Using Wearable Technology to Gain Insight into Children's Physical and Social Behaviors

By

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Submitted to the System Design and Management Program in
Partial Fulfillment of the Requirements for the Degree of

MASTER OF SCIENCE IN ENGINEERING AND MANAGEMENT

at the

MASSACHUSETTS INSTITUTE OF TECHNOLOGY
FEBRUARY 2016

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To my son Ellalan who changed my life forever

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Submitted to the MIT System Design and Management Program
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Abstract

Due to social and financial demands, at least 61% of households have both parents working. Parents and children spend 8 to 10 hours away from each other on a daily basis. During this time, there is very limited communication between parents and the children. Parents have little visibility into what happens during the day with their children and have to heavily rely on the basic notes provided by the teachers. Alternatively, their children have to communicate to them the happenings of their day. Young children and children with special needs have a much harder time communicating the details of their day to their parents.

Wearable technology is going through a revolution with 1 in 5 Americans owning a wearable device. There are already many devices on the market which measure biological functions. As a result, we are presented with an opportunity to close the communication gap using technology to gather data on children while they are away from their parents. This data can be analyzed to gain better insight into children's social and physical behaviors.

An online survey was conducted for this thesis to understand the potential market. Research was done to understand what physiological factors would be of interest to parents as well as other factors. Results concluded that parents were in fact interested in receiving data about their children. They were most interested in knowing their child's location and when their child was experiencing a stressful situation. Based on the results of the survey, a device is proposed to help address this problem. An approach for a phased rollout is provided as well as an experiment to gather data.

Thesis Supervisor: Patrick Hale
Title: Using Wearable Technology to Gain Insight into Children's Physical and Social Behaviors

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Acknowledgments

I am eternally grateful to my mother who is the anchor in my life. Her sacrifice and unwavering support in maintaining my household, taking care of my boys and providing love and encouragement has allowed me to succeed in my academic and professional pursuits.

I would have not started or completed this journey without my husband Ramesh. I am appreciative that he broke cultural norms and pushed me to pursue my dream of attending MIT. It was a demanding and stressful two years and we faced many challenges along the way, but he stuck with me through it all. I am thankful to my eldest son Ellalan for opening my eyes and inspiring me to pursue this topic for my thesis and my newborn son Cholan for putting a smile on my face and giving me the needed breaks from writing it.

I am honored to have had three remarkable men as father figures who taught me life's most important lessons. I am thankful to my uncle Chandrasegaram who instilled in me the value of hard work and the importance of education. I am grateful to thank my uncle Uthayakumar who gave me the confidence to follow my dreams, take risks and not fear failure. I am privileged to have known my departed father-in-law Sutharalingam, who taught me to be a fair, just and considerate human being because that's what matters at the end.

I am indebted to my sister Salini for constantly providing encouragement, inspiration and most importantly sanity to my life. She provided support with my thesis research and spent time explaining the medical concepts that influenced the problem I was trying to address. I am thankful to my sister-in-law Suba who during these two trying years ensured my marriage did not fall apart and in the process has become of one of my best friends.

I am grateful to Pat Hale and the SDM staff for accepting me into this amazing program. The knowledge, insights and skills I learned from the professors, teaching assistants and my fellow classmates will carry with me forward.

Finally, I would not have been able to complete this thesis without the help of my teammates who worked on various wearable technology projects with me during my time in SDM, the brainstorming and ideas provided by brother-in-law Nishanth and my cousin Niroshan and all the parents who came forward to participate in my research.

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Motivation

When my son was 18 months, we realized that he was not meeting his communication milestones. We enrolled him into the early intervention program that was provided by our local community to help with his speech development. He was almost two years old when we went on a family vacation to India and on our flight back home, he was playing with a new application on the iPad. I was amazed at what he was able to accomplish; he learned all his alphabets, both big and small letters, by the time we landed in Boston. From identifying characters in the alphabet, he soon advanced to memorizing and spelling words from flashcards. The entire family was amazed at his academic abilities and encouraged him. Regardless of the advancements he was making academically, he did not understand the cue to respond when someone asked him for his name or to play with other children. As a parent, I found it difficult to accept that my brilliant child had limited social and communication skills and that he needed a lot of help in these areas to be considered 'normal'.

I was fortunate for two things: we lived in the state of Massachusetts, which had many resources that can be utilized to help my son, and my sister was entering her residency training as a pediatric neurologist. Coming from a South Asian community, this was even more difficult because when people met my son, they assumed he was a smart-shy type or that we were culturally raising him as an isolated American and not exposing him enough to other children. It was definitely a challenging two years with many ups and downs, but as a family, we never gave up and endured forward. Nonetheless, I knew in my heart that in the current world we lived in, academic smarts without adequate communication and social skills will make life very difficult.

During this journey, I was exposed to the community of parents who also have children with special needs. As a result, we were very fortunate that to have them as a support and resource. With the help of the community and early intervention, our son blossomed; by the age of four, he was talking in full sentences and we were able to work through the social barriers he faced. With a lot of patience and the right amount of probing, he soon was able to communicate how he feels and what he wants. Every time I saw a parent struggle to understand their child during a meltdown or discuss in parent groups where they shared their fears about their child being able to make friends and fit into a typical school setting or simply be able to communicate if they were being bullied or not feeling well, it broke my heart. I remembered the months where I had felt the same and had the very same questions. I was the overzealous mother who took up the teacher's time asking many details because I felt the communication note, which a smiley face, did not give me the level of detail I wanted and needed to know about my child.

I wanted a way to understand my child better, to figure out how he was doing socially and physically while he was not in my presence. If there was a way to get additional data and make sense of it, I felt I could have more informed conversations with my child and the adults who take care of him during the day. If there was a way for me to notice patterns in his physical behaviors, I believe it may help inform me on why he behaved a particular way socially.

During my time at MIT, I spent many hours working on team projects with very bright individuals on wearable technology and its advancements in different sectors. Using wearable technology to help better understand my child just made sense. I knew, just like me, others adults entering parenthood also grew up in the internet age and would be open to using technology to gather information that would help to understand their child.

1 - Introduction

When an individual becomes a parent, along with the joys of a new child, they have also become entrusted with many new responsibilities, which they carry forth with them for the rest of their lives. At the core of these all responsibilities, a parent's most important roles include providing a safe home for the child and to protect and maintain the child [1].

As long the parent has financial means, they can provide a home for a child. However, the role to protect and maintain a child is much more complex. The dynamics of a family has changed significantly over the past century, attributable to the women entering the workplace [2]. According to the United States Department of Labor, 61% of families have both parents that work to financially provide for their children [3]. In the United States, 50% of mothers are back to work 12 weeks after delivering their child and 70% of mothers went back to work by the end of the first year [4]. As a result, the child spends majority of his/her time outside the home under the supervision of a personnel who is not the parents. Infants and toddlers are commonly dropped off at daycare centers or with a relative, most commonly grandparents. Once the child enters the school system, they typically spend six hours at school and this is normally followed by an after school program or babysitters for a few more hours until the parents work day is complete and are able to take over the care of their child.

An integral part of understanding, protecting and maintaining a child's wellbeing is based on the communication between the child and his parents. However, the communication is very limited or one-directional during the eight to ten hours that a child spends away from his parents. Hence, parents have reduced visibility or no visibility into what happens during this time. The child could experience positive situations, but could also experience complex emotions such as stress, anxiety or panic due to difficult situations. The child could begin to show symptoms an oncoming fever or become reserved and depressed due to bullying by peers. Parents rely heavily on their child to tell them the happenings of their day, but not all children have this communication capacity or the vocabulary to do so.

This is especially difficult for parents who have children with special needs. A child who is on the autism spectrum disorder (ASD) has a very difficult time communicating the reasons for his physical and social behaviors. He might feel stressed and experience a meltdown, but unless the caretaker reports this to the parents, the parents will never know. Without this information it is difficult for parents to help their child and provide them with comfort and support.

We are in the midst of a wearable technology revolution and more than $1.4B have been invested in wearables since 2009 [1][2]. Innovative giants such as Apple and Google are already making strides for market segment. According to PwC, 1 in 5 Americans own a wearable and 1 in 10 wear it daily [3]. Many devices already exist which can measure biological functions such as heart rate, sleep patterns, stress, activity, oxygen level and so forth.

As a result of social and financial demands, we are not nested in homes to care for our children and therefore, yearn to know and understand our children better. There is an opportunity expand the use of this technology to gather data on children when they are away from parents and analyze this data to gain better insight into their social and physical behaviors.

2 - Document Structure

As presented in the Introduction chapter, this paper aims to explore how wearable technology can be used to help parents gain a better understanding of their children's physical and social behaviors when their children are not in their presence. Chapter 3 defines the problem statement and focuses on the importance of communication between parents and their children. This chapter discusses how communication between parents and children is often inadequate at younger ages and for children with special needs and how communicate methods used by daycare centers and schools do not provide sufficient insight on the children that parents are typically looking for.

Chapter 4 will present background information of wearable technology. This chapter will begin with a brief review of the history of wearable devices and how it has evolved over the centuries. The chapter then highlights product developments seen in the three broad categories of wearables: devices worn on the core body, devices worn on the eye and devices worn on the wrist. The chapter then focuses on existing wearable technology used for monitoring the vital functions of the human body that are relevant for the problem statement presented: heart rate monitoring, oxygen level, body temperature, respiratory rate and skin conductance. Predictions made by information analysis companies such as IHS, IDTechEx, IDC and Canalys for wearable devices, sensors and MEMS for the next five years are also presented in this chapter. The chapter concludes with technical information on how wearable devices are classified, the types of sensors available and the communication protocols that are used.

Chapter 5 will analyze the results from the survey that was conducted to validate the hypothesis that parents and other primary caregivers are in fact interested in using wearable technology to collect data about their children. This chapter provides details on the survey composition, how participation was solicited and the medium and timeframe in which the survey was conducted. Detailed data analyses are performed on the aggregated information collected during the survey. This information includes data about the parents and their children, the existing communication methods currently used by parents to gain access to information about their children's daily activities, primary caregiver's interest in their children's physiological data, existing wearable technology used by their children and market research for the proposed product.

Chapter 6 will present the proposed product to address the problem. The chapter will discuss the form factor selected for the product, and the high level product and functional requirements. The chapter then moves to discuss the device architecture and breaks the architecture down from a hardware and software perspective.

Chapter 7 concludes with the findings and the phased approach that should be undertaken to validate the hypothesis further and understand the user market.

3 - Problem Statement

A normal day consists of both parents going to work and children spending their time at a daycare or educational facility. Once the child is dropped at daycare or at school, parents have very limited information on their child's wellbeing. Most daycare centers allow for parents to call and check in on the child. However, once the child enters the school system, there is not an easy way to check on your child during the day.

Communication, for the most part, as a result becomes one-way when the child enters the school system. If there is an emergency situation, the school will reach out to the parents to inform them. The younger children sometimes get a communication folder or note, which indicates to the parents what the child had worked on during the day and overall statement of whether the child had a good day or a bad day. Beyond this limited information, parents are unable to have a window into their child's day. Parents have to rely on the communication with their child after school to find out what happened during the day, resulting in the standard "How was your day today" question at dinner time.

This becomes especially more difficult if you have a child with special needs that is not able to communicate and provide you a meaningful answer. Children also might not know how to communicate how they are feeling at school or elsewhere.

Hence, parents and primary caregivers need a way to gain insight on the physical and social behaviors of their children. This paper explores how this can be accomplished by monitoring the activities of the children using a wearable device and interpreting and notifying the parents with this information. With this information, parents will be able to view and understand the physical and social state their child is in and perhaps be able to develop further detailed conversations with their child.

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4 - Background on Wearable Technology

Throughout history, humans have been applying technology to items that can be worn on their bodies. The first recorded example of wearable technology is from 333 BC, where Alexander the Great wore laminated linen body armor called linothorox to the Battle of Issus [4]. The body armor protected the wearer from injury by arrows, swords, axes and spears. Today, eyeglasses and contact lenses are common commodities that are used to improve the eyesight of the wearer. These two simple wearable items originated from the discovery of spectacles, thin lenses placed directly on the eyeball in Italy in the year 1286 [4]. In 1571, Elizabeth I was gifted the earliest recorded wristwatch, a jeweled armlet-mounted watch by Robert Dudley the 1st Earl of Leicester. Since men preferred pocket watches, wrist watches were only worn by women. It was only in the 19th century that men began to wear wristwatches using for military purposes [4]. The discovery of the wristwatch paved the way for many of the wrist-worn wearable technologies that followed throughout the centuries.

Evolution of Wearable Technology

Over the next centuries, wearable technology evolved and took on many different forms and purposes [4]. These inventions served many industry sectors as seen Figure 1. Furthermore, the definition of wearable technology progressed to the broad category of wearable computing devices. This included any wearable device that has a microprocessor, which can be the simplest digital watch to full augmented-reality full-body wear [5].

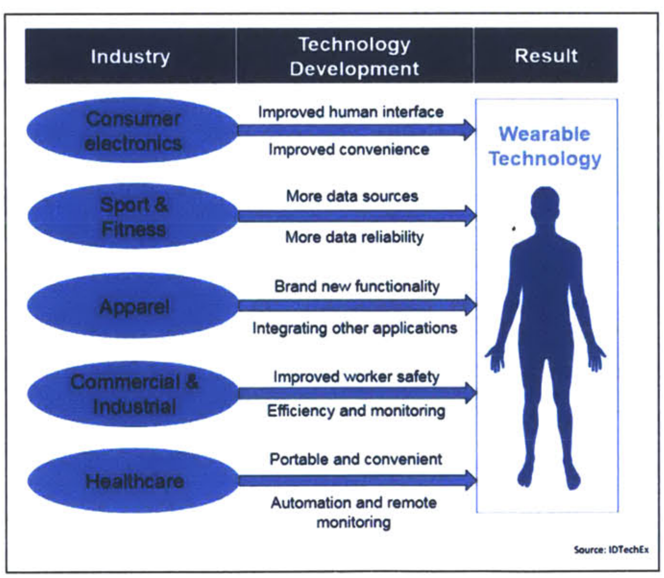

Figure 1: Wearable technology development in different industries

Body armor, spectacles and wristwatches were early inventions that have been iterated in the wearable space over and over again. The first spacesuit worn in Russia in 1961 is an advance iteration of the body armor worn in the Battle of Issus [4]. General Electric invented Hardiman, the first powered exoskeleton which gave the wearer strength to easily lift 680 kg [7][8]. Although, it was a failure Xybernaut even tried to design the first wearable PC in the year 2002 [8].

Building on the concept of vision and eyeglasses, many different wearable products were created in this realm as well. Head-mounted lights and cameras became very popular to help capture and document experiences seen by the wearer. The Google Glass is an optical head-mounted display, which is worn by the wearer like eyeglasses. Although, it does not improve the wearer's eyesight, it displays information to the wearer like a smartphone in a hands-free format. Wearers are able to communicate with the Internet using nature language commands and also record everything they see [10][11].

The wristwatches went through the most innovation in the wearable space. Prior to the 1970s, the wristwatch was considered a luxury item, intricately crafted and appropriately priced as fine jewelry. Then in the mid-1970s, Japanese and Hong Kong manufacturers combined the inexpensive quartz design with the region's cheap labor and flooded the low-end market, essentially changing the meaning of the watches from 'watches as jewels' to 'watches as instruments' [11]. Seiko created both a TV watch and a smartwatch in 1983, which could store notes, appointments and even perform calculator functions [4]. Throughout the 80s and 90s wrist devices primarily helped the wearer to improve productivity for their business operations. In 2003 the Garmin launched the Forerunner series of GPS sport watches, which soon began a trend of wrist worn devices for the fitness market. The FitBit, Jawbone UP and Nike+Fuelband were introduced to the fitness market following this and gained immense popularity. This was later followed by a trend of smartwatches with the introduction of the Sony SmartWatch in 2012, where the smartwatch can be paired with the company's smartphone. In 2013 mobile giant Samsung unveiled the Galaxy Gear and in 2014 Apple introduced the Apple Watch [4].

Figure 2: Timeline of Smartwatches

Based on the prediction released in the IHS report in 2014 for wearable devices, smart watches will once again begin to dominate the wearable device market. This has already been observed in 2015 with the popularity of Apple Watch and Galaxy Gear 2 by Samsung [12].

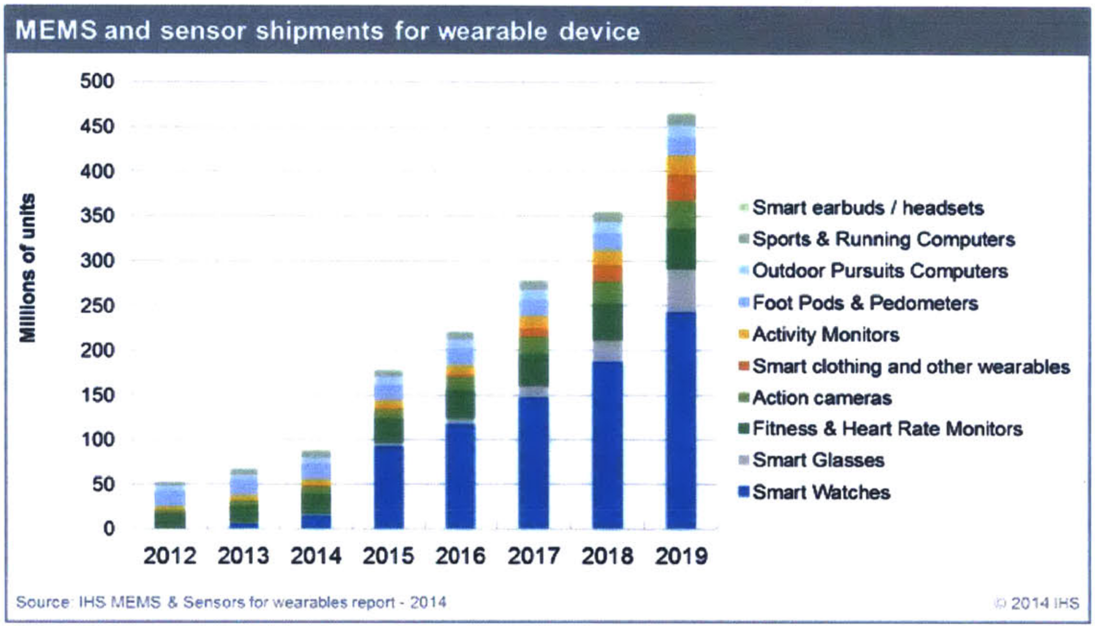

Figure 3: IHS MEMS & Sensors for Wearables [12]

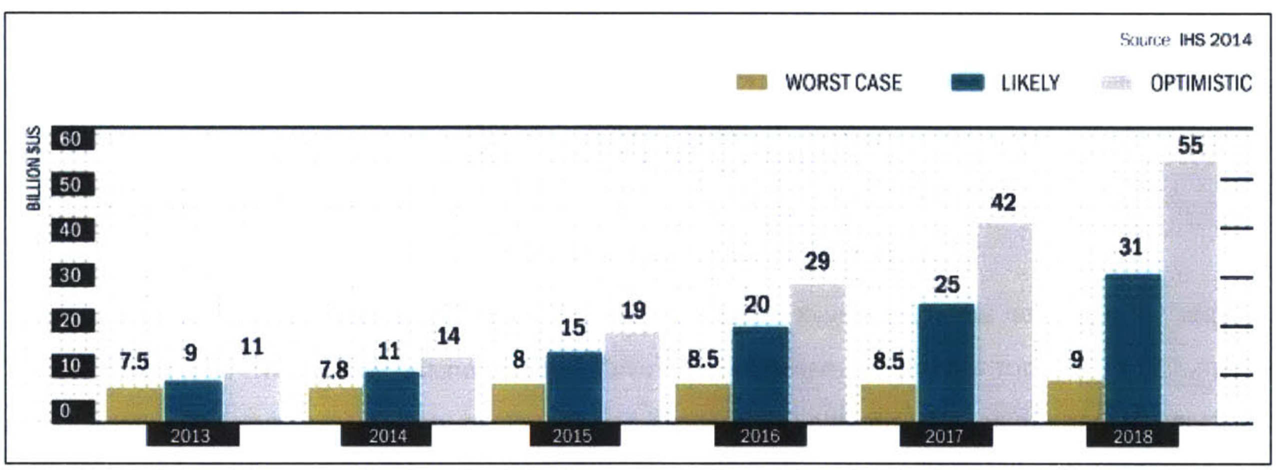

Figure 4: Preliminary Forecast for Wearables [12]

To better understand the growth of wearable devices and the markets they are penetrating it is important to understand their classification and technology behind them. These are explained in the subsections that follow.

Existing Wearable Products

Wearable devices can be found is many different sectors with many different purposes. Beecham Research provides an overall summary of this in the Figure 5 [13].

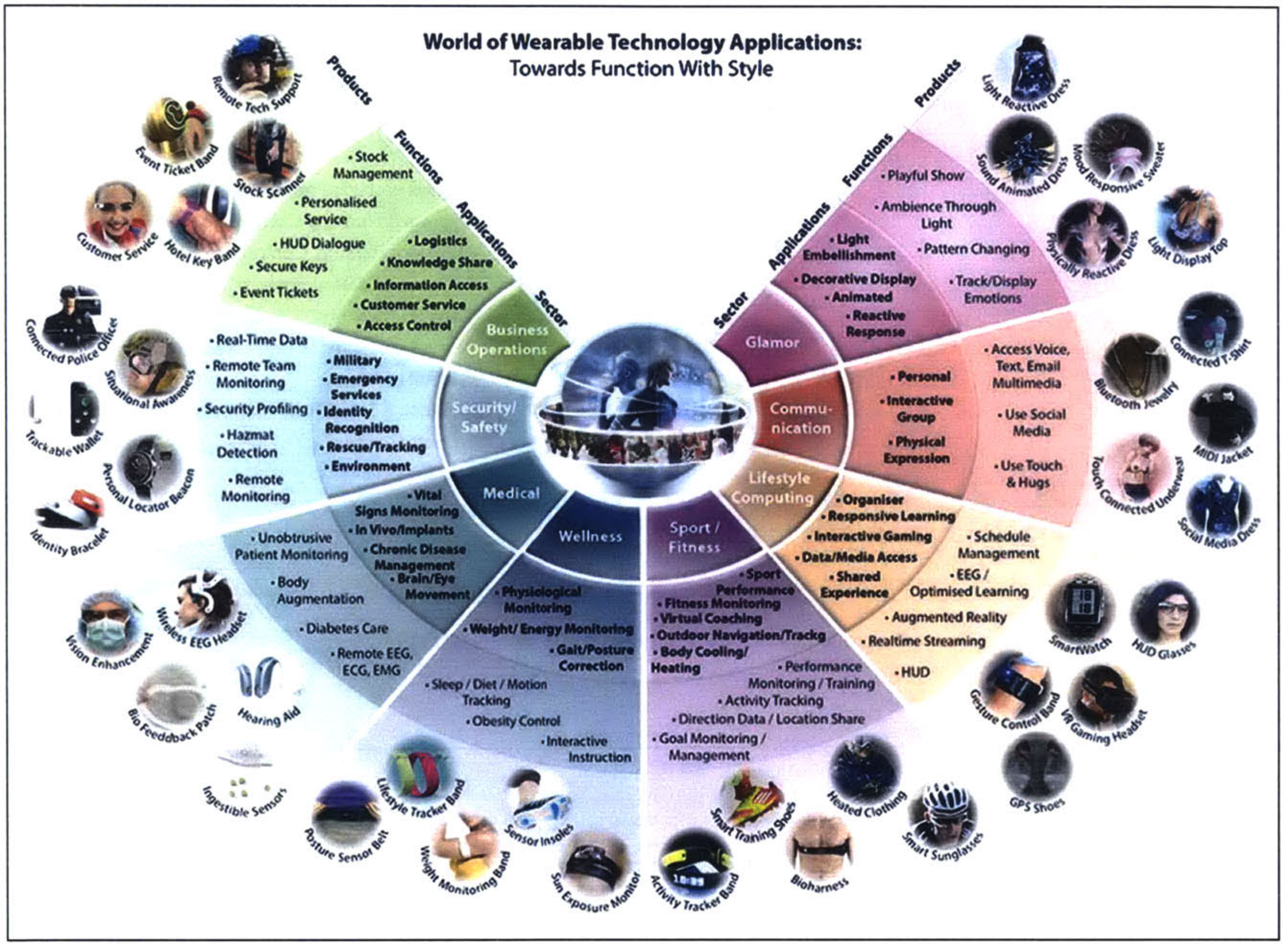

Figure 5: World of Wearable Technology Applications [13]

This paper will focus on wearable devices that monitor and collect information on the human body. Although, Figure 6 is not a comprehensive list, it provides details on the well-known companies with products in the marketplace that provide this service.

As seen in Figure 6 companies like FitBit, Samsung, Empatica, iHealth and Withings produce products with multiple sensors to collect different physiological data points about the human body. The most interesting and informative data required to address the problem statement in this paper are heart rate, body temperature, skin conductance, blood pressure, respiratory rate and oxygen level.

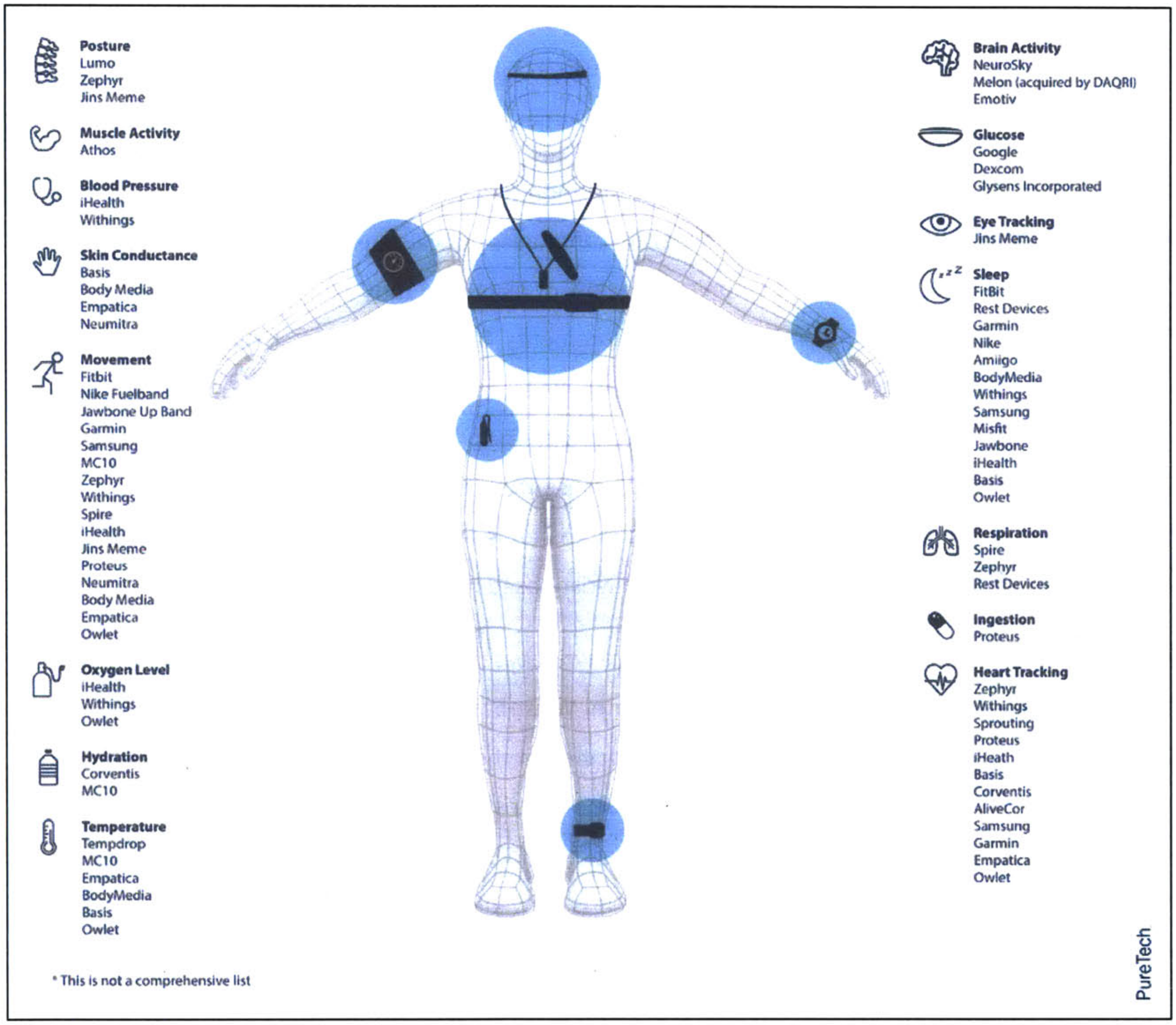

Figure 6: Wearable Devices Collecting Physiological Data points [14]

Heart Tracking

Devices require a heart rate monitor (HRM) to perform heart tracking. The heart rate monitor is a system made of sensors that measures and records the user's heart rate [15]. The earliest models consisted of a monitoring box with a set of electrodes connected to the chest [16]. Modern heart rate monitors comes in three popular forms: chest strap monitors, finger sensor monitors and wrist-based monitors [15], [17]–[19].

Chest strap monitors provide the greatest accuracy and they require two elements: a chest strap transmitter and a receiver, which can be either a wrist device such as a smartwatch or a smart phone

[16][17]. Chest strap monitors work by detecting the electrical activity that is transmitted through the heart muscle to make it contract [19]. Companies such as Garmin, Under Armor, Polar H7 and Suunto produce widely accepted chest strap monitors for consumer use.

Finger sensor monitors are simpler than chest strap monitors and can be found on smartphones like Samsung Galaxy S5. These devices have a finger unit that uses optical sensor to measure the heart rate. This is done with LEDs that are able to monitor the flow of blood and thus determine the heart rate. The finger sensor are good at providing one time measurements, but are not good at capturing continuous heart tracing because you need to stop your activity to measure them. For example, the Samsung Galaxy S5's reading is close to that of an actual electrocardiogram to measure heart rate, only off by 0.2% according to experiments done by CNET. This is because it utilizes the arterial vessel at the tip of the forefinger and the translucency of the fingertip's skin is easier to read compared to that of the wrist [20]. This makes finger sensors more accurate then wrist-based monitors.

The most popular heart rate monitors these days are wrist-based devices. It is a single unit that is placed around the wrist to easily obtain wearer's heart rate. Wrist-based heart rate monitors also use optical sensors as finger sensor monitors. There are LEDs located at the bottom of the watch and the LEDs look through the wearer's skin and monitor the flow of blood. Wrist-based devices look at the slow-pumping capillaries in your wrist to make the reading. Although, it does not have the accuracy of the other two types of heart rate monitors, it is popular because it is convenient and comfortable to wear and it can provide continuous monitoring. Within wrist-based devices there are basic wearable devices and smart wearable devices. Smart wearable bands such as Samsung Gear Fit, Apple Watch and Microsoft Band provide other services in addition to heart rate monitoring [15].

Figure 7: Examples of heart tracking wrist-based devices

Oxygen Level

Oxygen level is measured by an oximeter device. An oximeter measures the user's O2 saturation [21]. The most common way of measuring a person's oxygen saturation is by placing a sensor device on their fingertip or earlobe, which are the thin parts of the human body. The device uses an optical sensor and passes two wavelengths of light through the body part to a photo detector. Oxygen level is calculated based on the change in absorbance of the two wavelengths [22]. The device then displays the percentage of blood that is loaded with oxygen, the acceptable ranges are between 95 to 99% [23][24].

Figure 8: Examples of oxygen level tracking devices

Body Temperature

Thermal sensors are used to detect changes in body temperature. Thermistors are the most common type of sensor that is used. Thermistors are thermally sensitive resistors that exhibit a large, predictable and precise change in electrical resistance when they experience a change in body temperature [25]–[27].

Skin Conductance

The skin conductance sensor measures electrical conductance between two points on the skin, and is normally connected to the fingers or toes. This is often referred to as electro dermal activity (EDA) and it is the property of the human body that causes continuous variation in the electrical characteristics of the skin. Skin resistance varies with the state of sweat glands in the skin and skin conductance is an indication of psychological or physiological arousal.

Classification of Wearables

IDC classifies wearables into the six categories: simple wearables, simple connected accessories, IP-connected accessories, complex accessories, smart accessories and smart wearables [5]. As more capability is added to the wearable device, it becomes more complex and consumes more power and inherently costs more money.

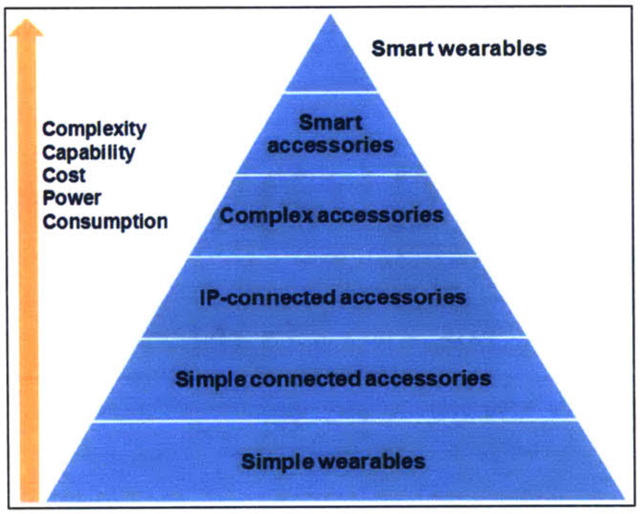

Figure 9: IDC's Wearable Computing Devices Taxonomy [5]

Simple Wearables

Digital wrist watch is a simple wearable device. It does not communicate with other devices or with the internet. The capabilities of a simple wearable are defined out of the box, and consumers cannot add new software or apps to them.

Simple Connected Accessories

A simple connected accessory is a where one wearable device transmits data to another device. This other device can be a wearable device but does not have to be and the device does not need to connect to the internet. An example of a simple connected accessory is a temperature monitor that transmits the body temperature to a hand held screen nearby.

IP-Connected Accessories

An IP-connected accessory is wearable device that transmits data wirelessly to a device that is able to connect to the Internet. An example of this is a Bluetooth headset that connects to a mobile phone.

Complex Accessories

A complex accessory is a subset of IP-connected accessories that is designed to operate partially independent of any other device but is fully capable of all its functions when it is connected with an IP-capable device such as a smartphone, tablet, or PC. These devices collect data and in cases are able to display data on their own. However, they do need to connect to the internet to offload the data. Most of the existing wearable devices fall into this category, such as a Fitbit, Jawbone, Empathica or iHealth Pulse Oximetry.

Smart Accessories

Smart accessories have been gaining popularity over the last 12 months, especially with the introduction of the Apple Watch. A smart accessory is like a complex accessory, but with the added feature of enabling the user to install third-party software or apps to the smart accessory. These devices still rely on connecting with an IP-capable device such as a smartphone, tablet, or PC to fully function. Examples of smart accessories are Apple Watch, Sony SmartWatch and GALAXY Gear from Samsung.

Smart Wearable

Smart wearables are at top of all wearable devices because they are capable of fully functioning autonomously and independently. The most important functionality is that smart wearables connect to the internet wirelessly on their own. Smart wearables also have the same capability of smart accessories and allow the user to install third-party software or apps onto the device. An example of a smart wearable is the Google Glass.

Wearable Device Sensors

Most wearable devices, especially devices used in the medical and fitness sectors are built with multiple sensors. It is the sensors that are integrated into these devices that provide the real value to the user. Sensors can measure a variety of things and convert inputs from the physical environment into readable data. The number of wearable sensors used for creating devices will continue to increase significantly over the next decade. IDTechEx predicts that by 2025 that there will be over three billion units sold and almost half of them will be designed for specifically for wearable products [28].

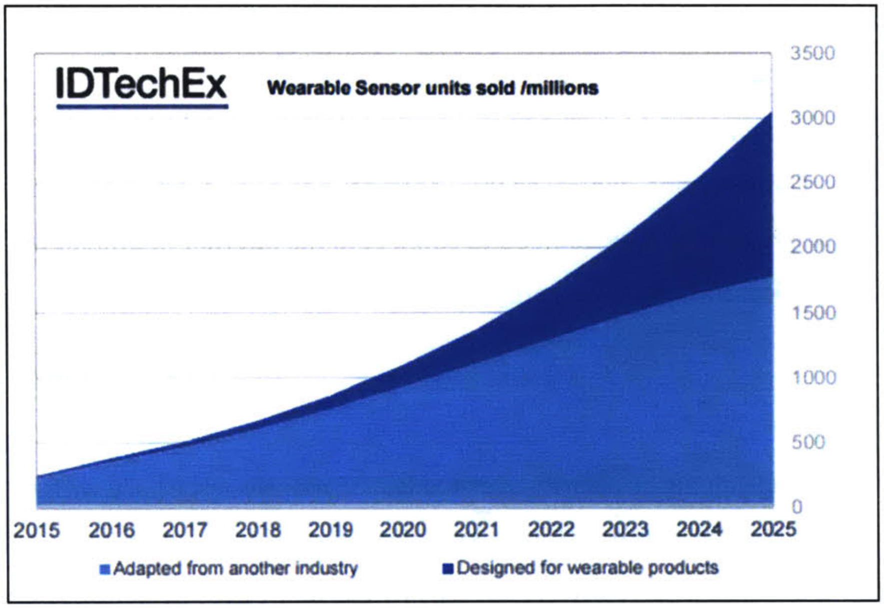

Figure 10: Prediction for Wearable Sensor Units Sold [28]

IDTechEx further breaks down their prediction by sensor type and predicts that by year 2020 chemical sensors will own a significant share of the market, followed by inertial measurement unit sensors and optical sensors.

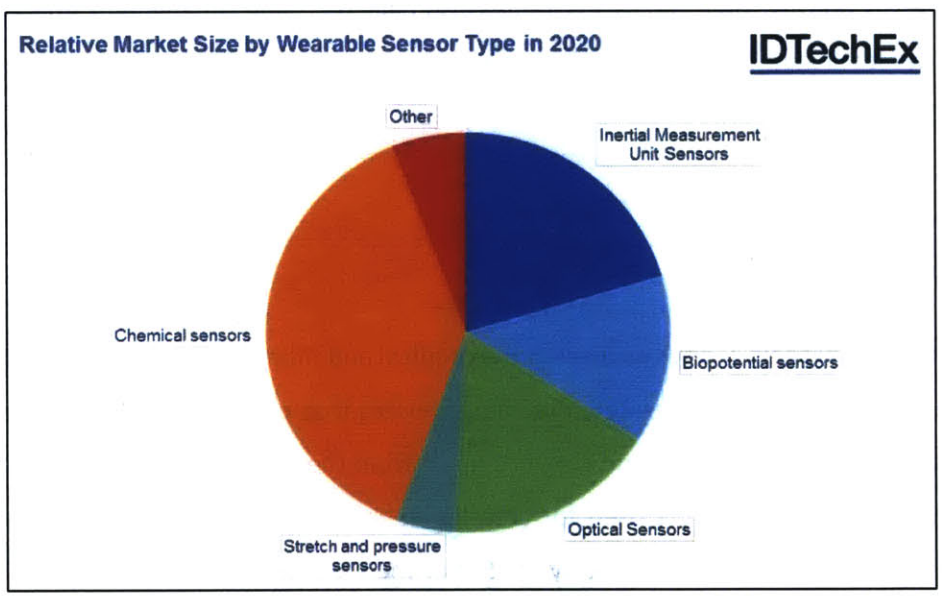

Figure 11: Relative Market Size by Wearable Sensor Type in 2020 [28]

Inertial Measurement Unit Sensors

Inertial measurement unit (IMU) sensors measure and report specific force and angular rate using a combination of accelerometers and gyroscopes. IMUs helped the early growth of wearable technology especially in the fitness sector by measuring steps taken, speed, etc. [29]. IMUs are well established and have lost cost and can be found everywhere. This is primarily due to their large volume integration into automotive and smartphone sectors. These IMUs were adapted later for wearable devices [30]. Example products with IMUs are activity trackers like FitBit, smartwatches, smart footwear and smart clothing.

Optical Sensors

At the basic level, an optical sensor converts light rays into electronic signals by measuring the physical quantity of light and then translating it into a form that is readable by an instrument. Optical sensors can be seen almost anywhere, with common applications such as smartphones where they are used to adjust screen brightness. In smartwatches, the sensors are used the measure the wearer's heartbeat. Optical sensors have grown significantly in popularity due to smartwatches monitoring heart rates [28], [31].

Chemical Sensors

Chemical sensors measure properties such as composition, concentration, reaction rate, acidity, and oxidation by looking for chemical information ranging from the concentration of a specific sample component to total composition analysis [13] [14]. Glucose sensing on its own is a large market, however there are other chemical sensors being developed as well. These include other healthcare examples such skin patches for monitoring temperature. There is also a market for gas sensors and other environmental sensors that are being developed.

Biopotential Sensors

Biopotential sensors are commonly known as electrodes and they have been in widely used in the medical applications over the past century [28], [30]. Heart rate monitoring electrodes have been used in sports and fitness for the last three decades. Recently, they are making their way into the consumer market as development is being done to make electrodes more comfortable. New applications are beginning to emerge as electrodes become more reliable, such as EMG clothing, ECG patches and EEG. The market for medical electrodes alone is around $800 million USD. Hence, these sensors are still more popular in the medical sector [5], [28].

Communication Protocols Used By Wearables

With the exception of devices in the simple wearables category, all other wearable devices need to have some communications capability. At least one of the following protocols is used in these devices. As seen in Figure 12, the higher the throughput and range of the device, the more power it consumes. A smart wearable such the Google Glass, which is fully autonomous and can communicate with the internet on its own using 3G or 4G/LTE requires much more power than a wireless thermometer that uses NFC to send its read out to a remote display monitor.

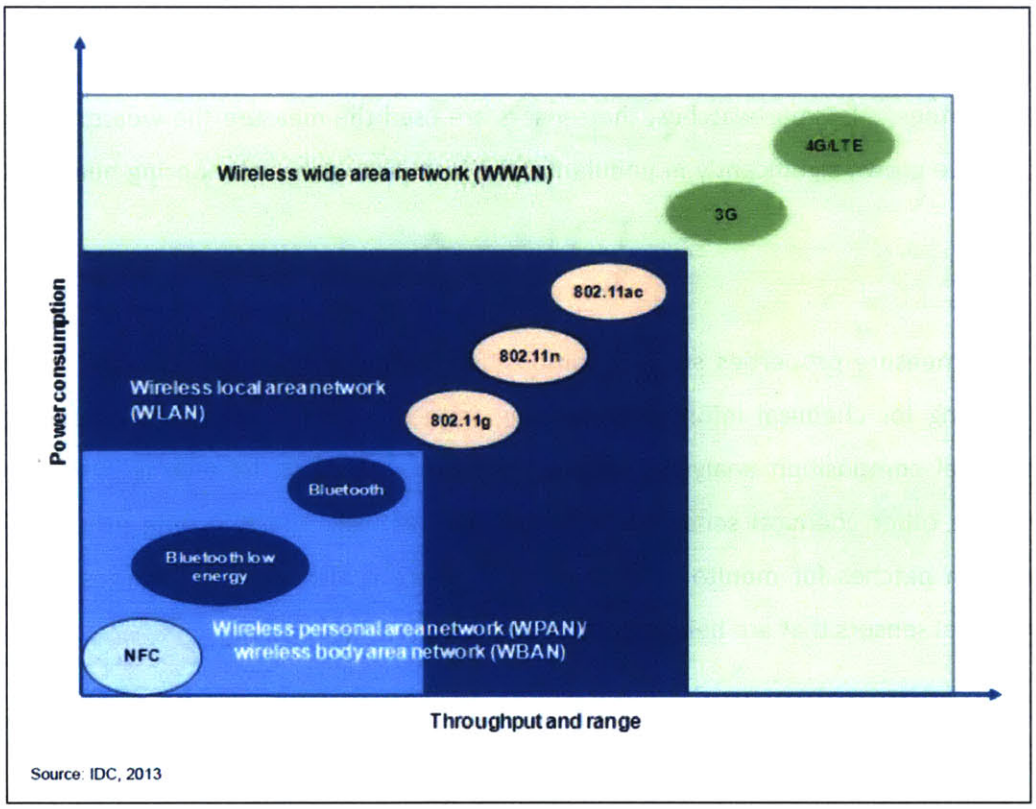

Figure 12: Trade-Offs Between Range and Throughput vs. Power Consumption [5]

Near Field communication (NFC)

NFC is used to describe a specific set of protocols that enable two electronic devices to communicate with each other using a radio data communication. One of the devices acts as the NFC initiator and generates a radio frequency that powers the other device which is transmitting the data, the passive

NFC target. Wearable devices using NFC protocol have a very short range, typically no more than 10 cm [5].

Bluetooth Low Energy (BLE)

Bluetooth low energy (BLE) or Bluetooth LE is marketed as Bluetooth Smart. It is a wireless personal area network technology designed and marketed for applications in the healthcare, fitness, beacons, security and home entertainment industries. This protocol has a range of 50 m and an over-the-air-data rate of 1 Mbps, but application level throughput of quarter 1 Mbps. BLE is intended to have a similar communication range as classic Bluetooth but with much less power consumption [5].

Bluetooth

Classic Bluetooth allows for the exchange of data over short distances using short-wavelength UHF radio waves. It has a range of 100 m in ideal conditions and a data rate of 3 Mbps, which falls to 2 Mbps at the application level. Bluetooth allows a fixed or mobile device, such a mobile phone to build a wireless personal area network (WPAN) similar to Bluetooth Low Energy [5].

Wi-Fi

The previously mentioned communication protocols are frequently used to create a network between two devices, whereas the Wi-Fi protocol allows for a hub-and-spoke design. This allows any client on the Wi-Fi network to connect with any other client on the same network. Most Wi-Fi devices communicate on the 2.4GHz band using the 802.11b, 802.11g, or 802.11n protocols. However, a growing number of devices also use the 5GHz band, using the 802.11ac protocol, which has much higher throughput but a shorter range [5].

3G and 4G/LTE

Most commonly used by mobile phones, the packet data components of these protocols are increasingly suitable for "standalone" implementation into being adopted by consumer Wi-Fi routers that use the mobile phone network as a backhaul, instead of cable or telephone lines. Residential security systems also frequently use the mobile phone network [5].

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5 - Analysis

To validate the hypothesis for this thesis, it is important to understand whether primary caregivers want to gain insight into the physical and social behaviors of their children through the use of wearable technology. To confirm this theory, an online survey was designed to collect responses from primary caregivers. The survey was composed predominately of multiple choice questions and took on an average of five minutes to complete. The survey was conducted on a strictly volunteer basis and participants had the option to stop the survey at any time for any reason. Furthermore, the survey was conducted anonymously and no identifiable information about the participants or their children was collected.

Participants who were invited to complete the survey were solicited through the author's personal network on social media, personal community networks and the MIT SDM network. The results gathered are indicative of primary caregivers with young children within the age range of were the intended target for this product. However, due to the anonymous nature of the survey, it is not possible to discern the social-economic status of the participants and therefore, this cannot be commented on.

The survey was active online for the duration of one month from November 11, 2015 to December 11, 2015. During this time period 106, survey results were collected and the following subsections analyze these results. The survey questionnaire and raw result set can be found in Appendix A.

Survey Composition

The survey was intended for primary caregivers, mostly parents with young children who have full-time jobs. Hence, it was important that the survey had to be quick and simple so respondents would be able to complete it in one attempt. Based on insight from SurveyMonkey and Qualtrics, multiple choice questions and scales were used [34][35]. To increase participation, the survey was broken into several simple sections with no more than six questions per sections. Descriptions for each section were provided where required, and explanations for key terms were also provided to aid the respondents in answering the questions. The survey questions and their results are discussed in the subsequent sections.

Section	Nature of Questions in Section
1	Information about yourself
2	Information about yourself with respect to your children
3	Specific details on all of your children
4	Specific details about your child with special needs, if applicable
5	Communication style used access information about your children
6	Interest in knowing your child is experiencing a stressful situation and the possible causes
7	Interest in knowing your child is experiencing abnormal heart rate
8	Interest in knowing your child is experiencing abnormal body temperature
9	Interest in knowing your child is experiencing abnormal respiratory rate
10	Interest in knowing your child's location
11	Interest in knowing your child's physical activity level
12	Technology used by your children
13	Mediums used to receive information about your child

Analysis on the Primary Caregivers

Section 1 collected information about the respondent through the questions below. If a respondent had indicated that they were not a primary caregiver, the survey terminated after Section 1.

1. Are you a parent or primary caregiver?
    - Primary caregiver was defined as a person who primary responsibility of a child such as parent, grandparent, etc.
2. What is your role?
3. What is your age?

In analyzing the results of the survey, it was interesting to see that three-quarters of the respondents were mothers as seen in Figure 13.

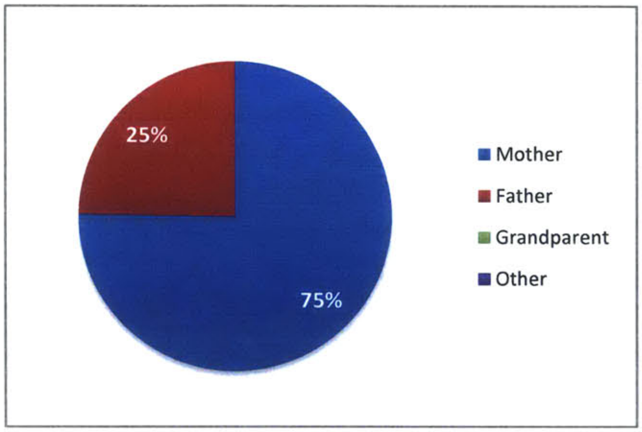

Figure 13: Role of Primary Caregiver

In the United States, seven percent of children lived in a household headed by a grandparent and this number has been increasing [34]. However, there were no survey responses from grandparents. This could be due to the fact that this survey was conducted online and it did not reach the older generation in a form that was comfortable for them to respond to. This is further proven when looking at the age of the respondents. Almost 90% of the respondents were between the ages of 25 – 44 as seen in Figure 14.

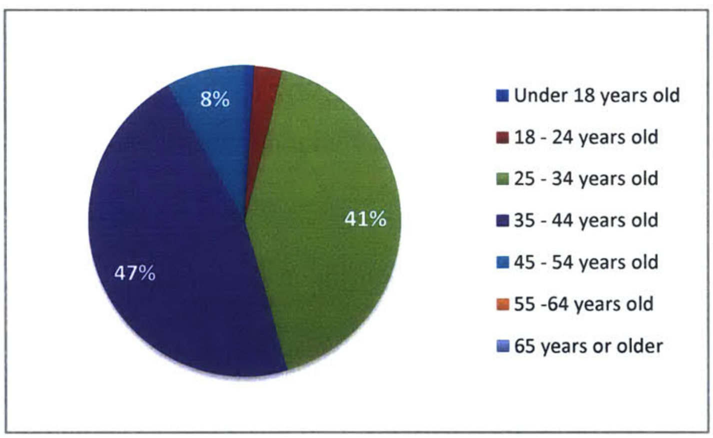

Figure 14: Age Range of Primary Caregiver

Section 2 collected additional information about the respondent and the children. This information is used to understand what a typical day is for the respondent is and how much time she spends away from her children.

1. How many children do you have?
2. What best describes your current situation?
3. On a normal day how many hours are you away from your children?

The average number of children in a household is around 1.75 according to the United States Census Bureau [35]. The results from the survey are representative of this: 85% of families surveyed had less than two children in their household. The breakdown of the number of children in the families surveyed can be seen below in.

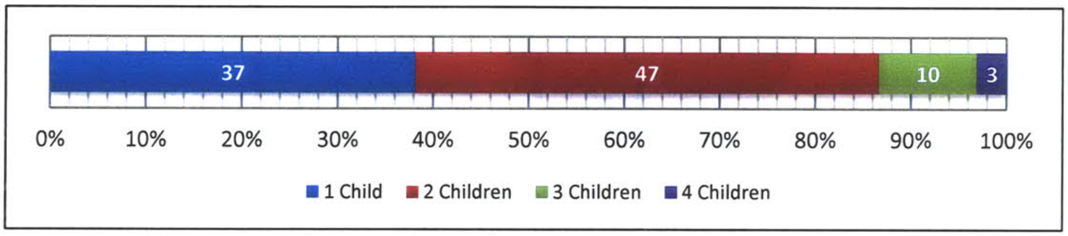

Figure 15: Number of Children in Households

The foundation of the problem statement is based on the notion that primary caregivers spend a significant portion of their functional day, the time they are not sleeping away from their children. If the average American gets around 6.8 hours of sleep [36], this leaves roughly 17 hours in the day to go about daily life, which also consists of a full-time job that takes about ten hours in the day.

The survey results are indicative of this as seen in Figure 16, which shows the breakdown of the caregiver's current employment situation. It can been seen that 73% of the surveyed population held a full-time job or attended school full-time and 12% of the surveyed population did a combination of work and school. Together, this makes up 85% of the total population that was surveyed.

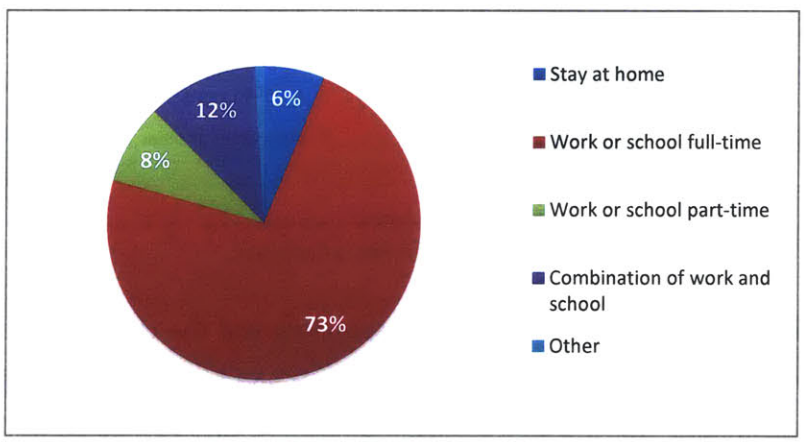

Figure 16: Caregiver's Current Situation

According to the United States Department of Labor, the percentage of women in the labor force has been increasing and since the year 2000, it has been at 47% percent [37]. This is also indicative in the survey results, as seen in Figure 17. However, based on the results from the respondents, it can be concluded that mothers more likely to stay at home to take care of the children, or does work or school part-time when compared to fathers.

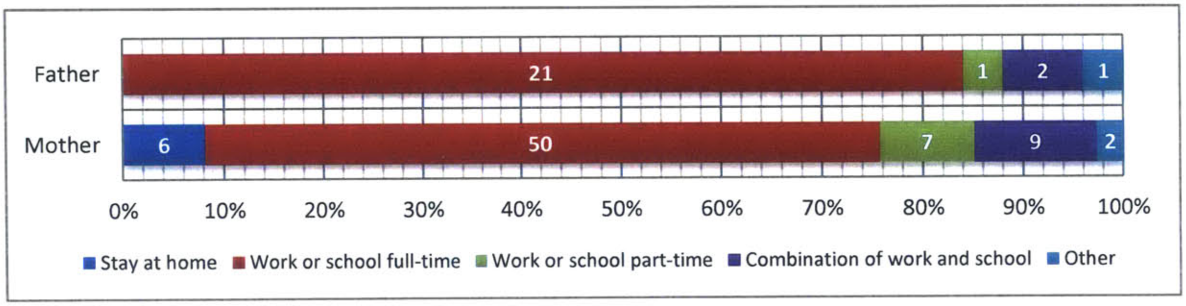

Figure 17: Current Situation: Mothers vs Fathers

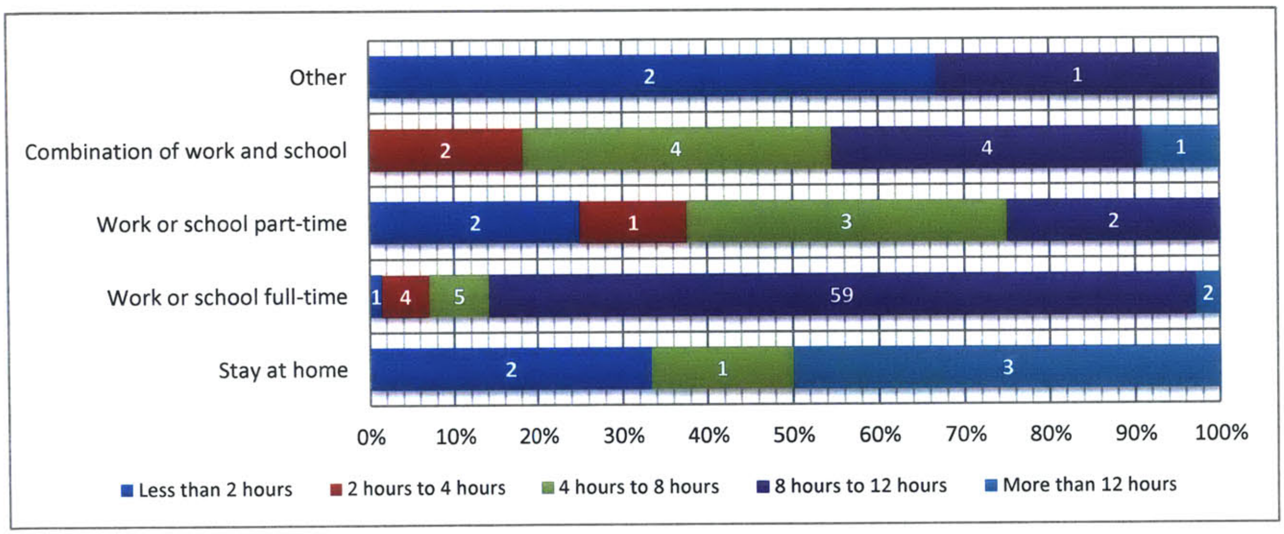

Figure 18: Average Hours Spent Away from Child Daily

The need to design a product to bridge the gap between parents and children is validated by confirming the amount of time that primary caregivers spent away from their children. In Figure 18, it can be seen that over 85% of respondents that held a full time job or attended full time school were away from their children at least 8 hours, which can be up to 10 hours, when travel time is factored in.

Analysis on Children

Section 3 of the survey collected specific details on each child. Details on a maximum of four children per respondent were collected and if the respondent had more than four children, they were asked to start with their youngest child. Questions 1, 2, 3, and 5 in this section were multiple choice responses. Question 4 was setup as a range from 0 to 5 (0 meaning None to 5 meaning Very High).

1. How old is this child?
2. Do you take care of this child during the day?
3. What is a typical day for this child?
4. What is this child's ability to communicate the details of his/her day to you?
5. Does this child have a special needs diagnosis?
    a. Examples of special needs diagnosis were provided such as speech delays, autism spectrum disorder (ASD), attention deficit hyperactivity disorder (ADHD), anxiety disorders, learning disabilities, etc.

The surveyed population provided details on 174 children in total. Over 80% of the children of the respondents surveyed were under the age of 10 as seen in Figure 19, which is the age population of the children that the problem statement looks to target.

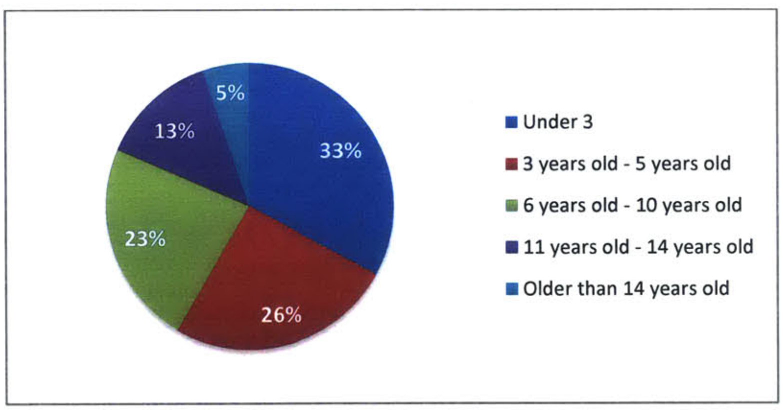

Figure 19: Age Range of Children

To further validate the need for product to help bridge the gap between primary caregivers and children, the results were analyzed by looking at the age range of each child and whether the child was cared for at home by the respondent or not. Figure 20 shows that the number of children being cared for during day by a non-primary caregiver is roughly consistent between the three age ranges: Under 3, 3 years old – 5 years old, 6 years old – 10 years old. Furthermore, children within these age ranges attend the expected educational institutions for their age groups as seen in Figure 21. Hence, the product being designed would need to take this into consideration.

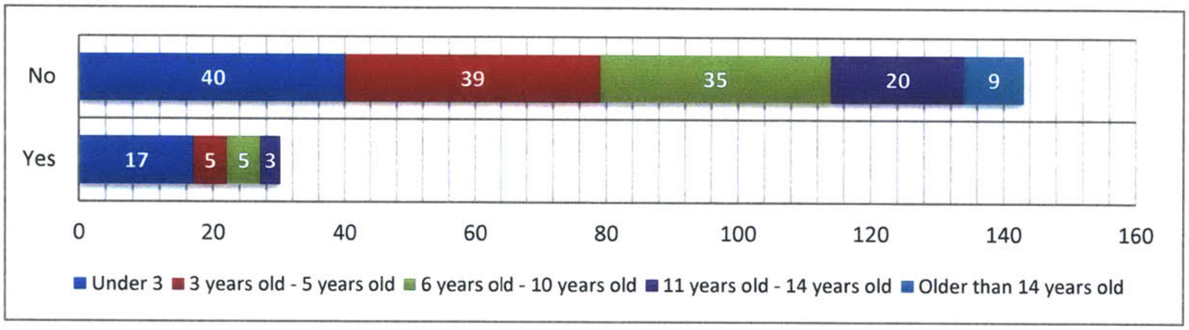

Figure 20: Age Range of Children Cared for Daily by Parents

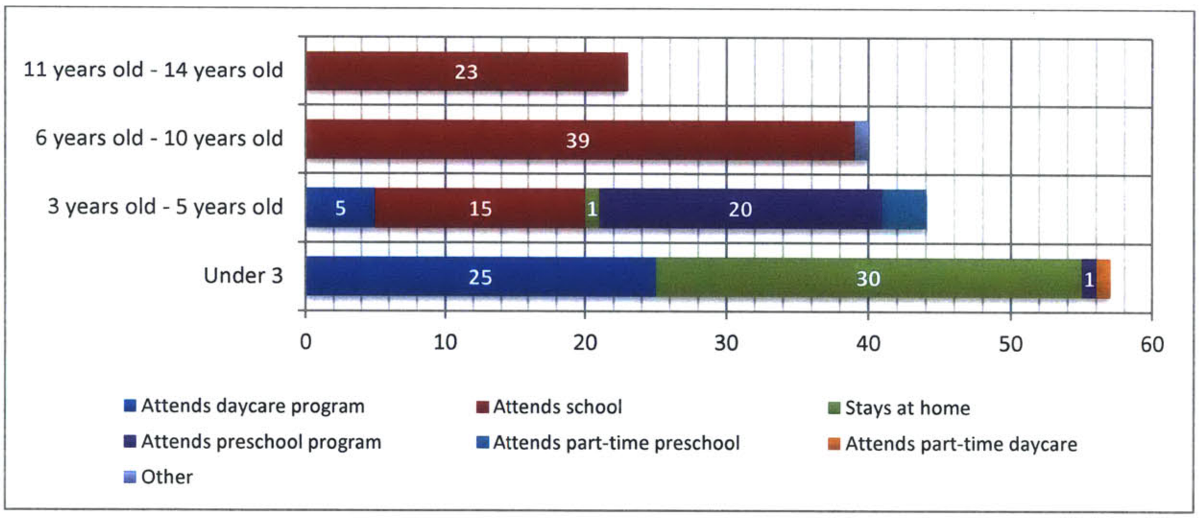

Figure 21: Children's Current Care Situation by Age Range

Communication is at the root of helping children connect with their parents to provide details of their day. Many factors can contribute to the lack of communication between parents and children. This could be due to physical problem such as speech impairment or social problems such delayed development of social skills or interest in communicating. Furthermore, children in the younger age groups do not have the vocabulary or mental capacity to communicate their day in detail to their parents and this is normal for that age group.

The social settings that children are in during the day also contribute to the amount of detail children may choose to share with their parents about the details of their day. BullyingStatistics.org states that 77% of all students are being bullied, whether it is verbal or mental abuse [38]. When children are bullied by their peers they often become withdrawn and this impacts their ability to share details of their day.

Parents also have their own issues including financial problems, emotional problems, physical problems, etc. Hence, it is very possible that parents may not have the time or ability to deal with their own stressful situations that they may forget to ask their children how their day was and if there were any problems. Parents may expect that children will report issues to them if something is wrong.

Figure 22 shows the ratings that parents that were surveyed provided on their children's ability to communicate the details of their day to them and the results have been grouped by age. It is not surprising those children under 3 have very low or no ability to communicate details of their day. Children's ability to communicate improves with age and parents with children 6 years old – 10 years old stated that 65% percent of their children had high or very high communication skills when it came to providing the details of their day.

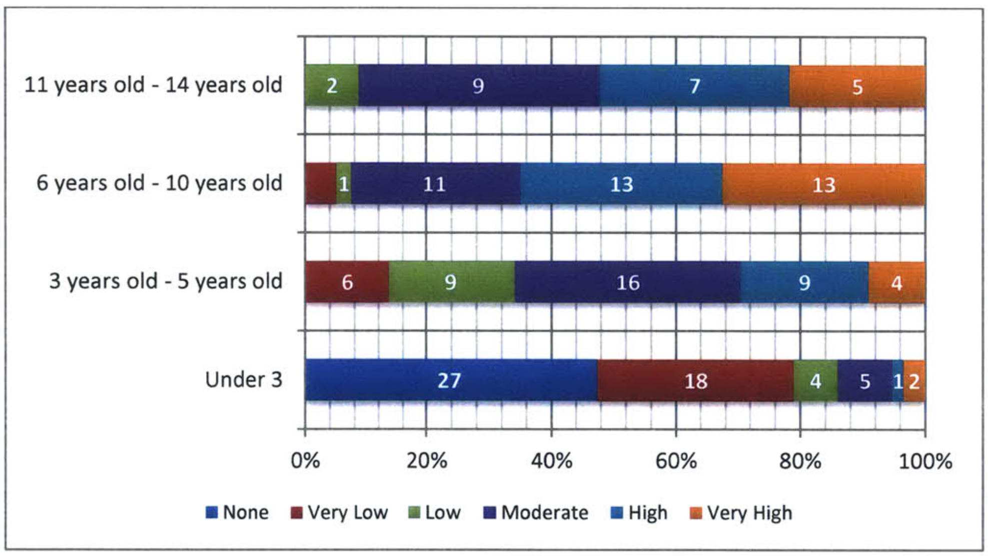

Figure 22: Communication Skills of Children in Different Age Ranges

Children with Special Needs Diagnosis

According to the details provided by the surveyed parents, nine percent of the children were indicated to have a special needs diagnosis. Data also revealed that four percent of the children might have a special needs diagnosis, but it was not formally diagnosed.

Figure 23 shows that within the parents that were surveyed, there was no child under 3 reported to have a special needs diagnosis. This is expected, as most special needs diagnoses are not discovered before the age of 3. ADHD is generally not an issue before the child is in school [39]. Similarly, although children with ASD begin to show behavioral signs at early as six months, the diagnosis is not often made until 24 months. Unless, the child is showing obvious symptoms, parents generally will expect their children to catch to their peers [40]. Majority of the population surveyed are from personal networks in Massachusetts, hence it is expected that children that do have a special needs diagnosis are provided appropriate services in their communities through the educational establishments. In Massachusetts, children with special needs are transitioned into preschool special education in their local communities [41].

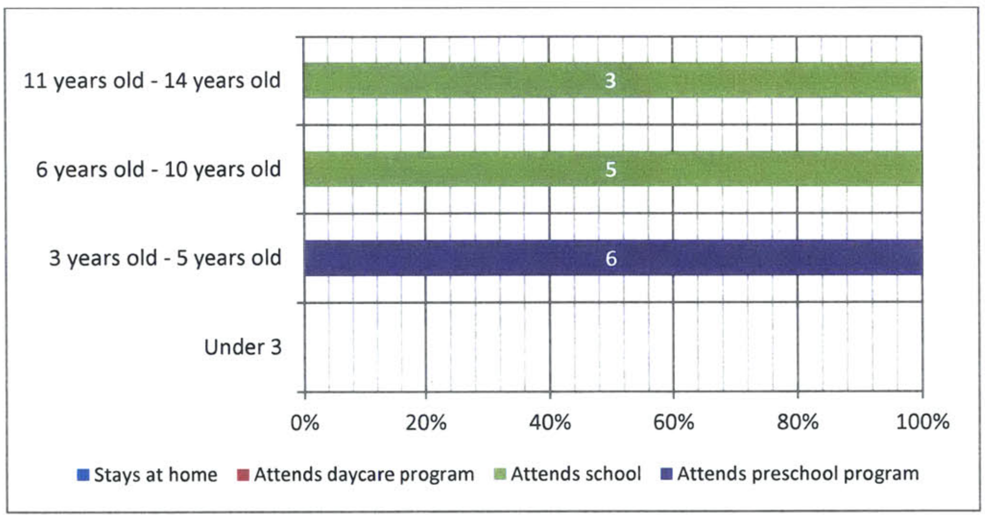

Figure 23: Age Range of Children with Special Needs Diagnosis

The motivation behind this thesis is based on personal experience that children with special needs tend to have communication skills below that of their typical peers. This is validated in the survey results where there is a difference in the communication skills of each age range between children with special needs and children without.

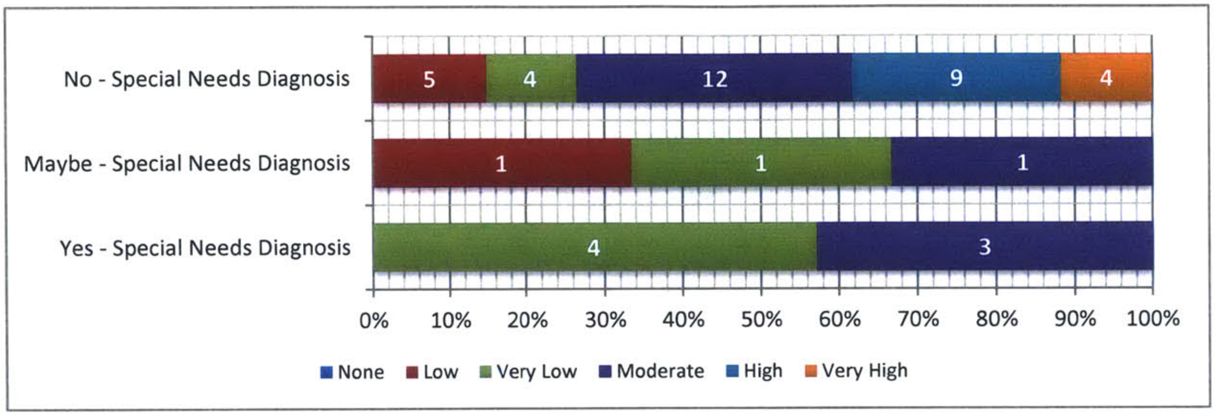

Figure 25: Comparing Communication Skills of 3 - 5 Years Old Children

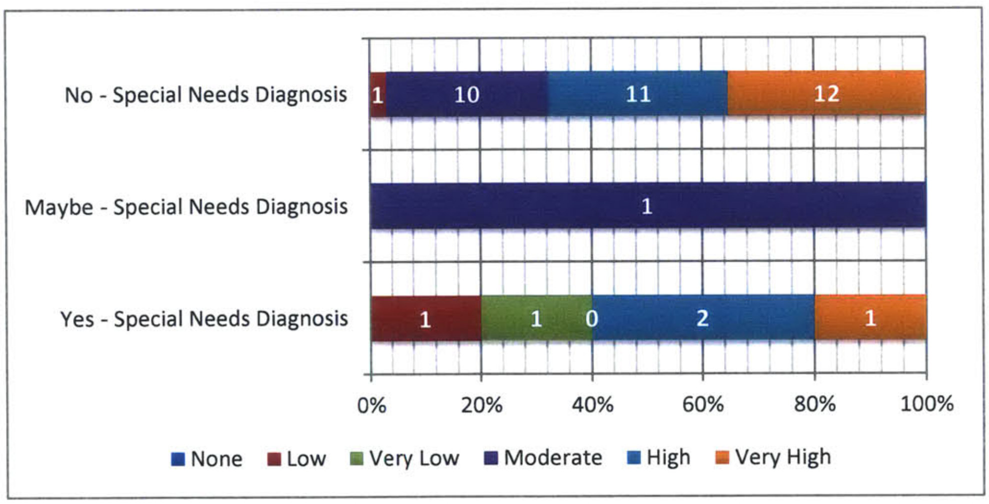

Figure 24: Comparing Communication Skills of 6 - 10 Years Old Children

As seen from Figure 25Figure 24 and Figure 25, parents of children with special needs can definitely benefit from a product that can help bridge the communication gap between them and their children. Children with special needs may not be able to communicate all of the details on their own. However, they often are able to communicate and provide more details with the correct amount of probing or prompting. Therefore, having a mechanism that can provide additional information to parents about their children can help parents begin to have more targeted conversations with their children and the caregivers that their children are with during the day, such as teachers and special education providers.

Section 4 builds on the previous section and asks respondents who had indicated that they had a child with special needs to answer the following questions.

- Is your child able to speak?
- Does your child have autism spectrum disorder (ASD)?
- Does your child have an anxiety disorder such as selective mutism, social phobia or panic disorder?
- Does your child have any sensory problems with certain materials touching their skin?
    - Provide a list of the materials causing the sensory problem.

Communication about Children

Section 5 of the survey seeks to understand the communication that primary caregivers have with caretakers of their children during the day when their children are not in their presence. This was accomplished through the multiple choice questions below.

- How often do you worry about your children when they are not in your presence?
- How often do you check on your children during the day when you are away from them?
- What method do you most commonly use to check on your children?
- Do your children receive a communication folder or slip from their school or daycare on details of their day?

50% of parents worry about their children sometimes and 28% worry about their children most of the time or all the time.

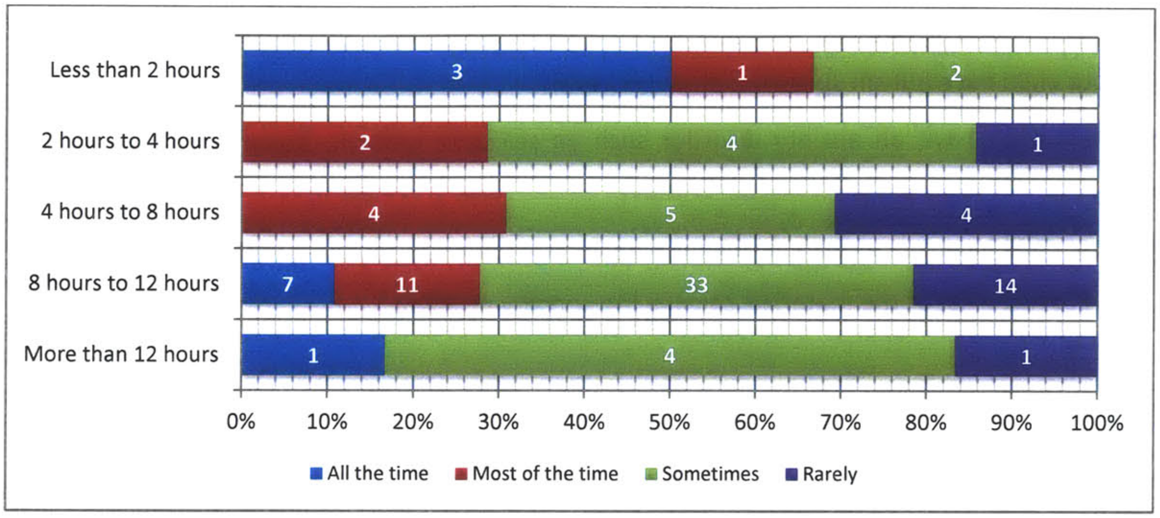

Figure 26: Percentage of Parents Worrying about Children during the Day

Furthermore, looking at Figure 27 it can be seen that 36% of parents are not able to check on their children during the day unless there is an emergency situation. The remaining 64% check in on their children at least once a day. Over 52% of the parents check on their children with a phone call and 27% check on their children with a text message as seen in Figure 28.

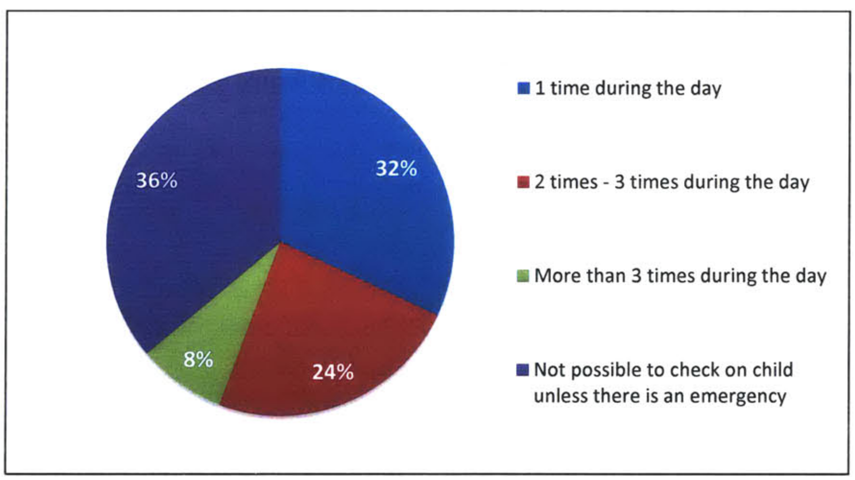

Figure 27: Frequency of Check-Ins on Children

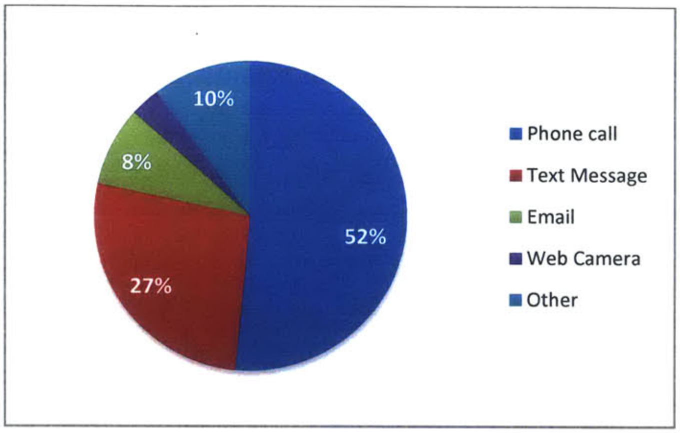

Figure 28: Communication Methods Used to Check on Children

Caregivers Interest in Child's Physiological Data

Section 6, 7, 8, 9 and 10 were questions directed to determine if parents would be interested in obtaining physiological data that may be related to their child's physical or social behaviors.

Stress

Section 6 asks the respondent if they would be interested in getting information when their child is experiencing high stress and anxiety. This is done through the following questions.

1. Do you have a child that has tantrums or meltdowns?
2. Do you know what normally causes the tantrum or meltdown?
3. Are you interested in knowing if your child is experiencing a high stress situation?
4. Would you like to be notified, when your child experiences this?

It is common for young children to throw temper tantrums. However, children with ASD have meltdowns that are different from tantrums. During a meltdown, a child does not consider their own safety or the safety of others around them [42]. This is different from a child throwing a tantrum, where they will ensure they do not get hurt while doing it. During a meltdown a child experiences physical stress on their body as well as mental stress [42]. When a child with autism has a meltdown the reasons for the meltdown are not always obvious. This can be really frustrating and stressful for a parent or caregiver when this happens in a public setting. A child that is throwing a tantrum also exhibits signs of physical stress.

In the population that was surveyed, 37% of parents indicated that their children experience tantrums or meltdowns. From Figure 29 it can be seen that 9% of parents rarely know the cause of their child's tantrum or meltdown and 34% of parents sometimes know the cause.

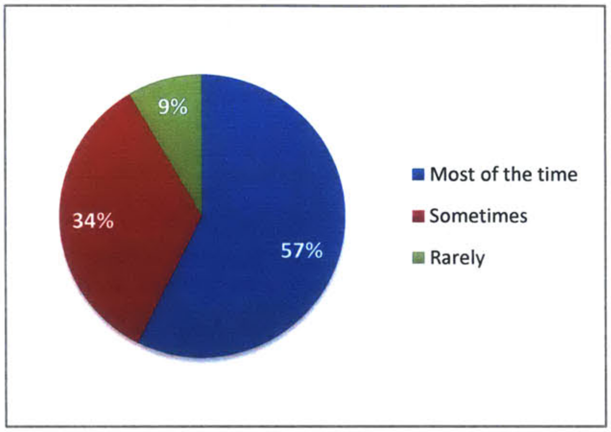

Figure 29: Knowing the Cause of Child's Tantrum or Meltdown

There are other factors which can cause a child to experience stress and/or anxiety. This could be due to a writing a test, experiencing bullying, speaking in a front of people, trying something new, etc. In these situations, the stress that is being experienced is not obvious to the child or those around him. It can often get classified as nervousness or fear.

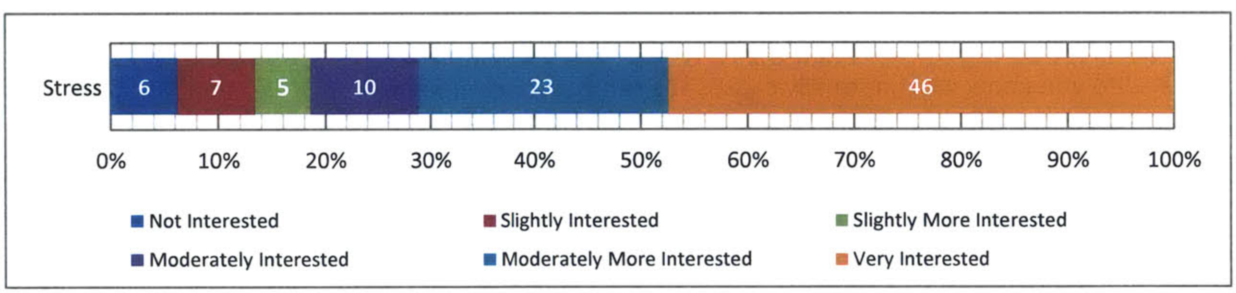

Figure 30: Interest in Knowing About Stressful Experience

More than 80% of the surveyed parents were moderately interested or higher in finding out if their child is experiencing a stressful situation. More interestingly, 88% percent of the parents wished to be notified if their child was experiencing such a situation.

Heart Rate

Section 7 seeks to understand if primary caregivers would be interested in getting information when their child is experiencing elevated heart rate or an abnormal heart rate. This was done through the following questions.

1. Are you interested in knowing if your child's heart rate is going outside the normal range?
2. Would you like to be notified, when your child begins to experience this?

It is possible that a child experiences a heart rate that is out of the normal range of what is expected for his/her age due to several factors. This could be due to a stressful situation, excitement or intense physical activity. Some of situations might be perfectly normal and the body is behaving as expected. Unless the child reports that they are feeling ill or it is severe enough for people around them to notice that something is wrong, elevation in heart rate may be overlooked. Having this data will get the conversations started, especially when the data about heart rate is combined with other meaningful data such as location and time of day.

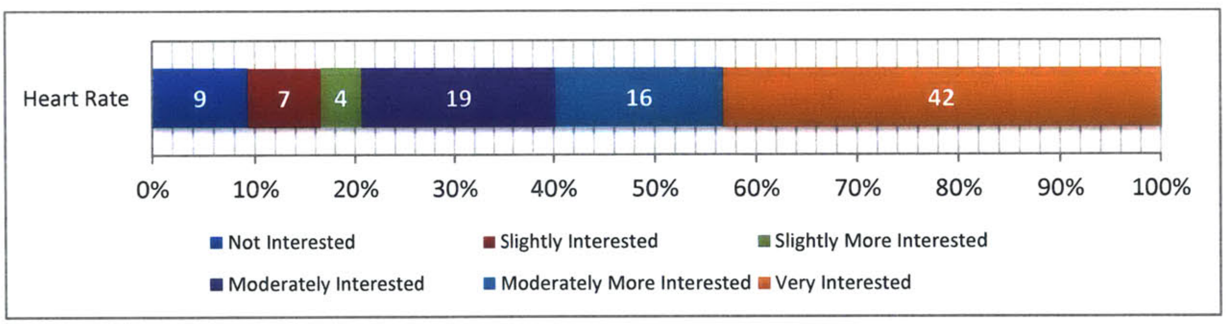

Figure 31: Interest in Knowing About Elevated Heart Rate

More than 80% of the surveyed parents were moderately interested or higher in finding out if their child is experiencing abnormal heart rates. In addition, 77% of parents wished to be notified if their child was experiencing such as situation.

Body Temperature

Section 8 seeks to understand if primary caregivers would be interested in getting information when their child is experiencing an evaluated body temperature. This was done through the following questions.

1. Are you interested in knowing if your child's body temperature is going outside the normal range?
2. Would you like to be notified, when your child begins to experience this?

Change in body temperature is one of the four vital signs doctors watch. Trending upward change in body temperature could mean the child could be fighting an infection and trending downward change in temperature could be due fast breathing due to an asthma attack [25]. Especially with a younger child or a child with limited communication, this information can help inform why the child might be extra cranky or refusing to eat or drink.

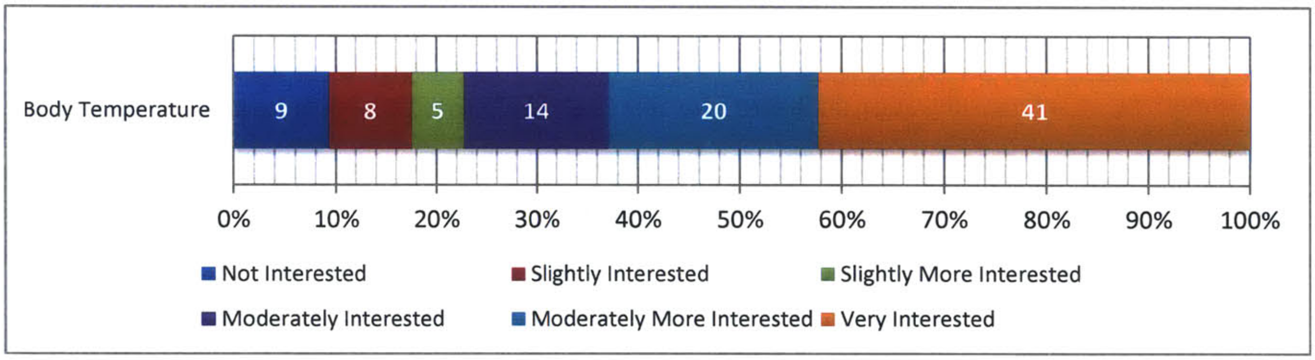

Figure 32: Interest in Knowing About Body Temperature

Around 78% of the surveyed parents were moderately interested or higher in finding out if their child is experiencing abnormal changes in body temperature. In addition, 77% of parents wished to be notified if their child was experiencing such as situation.

Respiratory Rate

Section 9 seeks to understand if primary caregivers would be interested in getting information when their child is experiencing a low respiratory rate. This was done through the following questions.

1. Are you interested in knowing if your child's respiratory rate is going outside the normal range?
2. Would you like to be notified, when your child begins to experience this?

When a child is experiencing anxiety they can experience shortness of breath [] due to hyperventilation. As well, a child with a known history of asthma could be experiencing an exacerbation, which has led to the change in respiratory rate.

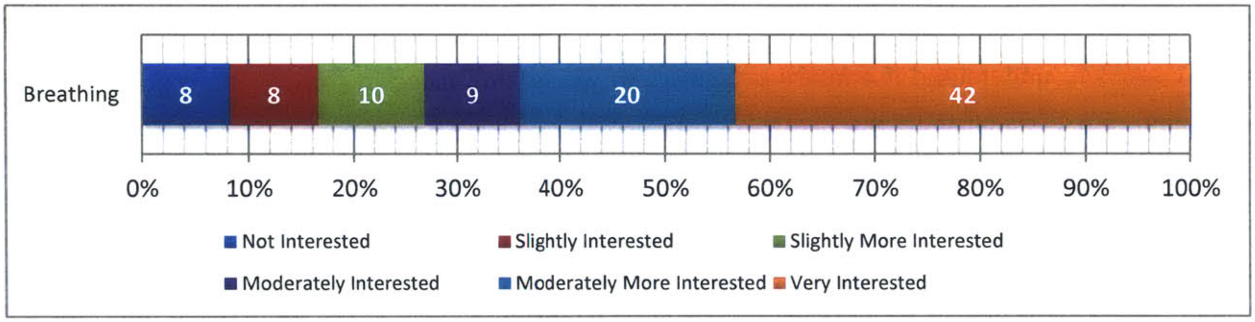

Figure 33: Interest in Knowing About Breathing

Around 70% of the surveyed parents were moderately interested or higher in finding out if their child is experiencing abnormal changes in body temperature. In addition, 74% of parents wished to be notified if their child was experiencing such as situation.

Location

Section 10 seeks to understand if primary caregivers would be interested in getting information when their child location. This was done through the following questions.

1. Do you currently have a way of monitoring the location of your child?
2. Are you interested in knowing the location of your child?
3. Would you like to be notified if your child is not in their expected location?

Based on the survey results 20% of respondents have an existing way of monitoring the location of their children.

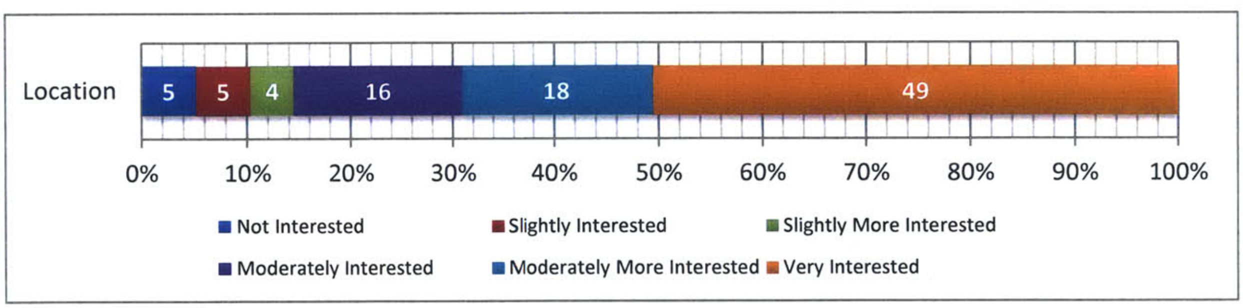

Figure 34: Interest in Knowing About Location

In analyzing the results at least 85% of parents wanted a way to monitor the location of their children. Furthermore, 94% of parents wanted to be informed if their child was not in their expected location.

Physical Activity

Section 11 seeks to understand if primary caregivers would be interested in getting information when their child physical activity levels. This was done through the following questions.

1. Do you currently monitor the physical activity level of your child?
2. Are you interested in knowing how physically active your child is during the day?
3. Would you like to be notified if your child is not meeting the expected level of physical activity?

Based on the survey results, 30% of respondents monitor the physical activity level of their children and only 70% of respondents are interested in being informed if their child is not meeting expected levels.

Ranking of Collected Data

Figure 35 shows the ratings that respondents provided for wanting to know the about their children. Parents were the most interested in finding out the location of their child and then followed by finding out if their child was experiencing a stress situation. Finding out abnormalities in breathing, heart rate and body temperature followed third. Figure 36 shows the data on what factors parents wanted to receive notifications about, and these mirrored the interest ratings as expected.

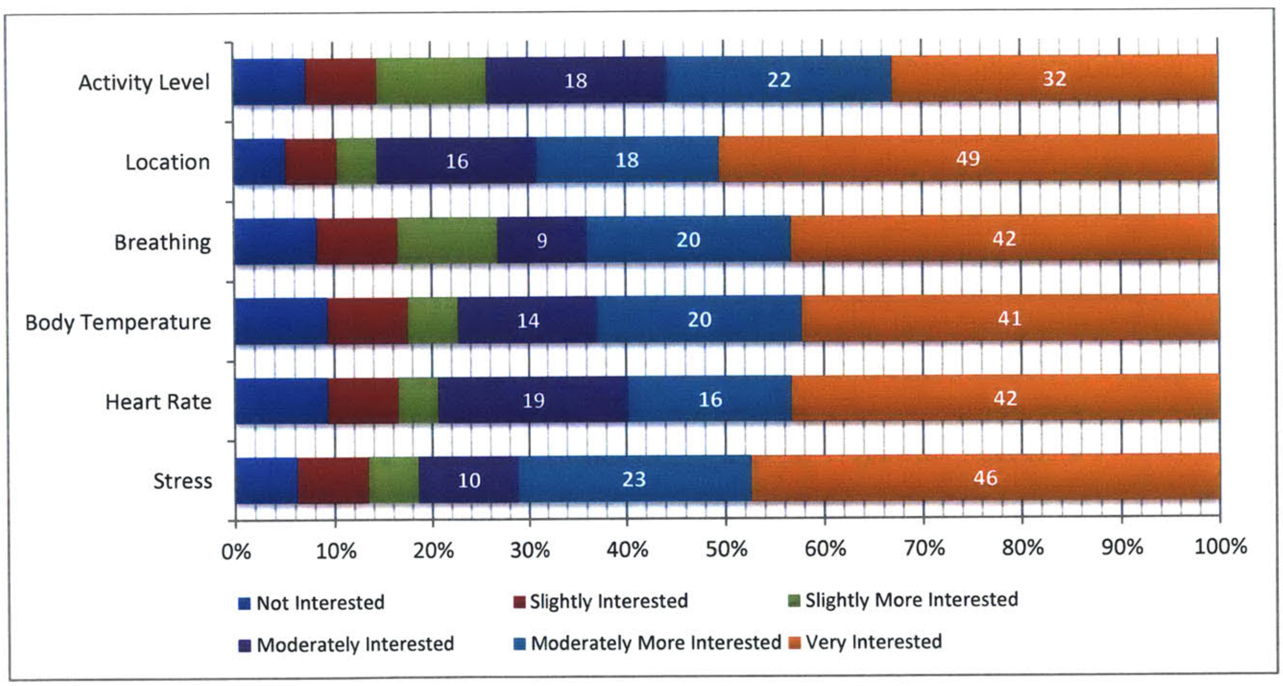

Figure 35: Interest Level of Collected Data Points About Child

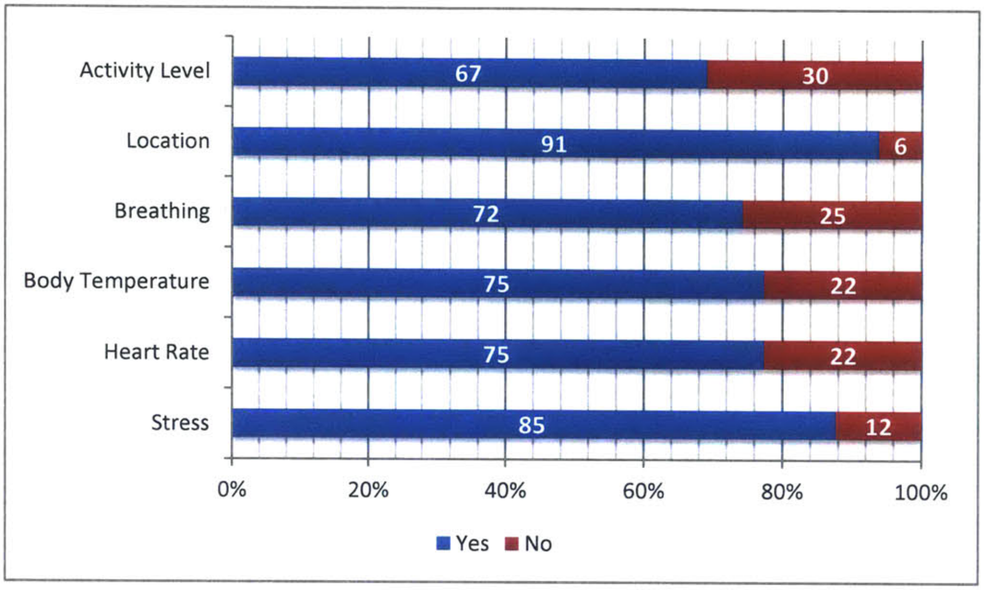

Figure 36: Interest in Notifications About Abnormal Physical Signs

Technology Used By Children

Section 12 looks to understand the technology that is used by the respondent's children through the following questions.

1. Do any of your children under the age 11 have a cell phone?
2. Do any of your children under the age 11 wear a wrist watch?
3. Do any of your children under the age 11 wear a mobile fitness band or health tracker device?
    - Examples provided such as FitBit, Jawbone, iFit, Apple Watch, etc.

Understanding the existing technology being used by children will help with selecting architecture for product design.

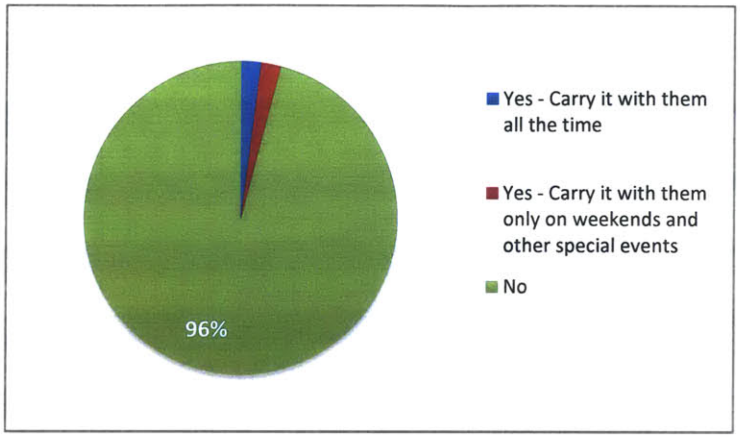

Figure 37: Children With Cell Phones

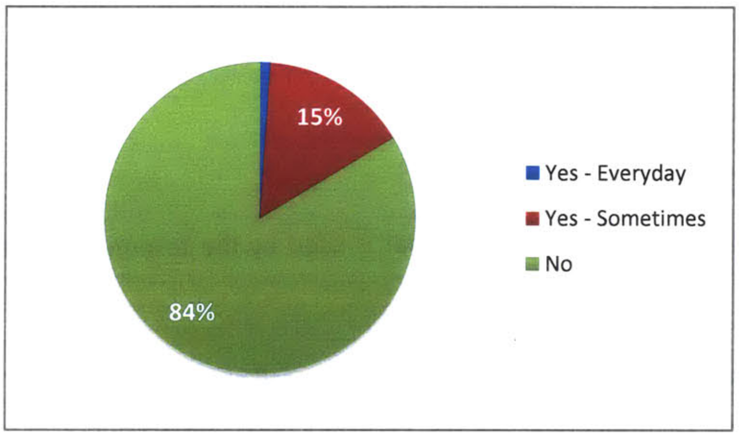

Figure 38: Children Wearing Wristwatches

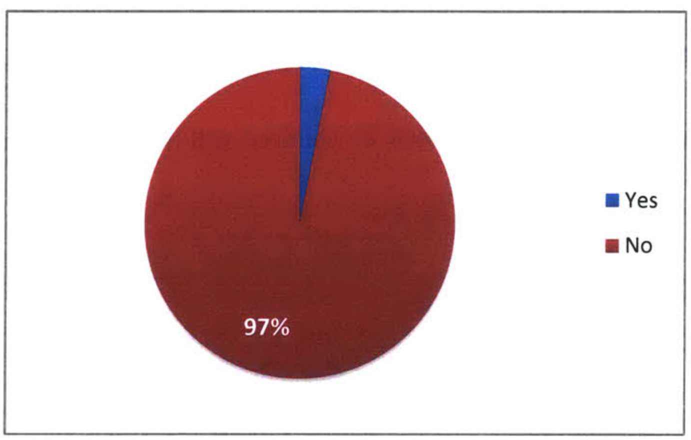

Figure 39: Children With Fitness Bands or Health Trackers

From the information collected from the survey, it can be seen that 96% of children do not carry a mobile phone with them. Most wearable devices available currently fall into the smart accessories category [5], which means they need to connect to an IP-connected device such as a smart phone to fully function and transmit data.

Only 3% of the surveyed children wore an existing fitness product 84% of these children wore wrist watches. Hence, these are factors to consider when designing a product that can be safely used by children without disrupting their daily activities.

Preliminary Product Research

The final section, Section 13 looks to understand the interest level in a product that can communicate details about their children when they are not in their presence through these questions.

1. Would you buy a device that your child can wear to capture all this information?
2. How would you like to receive the information collected about your child?
3. Would you be interested in seeing real-time information?
4. If your child is experiencing something that's not normal ex. elevated heart rate, what type of notification about your would you be interested in? Check all that apply.

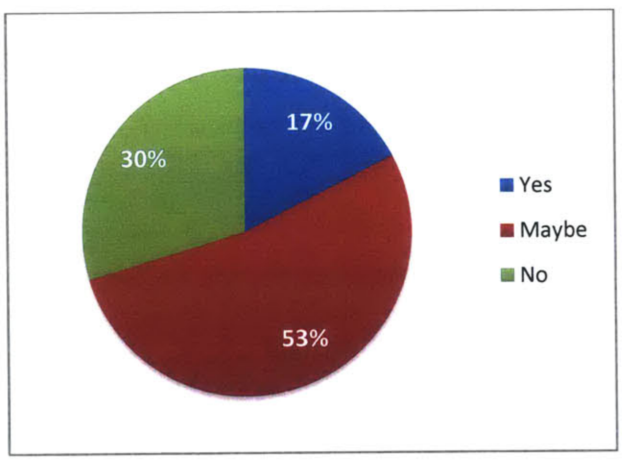

Figure 40: Interest in purchasing a device that captured child's data

To understand whether there would be a market for such a device, it was important to see how many parents would actually be interested in such a device. From the results 53% of parents said they may buy such a device and 17% of parents said they yes to buying such a device if it exists. It is important to keep in mind, these preliminary answer is based on providing no technical or pricing information about the device at all.

Most parents were interested in receiving real-time data and the methods they preferred were text message and mobile application notification.

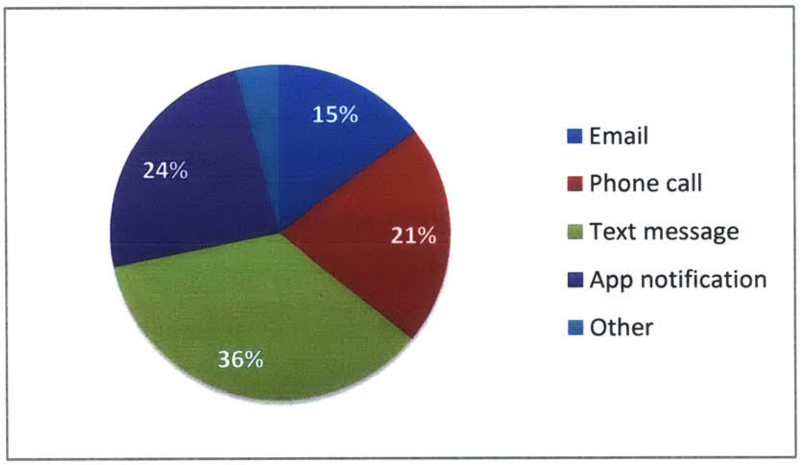

Figure 41: Preferred Notification Method for Parents

6 - Proposed Device

The survey results validate the hypothesis that parents are in interested in finding out more information about their children when they are not in their presence. In addition to understanding their child's physiological data, parents are also interested in finding out their child's geolocation. Furthermore, there was no significant difference between the parents who had children with special needs and parents with typical developing children when it came to receiving additional information about their children.

Collecting children's physiological data and their geolocation are foundation to gaining insight into their physical and social behaviors. Data collected for tracking heart rate and body temperature is much easier to interpret than the other inputs. These two markers are direct outputs of the human body and have predefined ranges. Respiration rate can be tracked using the pulse oximetry sensor with calculations [43]. Figure 432 and 43 provide ranges which can be used as thresholds. Stress was the factor as indicated in the survey results, parents were most interested in finding out.

Age (year)	Respiratory Rate (breaths/min)	Heart Rate (beats/min)
<1	30-60	100-160
1-2	24-40	90-150
2-5	22-34	80-140
6-12	18-30	70-120
>12	12-16	60-100
Lower limits of systolic pressure†		
0-28 days: 60 mm Hg 1-12 months: 70 mm Hg 1-10 years: 70 mm Hg + (2 times age in years)		

Figure 42: Range for Vitals for Children [44]

Measurement method	Normal temperature range
Rectal	36.6°C to 38°C (97.9°F to 100.4°F)
Ear	35.8°C to 38°C (96.4°F to 100.4°F)
Oral	35.5°C to 37.5°C (95.9°F to 99.5°F)
Axillary	34.7°C to 37.3°C (94.5°F to 99.1°F)

Figure 43: Temperature Ranges for Children [48]

Understanding Stress

Stress can affect anyone who feels overwhelmed and all children experience level of stress throughout their childhood. Stress is often a function of the demands placed on an individual balanced out by that individual's ability to meet them [44]. Stress for children can be caused by academic and social pressures along with pressures felt due to the family dynamic in the home.

Children with autism or developmental needs typically experience stress more than their neurotypical peers due to their physical and/or mental condition. For some children with autism, when there is too much sensory information to process, such a busy mall or amusement park, they experience high stress, which leads to a meltdown[42][45]. For children with communication delays or needs such as stuttering, lisping or lengthy pauses, stress can be experienced when they are trying to express themselves to others, further exacerbating their difficulties leading to a vicious cycle [46].

Stress can be measured by analyzing the child's Heart Rate Variability (HRV) or Electro Dermal Activity (EDA). Stress is typically measured by using both blood pressure and heart rate. HRV is the variation between heartbeat intervals. When a person is mentally stressed, their HRV will decrease. EDA measures skin conductance which is based on the state of sweat glands. Sweating is controlled by the sympathetic nervous system hence skin conductance can be an indication of psychological and physiological arousal.

Hence, it would be best to use both types of sensors to validate the occurrence of stress. With the GPS locators, parents can understand the location that the occurrences are happening, whether it is during recess on the playground or during a particular activity at school.

A beneficial factor is that parents can begin to see the signals as they trend. This will help especially for tracking and identifying the stress factors and scenarios leading to meltdowns.

Form Factor

As presented in Chapter 4, analysis done by information agencies on the growth of wearables show that wrist worn device will have the greatest market share. Within the category of wrist-worn devices, smart watches will continue to grow in popularity. Hence, when considering the form factor for this device, it is important to keep these trends in mind. However, the most important factor is the users of this device, whom are young children. It is important that this wrist-worn device does not disrupt the children from their daily activities especially during school or other establishment of educational learning. There have already been many studies done on the use of smartphones in schools by students and the distraction that it presents. A smart watch has the ability to run multiple applications on it will inherently present a distraction to children. Therefore, the best form factor to go with for this device is a simplified watch that is a smart wearable. The device needs to be a smart wearable, because it needs to function autonomously and independently [5]. Most importantly it has to have the capability to connect to the internet wirelessly on its own. The following is the proposed form factor for the device and further details about this device are explained in the following subsections.

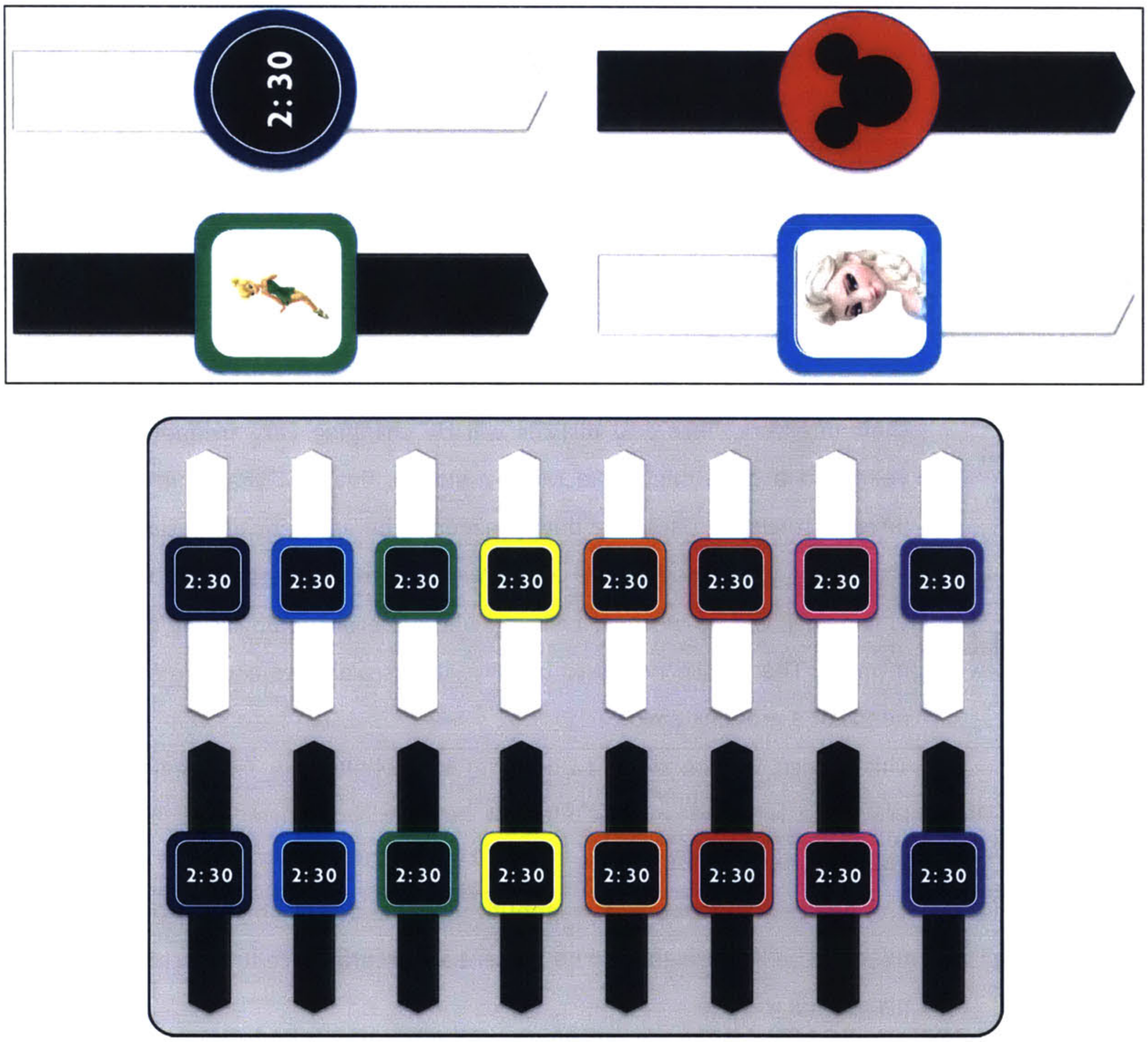

Figure 45: Form Factor for Proposed Device

Product Requirements

The proposed device has been crafted based on the following high level product requirements.

Requirement	Description
Durable	This device is being designed for children under the age of 10, who move around a lot and engage in lots of play and physical activities. This device should be durable enough to withstand this and not present any interference.
Cost	This device should be reasonably priced so that it is affordable for parents. The children who will be wearing this device are young and likely not careful as one would expect for a costly item. In the scenario of the complete device or parts of the device were to be lost, it needs to be replaceable.
Safe	This device will be worn by children throughout the whole day. The device needs to be safe to wear. It should have rounded surfaces so that it does not injure the child. The electronic components in the device should also be tested for safety.
Aesthetically Extensible	This device will be won by children who are highly impressionable, and their interests, likes and dislikes will be changing very frequently. At 3 years old a child might like Mickey Mouse, but at 4 years old the new interest might be Cars. The device needs to be aesthetically extensible, so that it can accommodate the constantly changing interest of a young child.
Physically Scalable	This device will be worn by children who are growing physically every few months. The device needs to be physically scalable to accommodate the needs of a growing child.
Long Battery Life	This device will be worn throughout the whole day. The device needs power to function and therefore it needs a long battery life to remain powered throughout the day.
Lightweight	This device will be worn throughout the whole day by children. The device needs to be lightweight and no present any interference to the child during his normal routine.
Inconspicuous	This device will be worn by children while they are at educational establishments. This device should not distract the child from learning or attract unnecessary attention from other children or adults.

Functional Requirements

The proposed device has been crafted based on the following high level functional requirements.

Requirement	Description
Heart Rate Monitoring	This device should be able to accurately monitor the child's heart rate from the wrist.
Body Temperature Monitoring	This device should be able to accurately monitor the child's skin temperature from the wrist.
Electro Dermal Activity Monitoring	This device should be able to accurately monitor the child's EDA from the wrist.
Oxygen Level Monitoring	This device should be able to monitor the child's oxygen level from the wrist.
Stress Monitoring	This device should be able to monitor the child's stress level using the data collected by the other sensors.
Location	This device should be able to monitor the child's location throughout the day.
Storage	This device should have flash memory large enough to store 1 week worth of data locally on device. This is important in the scenario, the device is unable to connect to the internet and offload data to the cloud.
Data Transmission	This device should be able to transmit the stored data through the internet to the cloud for analysis.
Connectivity	This device should be able to connect to the internet with 3G or 4G/LTE capability. As informed by the survey, the target user group do not own or carry smartphone.
Data Analysis	The data transmitted to the cloud should be analyzed in real-time by the system to be able to notify parents of abnormal behavior.
Send Parental Alerts	The system should be able to alert the parents through a mobile application if their child is experiencing abnormal situation.
Self-Learning	The system should be able to analyze the incoming sensor data and adapt the calculations. Example: The child has a higher heart rate during gym class every day. The system should recognize the pattern and not flag this as abnormal behavior.
Alert Sensitivity	The system should allow parents to set the sensitivity of the alerts. Some parents might not want to be alerted unless something is severely out of range, while others might want to set the alerts as data is beginning to trend in a certain direction.
Trend Analysis	The system should be able to provide trend analysis based on the data collected day over day for the child.

Device Architecture

Based on the high level product requirements, the following device architecture is proposed. The wrist device can be broken down into five individual components. Each of these components are customizable to the child's expectation.

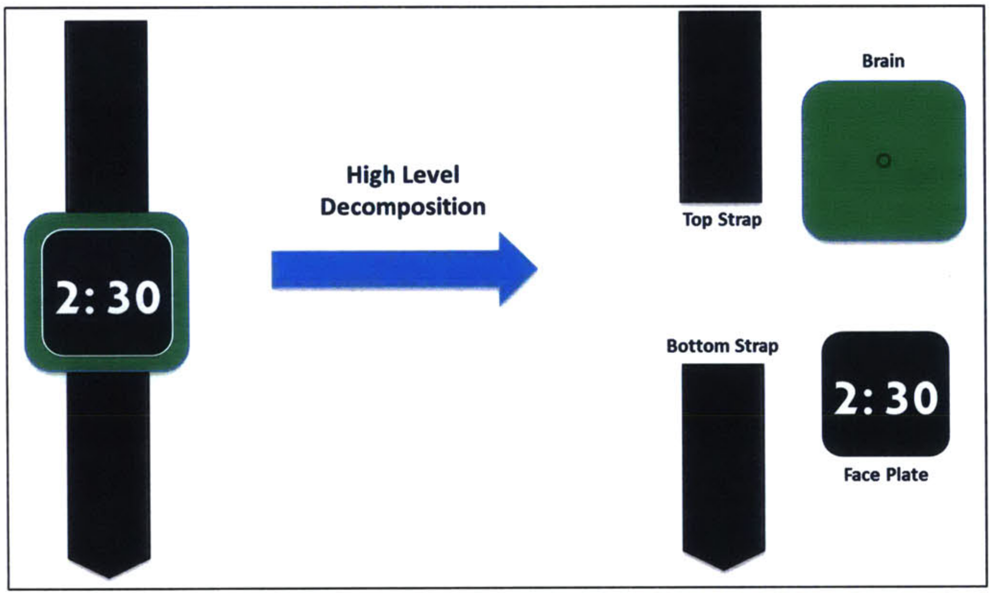

Figure 46: Proposed device architecture

Brain

The Brain houses all the key components to make this device work. This is the most imporant and most expensive part of the entire device. The brain block encases the sensors, processor, power and connectivity components.

Face Plate

The Face Plate allows the device to be aesthetically extensible. The Face Plate sits connected to the top of the Brain. The Face Plate can be simple digital watch that tells the wearer the time, or it can be the child's favorite character if the licensing is approved.

Top & Bottom Strap

The Top & Bottom Strap allows for the device to be fastened onto to the child's left or right wrist. These two straps would need to come in different sizes to grow with the child. There will be a clasp that connects on the Top Strap to the Bottom Strap. The Bottom Strap has two metal rounded leads which will be required to measure electro dermal activity.

Hardware Architecture

Figure 47 illustrates the architectural breakdown of the hardware for the device. The hardware for this proposed device will be the wrist device that the child will wear.

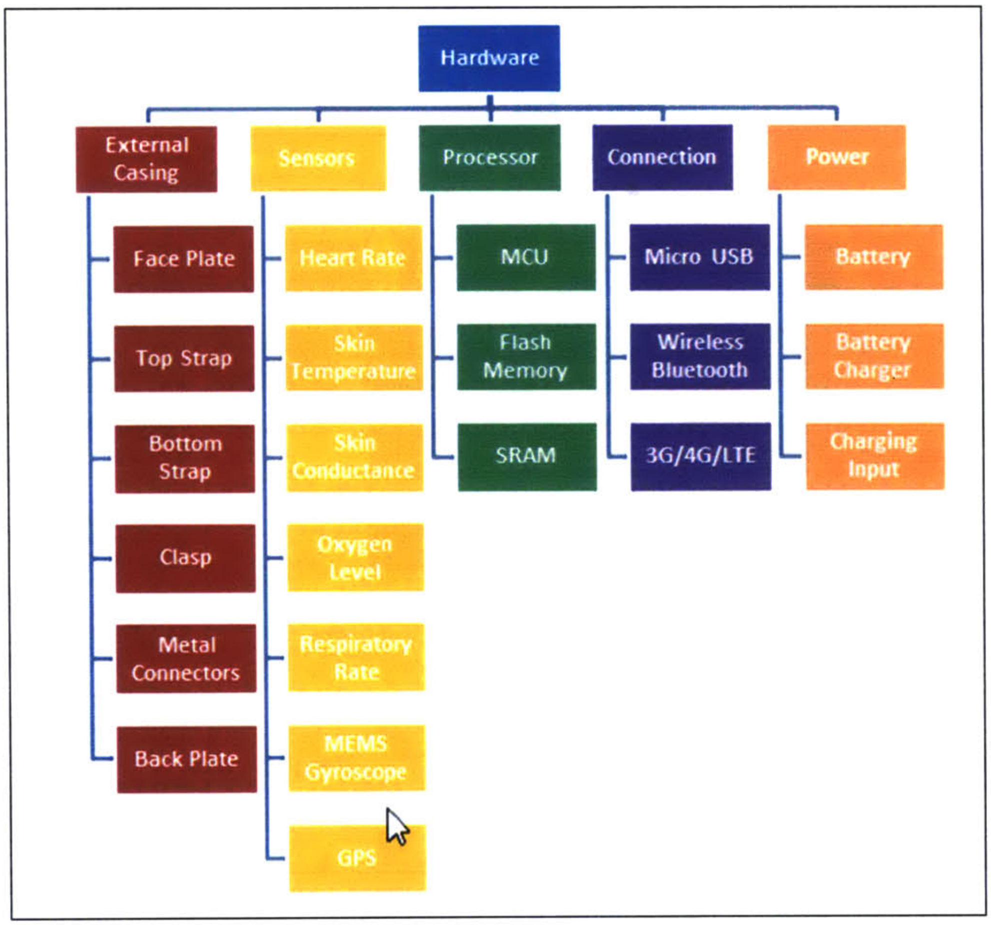

Figure 47: Hardware Architecture

Software Architecture

Figure 48 illustrates the software architecture break down for the device. The collected data from the Wrist Device is transmitted to the cloud. The cloud stores the data and performs analysis on the data to under the trends for the child and provides insight on the child's behaviors. This information is then pushed to the mobile application used by the parent.

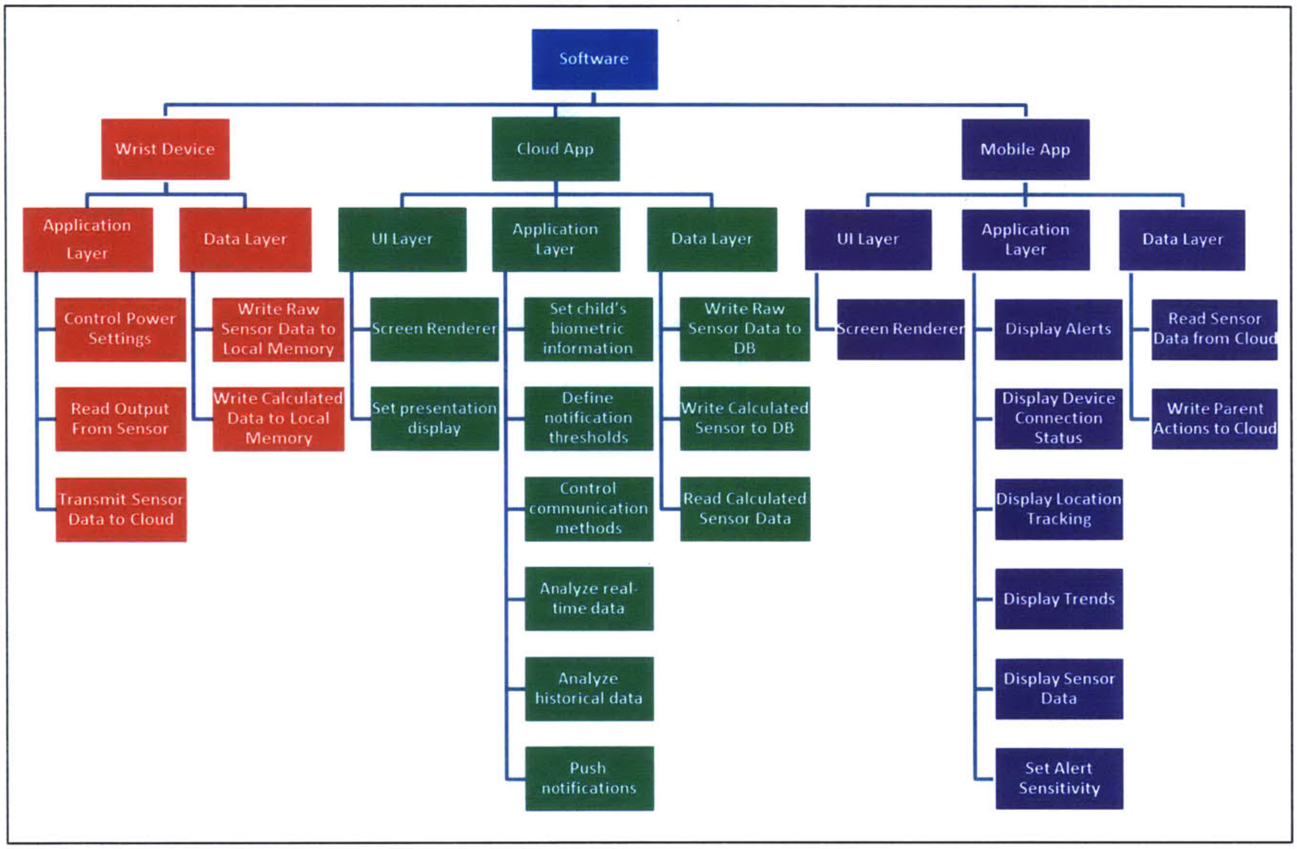

Figure 48: Software architecture

7 - Conclusion

With the advancements in wearable technology, there is an opportunity to use this technology to gain insight into children's physical and social behaviors. Having a comfortable wrist device that can collect data about a child's well-being, can help provide meaningful information to the parents. With additional data, parents can have more informed conversations with their children, as well as those adults that care for them during the day.

For parents with children with special needs, this device will be able to give them information on when their child is experiencing a meltdown and preliminary data to understand the situation, such as the time and place of the occurrence. As more data is collected about a child, the better the system will become in understanding the thresholds of normal and abnormal responses for that child.

Both the hardware and software setup are equally important for the success of this device. However, the real value is in analyzing the data collected from children and presenting it in a consumable fashion to the parents. There are numerous companies developing hardware for wearable devices, and hence there is a possibility to partner with a company that is already developing a device to collect most of these inputs. The focus will then be on developing the software application that will be able to analyze the trends and report the findings, in an easily accessible mobile application.

Existing wearable wrist bands require a smart phone or internet connected device to pair with to transmit data to the cloud. To be able to understand if this device would be successful, it is possible to have first version of the device work with a Bluetooth LTE connection. The data will not be in real time because the child will not always be connected to the paired device. However, even with the delay in receiving data, data can still be collected.

Phase Rollout

In Version 1 of the product, the collected data from the child will be stored locally. Once the child is with the parent, the device can pair with the parent's smartphone to offload the data. The parents can also choose to have the data offload to the cloud, by pairing the device to a smart device such as an iPad or laptop at home with a Bluetooth connection. The data will then be transmitted to the cloud. Once the data is in the cloud, it will be analyzed and results will be pushed to the parents' mobile application.

Version 2 of the product can take connectivity to the next level to provide parents with real-time data. With partnerships with educational establishments, it is possible to the use the school's secured network. While at school, the device can connect with school's WIFI network to transmit data for analysis to the cloud.

In the final product, the device should become a smart wearable and should have the capability to connect to the Internet on its own.

Next Steps

Initial data collection from children was started during this thesis research using the E4 Wristband from Empatica [47]. Empatica had developed a wrist device with uses EDA to measure stress. This test should be continued to collect more data from children. During the experiment, the child will wear the E4 wristband and it will be used to measure heart rate, body temperature, respiratory rate and EDA of the child. Results of this experiment can be found in Appendix A. Further data collection should be used to understand thresholds for readings. Once boundaries are established, alerts and reporting can be developed for parents.

Appendix A – Experiment

This study will be a 90 minute experiment per child, consisting of the following tests. Based on the age and comprehension of the test, it will be adapted slightly during the experiment. During the duration of the experiment wearable sensors will be used to measure heart rate, body temperature, respiratory rate and galvanic skin response of the child.

1. Establish Baseline – Allow the child to get comfortable by letting the child watch their favorite TV program for 15 to 30 minutes on the iPAD. Monitor for physiological changes.
2. White Coat Experiment (3 to 6 years) – Wear a white lab coat and walk into the room after the child has gotten comfortable watching TV. Ask the child to label different body parts and pretend to record on a clipboard. Monitor for physiological changes.
3. White Coat Experiment (6 to 10 years) – Wear a white lab coat and walk into the room after the child has gotten comfortable watching TV. Hand the child a speech consisting of couple sentences and have them read it and pretend to record on a clipboard. Monitor for physiological changes.
4. Color Stroop Test – Have child identify read the color on the index card, although the color of the letters is a different color. Example: The word red is written in the color green. Monitor for physiological changes.

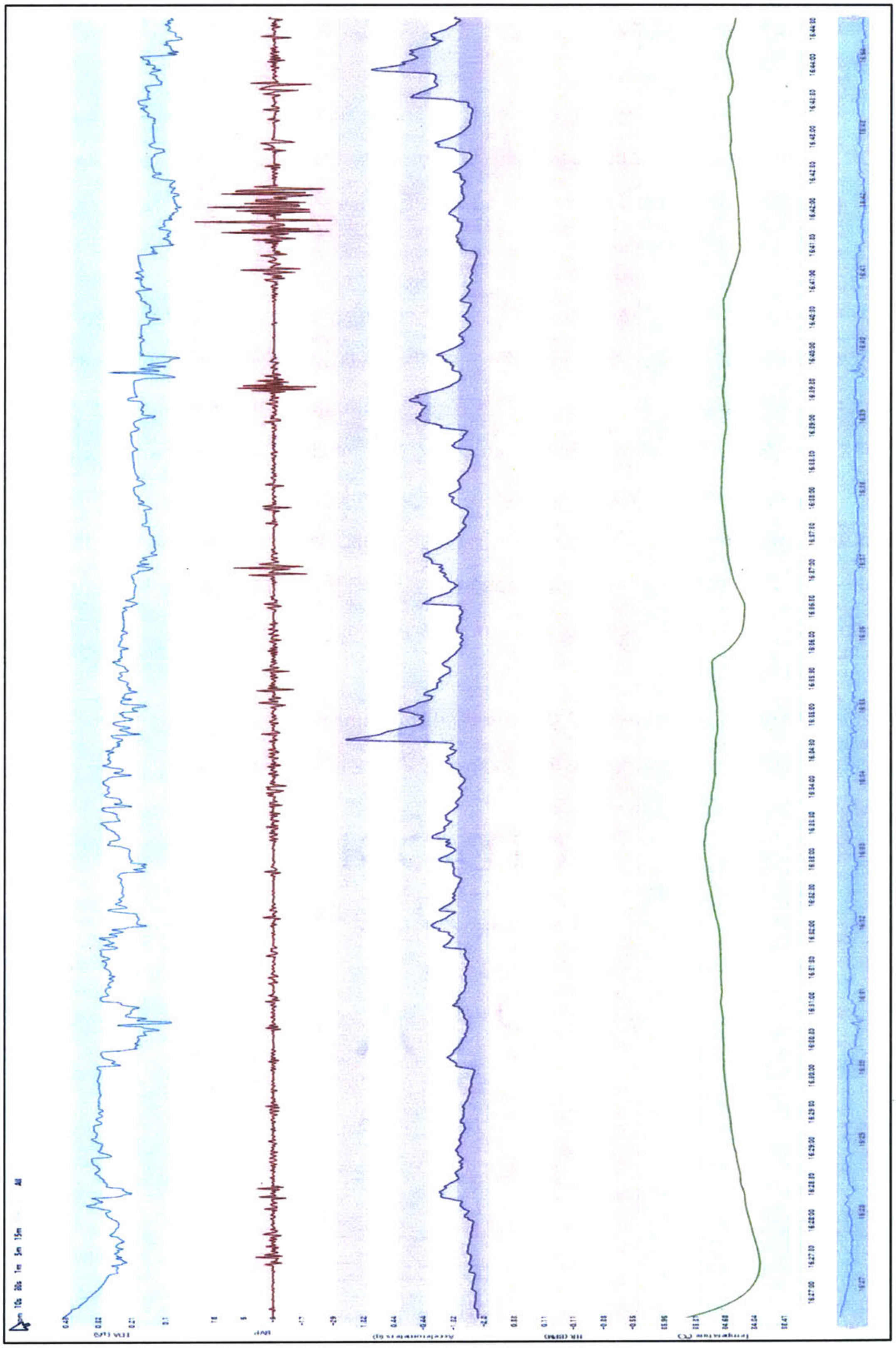

Figure 49: Measurements of 5-Year Old Boy

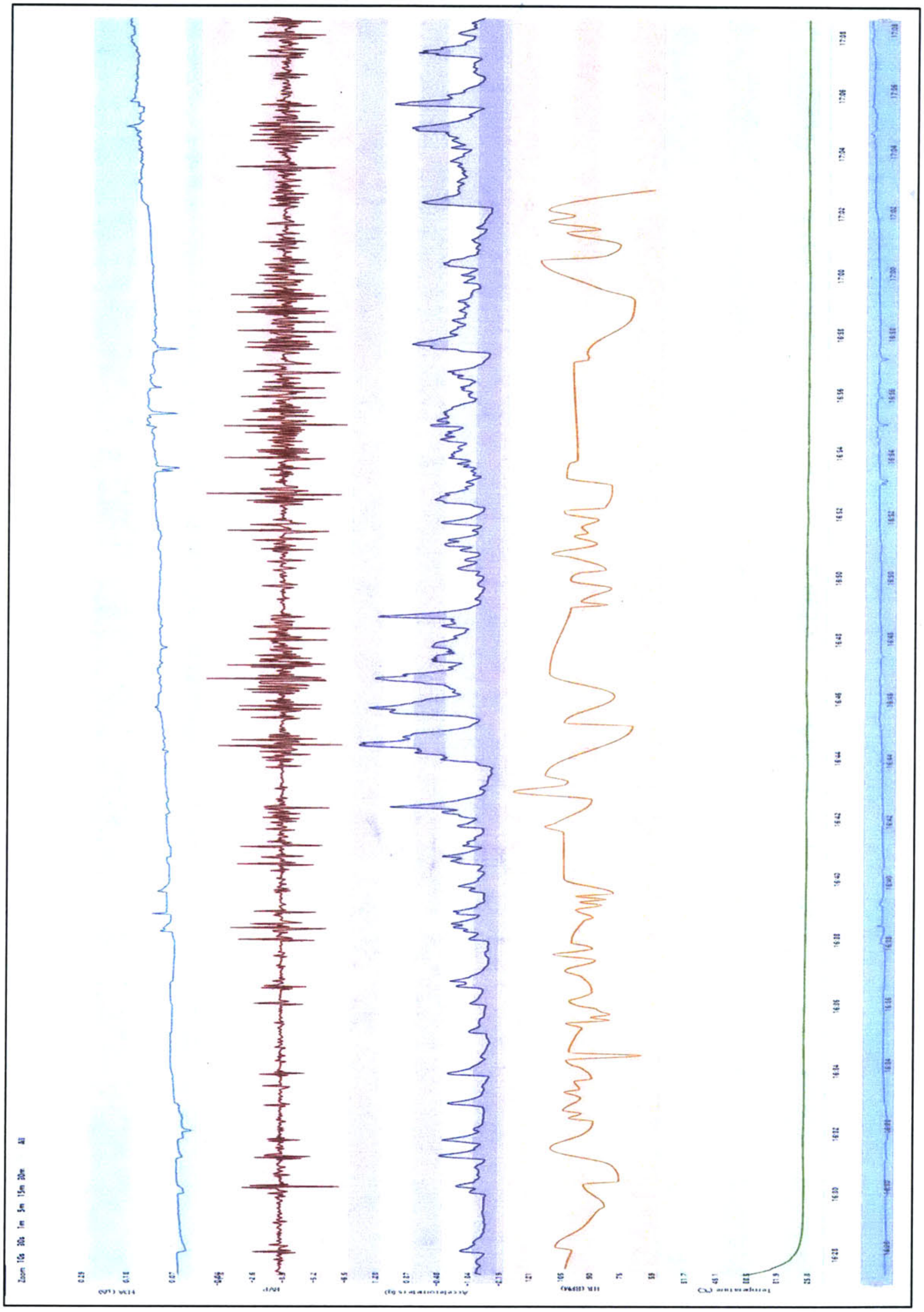

Figure 50: Measurements of 9-Year Old Girl

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