrations can be used for immediate actions, while lights can be used as a reference for what direction comes next. Using both signals simultaneously will allow for a system that feels automatic (vibrations) but will still have information available for when the cyclist needs it (lights).

Screen-less insights

Multimodal interactions have the potential to present richer experiences and deliver clear interactions. Despite the fact that each channel of communication – light, sound, or touch – can transmit the same message, each one is strong at transmitting certain pieces of information at certain points in time. For example, light is good for communicating a message at a distance while touch requires the user to be in contact with the object. This means that personal or intimate messages could be better passed on using haptics than with the use of lights. Moreover, combining several of these channels can increase the level of complexity in communications and therefore deliver rich interactions without the use screens.

Yu-Wen (Mark) Liang testing the prototype close to night time.

Exploration 7

Always On

Following the results from the previous exploration, this prototype evaluates users' response to having lights on at all times. Light signals are sent to indicate what is the next required maneuver. Unlike vibrations, which come immediately before the required action, lights are turned on after the cyclist completes the previous action. This way he will know in advance what is his next move.

What worked

Lights are able to communicate clear directions even when used on their own. With the signal present at all times, users were able to check their next required move at any time. This takes away from the anxiety that users may feel when not receiving any input at all.

What didn't work

In low ambient lighting conditions, like at night, the lights felt overwhelming and distracting. In some cases visibility was compromised. This directly affects the safety of the cyclist and deters from the purpose of helping cyclist get to their destination safely.

Learnings

Lights alone have the potential for communicating clear directions for bicycle navigation, but require the cyclist to consciously look for the signal. Unlike with vibrations, where actions become automatic, lights require the cyclist to concentrate on navigation. Though it happens for short moments, it takes away from the experience of concentrating on the ride.

A positive aspect of the continuity of the light indication is its availability at all times. The cyclist doesn't have to wait for it to come since it is always present. However, a constant bright signal proved to be distracting when present in low ambient lighting conditions. A solution to this inconvenience could be limiting the bright signal for the beginning of the cue and then dimming the light to a level where it's recognizable at a short glance.

What comes next?

The explorations executed in this project were iterations on the use of different modalities to find a good way to communicate navigating directions to a cyclist. Some of them proved to be good enough like the turn-by-turn voice navigation, however, leaving room for improvement. Other modalities like haptics, demonstrated that to transmit the message clearly enough it needed to be complemented by other means like voice. At the end the best solution resulted in a combination of all the different modalities:

Haptics were used to indicate the direction in which the cyclist should turn immediately before the corner. The users reacted well to this prompt, due to its clarity and because it did not create any distractions. However, patterns had to be created to communicate directions other than "turn left" or "turn right". These patterns had to be learned and were not as intuitive. Yet, after a brief explanation and a few tries, the user seemed to have no problem at all. Further explorations need to happen to determine the right frequency and intensity of the patterns to make for richer and clearer interactions.

Lights provided information about the next move. Presented at all times, this cue gives the user the possibility to check what is the upcoming action whenever he wants. This is especially important to prevent anxiety that results from not knowing what comes next. Although this modality would be able to function on its own as a navigational tool, it will require the cyclist to be focused on the changes in the lights, thus distracting him from the ride. By complementing it with haptics, the lights fall to a more passive indicator that is available for when the cyclist feels the need for information.

Sound or in this case voice, served as the perfect means to deliver complex directions and rich information. It was only used in specific situations when lights and haptics were not enough to communicate what to do next, e.g. at a roundabout. Additionally, it was a great channel to inform the cyclist about certain aspects of the ride like the estimated time of arrival, the time, or relevant information about the environment (weather, traffic, or famous landmarks.)

The prototypes that were tested were intended to explore screen-less interactions. However, the possibility of developing a smart cycling helmet seems like an interesting one. Being that the helmet is in direct contact with the cyclist, it allows for two-way communication. The helmet could be equipped with sensors to collect biometric information, which is not only valuable in the context of fitness, but also could help determine the optimal moment for the helmet to deliver information to the cyclist. It could also be equipped with microphones to permit voice interaction and allow the cyclist to input information while on his ride.

All of this is already technically possible and there is no need to develop new technology. Nevertheless, there is still a lot of work that needs to be done in identifying compelling use cases other than navigation and in designing the appropriate interactions with the different modalities.

Conclusions

The motivation to take on this project was to explore and hopefully find new ways to interact with digital devices different to using screens. A great number of people, including some who are part of the design discipline refer to interaction design as the two-way communication happening on a screen between a person and a digital device. In my opinion this is a narrow perception that limits interaction design to web design, and design of desktop and mobile applications. Yet, there is so much more behind interacting with digital devices, and this project's purpose was to examine other possibilities.

Soon, a variety of products will be part of the Internet of Things: smart locks, smart cars, smart light bulbs, smart everything. Eventually, objects that interact with each other and ourselves will be all around us every single moment of our lives. And though, for some this seems like a scary scenario, it does not have to be. Designers are responsible for understanding our relationships with such objects and defining how to best interact with them. It is my belief that all our senses should be considered, and that the notion of interaction design should encompass each touch point we have with our products. We should go beyond what the user encounters on a screen and think about new ways to communicate with our devices.

I am not against the use of screens; in many situations they are the best alternative to interacting with the user. However, there are plenty of instances where they are suboptimal and other means of human-computer communication provide a better fit. Therefore, I selected a scenario in which a screen would seem out of place, like bicycle riding, and built prototypes that used different modes of interaction with the cyclist.

Andrew Maxwell-Parish trying out the light cues.

I soon learned that cycling is more than getting from point A to point B; it is about enjoying your travel, it is about freedom. I also learned that the way cyclists navigate to unfamiliar destinations is peculiar and very similar across the spectrum of cyclists. Even when they claim to know the city well enough to easily get around, there is a point in time, toward the end of the trip when cyclists must access a navigational tool to aid them get to their destination. It is in these last few hundred meters where navigation becomes an interesting problem and where an opportunity lies to use multimodal interactions to improve the experience.

As my brief explorations show, it is possible to deliver clear directions and guide the cyclist to his final destination by integrating haptics, lights and sound. However, it is important to note that each mode must be used at specific times and for specific purposes. Vibrations have proven to be effective at communicating simple and immediate actions. With just a glance, lights provide the cyclist with information at anytime. And with sound as a medium, there are possibilities to enrich the trip, like presenting the cyclist with information about his surroundings, or simple bits of information like weather, speed, traffic, time, etc. Nevertheless, it is important to manage that information in such a way that the interaction does not become overwhelming. Too many cues at the same time, like sound, lights, and vibrations might worsen the ride and make the experience unpleasant.

When the task of navigation is appointed to the helmet, the cycling experience is positively affected; cyclists are able to pay attention to the context around them resulting in a more enjoyable ride. This is where interaction design has the possibility to go beyond just providing communication with a digital device. It is here where there is an interesting opportunity to explore new offerings for the cyclists that deliver a better user experience.

This exploration has provided results for a specific use case: way finding in urban areas. Still, this is a situation that occurs occasionally since the majority of bicycle trips have a known route. But with the helmet as a connected digital device, there are a lot of other opportunities that can be explored: training routes for cycling as a sport, provide cyclists with information created by a network of other cyclists, offer guided tours of urban areas, etc.

This project is just a brief exploration of how multimodal interactions can enrich the user experience. By adding haptics, sound and lights to a bicycle helmet, I was able to communicate navigation instructions to the cyclist and enhance her ride in a meaningful way. This is just one example of how designers can implement different modalities other than audio-visual to interact with digital devices. Haptic interaction design is a relatively new discipline that is just in its developing stage, but it shows potential for creating more humane interfaces. There is still a lot more to investigate and great opportunities to discover.

Appendix

This project was based on building, testing, and iterating on different prototypes in order to learn about different interaction modalities. The intent of the prototypes was functional rather than formal, and so the materials and technical elements were chosen accordingly.

The following is a description of the different technical elements used to build the prototypes for this project and the reason behind the selection of the prototypes.

Arduino

The Arduino Prototyping Platform (http://www.arduino.cc/) was selected as the foundation of the majority of the prototypes. This includes the Arduino Uno Board and the Arduino Software IDE (Integrated Development Environment). Arduino is an easy to use open-source prototyping platform with a big online community that makes it easy to learn how to program and share sketches with others.

I selected the Arduino Uno board (http://www.arduino.cc/en/Main/ArduinoBoardUno) since it is the most popular version of the Arduino boards and it has the largest amount of available resources online. The size of the board provided enough input/output pins (6 of which can be used as PWM output pins) to connect all the necessary actuators (LED's and vibration motors).

Neopixels

For the prototypes that used lights I selected Adafruit's Neopixels (http://www.adafruit.com/category/168.) These RGB LED's have a driver that allows the LED's to be chained together without loosing the ability to be independently controlled. I specifically opted for the Flora RGB Smart neopixels (http://www.adafruit.com/products/1260), which come as separate units and would let me locate each one independently. By chaining them together, I only needed one PWM output pin from the Arduino, and I would still be able to control the color and intensity of each of the pixels. If I had gone with regular RGB LED’s, I would have needed three pins for each one, and this would have limited the amount of lights.

Vibration motors

There are several vibration motors available online, yet I wanted to use the one with the smallest profile since I was going to place them in the interior side of the helmet. I selected the 10mm shaftless vibration motor from Sparkfun (https://www.sparkfun.com/products/8449) that only has a thickness of 3.8mm. This was thin enough to fit inside the helmets inner pads without adding too much bulk. It operates at 3V, which works perfectly with the Arduino Uno board.

For the initial prototypes I placed the motors in between two layers of masking tape. This helped me maintain each motor at a fixed distance from each other, and it was easy and inexpensive to modify if I wanted to iterate on the positions. It also allowed for a quick assemble and disassemble from the bicycle helmet that I was using.

X-bee Wireless

Due to my technical abilities and limited time, I was not able to connect the helmet to a smartphone to make use of its GPS. Instead, I built a remote control that I mounted on my bicycle, so I could play the role of the GPS when testing with other users. The remote control consists of an extra Arduino board that communicates with the one located on the helmet using a pair of Xbee S1 modules (http://www.digi.com/). Each RF Xbee module is connected to one of the Arduino boards using an Xbee shield (https://www.sparkfun.com/products/12847). The remote control Arduino has a sketch that, depending on which button I press, it sends a trigger that enables the Arduino that is located on the helmet to execute a specific navigation routine. This way I am able to send each navigation instruction with a push of a button from my own bicycle. If I want to add more routines, all I have to do is program the Arduinos and add the necessary buttons.

Audio transducer

The idea with the prototype that used audio was to communicate via sound without the use of earphones. For this purpose I selected the Cynaps tester kit (http://www.maxvirtual.com/all-products.html#!/Tester-Kit/p/26517326/category=12180222) that consists of a power source, an amplifier, a transducer and a 3.5mm audio connector, which allows to transmit sound via bone conduction. By placing the transducer in contact with certain areas of the head, the user is able to hear the sound without the need of an earphone. However, locating the transducer on the helmet in a position where it could transmit the sound waves using bone conduction proved to be difficult. Instead, I placed the transducer inside the helmet structure, which made the helmet vibrate and make sound just like a speaker. This way the user is still able to hear the sound without having to cover its ears.

As an alternative to recording sound messages and then playing them back to the user from an Arduino audio shield, I opted for connecting the user’s phone to the transducer via the 3.5mm connector. This way I could call the user’s phone and narrate the audio commands with the flexibility to change the commands on the go.

Bibliography

Manjoo, F. (2012, June 19). You Will Want Google Goggles. MIT Technology Review. Retrieved September 15, 2013, from http://www.technologyreview.com/review/428212/you-will-want-google-goggles/

Morgan, P. (n.d.). Hammerhead. Retrieved January 30, 2014, from http://hammerhead.io/

San Francisco Bicycle Coalition (2014, January). [About page]. Retrieved January 14, 2014, from https://www.sfbike.org/about/

Wilson, M. (2014, January 4). A Watch That Teaches The Value Of Time. *Co.Design*. Retrieved January 9, 2014, from http://www.fastcodesign.com/3024266/wanted/a-watch-that-teaches-the-value-of-time

Campbell-Dollaghan, K. (2013, July 18). What Comes After Click: A Crash Course in Tangible User Interfaces. *Gizmodo*. Retrieved November 24, 2013, from http://gizmodo.com/what-comes-after-click-a-crash-course-in-tangible-user-815532137

Norman, D. (2013, July 24). The Paradox of Wearable Technologies. *MIT Technology Review*. Retrieved January 9, 2014, from http://

www.technologyreview.com/news/517346/the-paradox-of-wearable-technologies/

Victor, B. (2011, November 8). A Brief Rant on the Future of Interaction Design. Retrieved January 15, 2014, from http://worrydream.com/ABriefRantOnTheFutureOfInteractionDesign/

Galbraith, D. (n.d.). 12 haptic interfaces. Retrieved April 18, 2015, from http://www.oobject.com/category/12-haptic-interfaces/

Einar, S.M. (2009). *Designing with RFID*. Paper presented at the 3rd International Conference on Tangible and Embedded Interaction, Cambridge, United Kingdom.

Lakatos, D., Ishii, H. (2012). Towards Radical Atoms – Form-giving to Transformable Materials. *3rd IEEE International Conference on Cognitive Infocommunications.* Kosice, Slovakia.

Hazelton, T., Karuei, I., MacLean, K., Baumann, M., & Pan, M. (2010). Presenting a Biometrically-Driven Haptic Interaction Loop. *Proc. Whole Body Interaction 2010, a SIGCHI 2010 Workshop.* Retrieved 2014, from http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.188.3443&rep=rep1&type=pdf

Ertan, S., Lee, C., Willets, A., Tan, H., & Pentland, A. (1998). A wearable haptic navigation guidance system. *Digest of Papers. Second International Symposium on Wearable Computers*, 164-165. doi:10.1109/ISWC.1998.729547

Dobbins, T., Van Erp, J., Van Veen, H., & Jansen, C. (2005). Waypoint navigation with a vibrotactile waist belt. *ACM Transactions on Applied Perception*, 2(2), 106-117.

Challis, B., & Edwards, A. (2001). Design principles for tactile interaction. *Haptic Human-Computer Interaction Lecture Notes in Computer Science*, 17-24.

Blair-Earle, A., Zender, M. (2008). User Interface Design Principles for Interaction Design. *Design Issues, Vol. 24, (3), Interaction Design Research in Human-Computer Interaction*, pp. 85-107.

Moggridge, B. (2007). *Designing interactions*. Cambridge, Mass.: MIT Press.

Moussette, C. (2012). *Simple Haptics - Sketching Perspectives for the Design of Haptic Interactions.* Umea: Larsson & Co.

Krishna, G. (2015). *Best Interface Is No Interface : The Simple Path to Brilliant Technology*. Pearson Education, Limited.