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March 30, 2017

Dr. Andrew Rawicz
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V5A 1S6

Re: ENSC 405 Design Specification for a Wearable Posture Correction Device

Dear Dr. Rawicz,
The following document outlines the design specification for the VertAlign. Meerkat Biotechnologies is designing a wearable device that aims to help improve a user's posture by providing reminders and feedback. Whenever the user's posture drifts out of proper position for a prolonged period of time, VertAlign will notify the user with a light vibration. VertAlign will also be able to send alerts and track data via Bluetooth pairing to an Android application.

The design specification outlines what design choices were made and their justification in regards to physics, ergonomics, and user interface theory. Also included are the test plan appendix and UI appendix. The test plan appendix provides the testing steps to be taken in order to meet the pre-established requirements. In the UI appendix we will cover the design choices and elements specifically related to the user interface elements of the VertAlign.

Meerkat Biotechnologies is composed of five experienced engineering students in their fifth year: Kushank Aggarwal, Erik Hoddevik, Julian Lo, Matthew Malinab, and Jason Park. The team has a diverse skill set as it consists of majors in Biomedical, Computer, and Systems Engineering. Please direct any questions or concerns about our design specification to me by email at mmalinab@sfu.ca.

Sincerely,
Matthew Malinab
Chief Communications Officer
Meerkat Biotechnologies

Enclosure: Design Specification for a Wearable Posture Correction Device

VertAlign by

meerkat
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ABSTRACT

This report provides the design specification for the VertAlign system. Included is the basis for the system's technical correctness, process details, and test plans.

The technical correctness section provides the overall basis for the system's technical background in respect to science and ergonomic design considerations. Specifically, the inner workings of accelerometer and gyroscopes considered for the design is explained. Also, hardware, cognitive and human compatible ergonomic considerations are discussed.

Also, covered in this report are the proof-of-concept design details on hardware circuitry, hardware enclosure, and requirement specifications that we were able to achieve in our mock up design. In addition, the data collected from human trial test plans are outlined in the report.

Finally, user interface appendix discusses the user analysis of the proposed device, considerations for seven stages of action from user interface appendix, analytical and empirical usability testing, graphical presentation, and graphical outline of our proposed designs.

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GLOSSARY

ADC: Analog to Digital Converter
CAD: Computer Aided Design
DAC: Digital to Analog Converter
DPS: Degrees Per Second
I2C: Inter-Integrated Circuit
KBPS: Kilobytes Per Second
MEMS: Micro Electro-Mechanical System
MBPS: Megabytes Per Second
LED: Light Emitting Diode
SoC: System on Chip
MBPS: Megabytes per second
SPI: Serial Peripheral Interface
RGB: Red Green Blue

1. Introduction

Chronic back pain is a significant problem endemic to today's society. Without proper attention, improper postures develop when using computers and phones, and, when sustained, can result in permanent damage to the neck and back. Per the National Institute of Neurological Disorders and Stroke (NINDS), lower back pain was determined, in 2010, to be the third most "burdensome" (in terms of mortality or general poor health) condition in the United States [1]. Only ischemic heart disease and chronic obstructive pulmonary disease (COPD) rank higher. Per the UK Statistics Authority, 9.96 million working days were lost due to back pain in 2014, of which 4.21 million came from people aged 50 - 64 [2]. This number is steadily growing, and can prove to be a worldwide epidemic in years to come.

Our solution to this is VertAlign, presented by Meerkat Biotechnologies. What we believe in, as a company, is that comfort and health in later life can be achieved through good decisions early on. Our goal is to make one of those decisions easier.

1.1 Scope

This design specifications document outlines the technical details and procedures regarding the design for the proof-of-concept model for VertAlign. The document outlines the basic science, hardware, firmware, and software behind the device. References to requirements in this document are listed in the requirements specifications document [3] and justifications will be provided as such. This document will also outline the preliminary testing procedures, performed on volunteers, used to determine postures that will be used in the final notification algorithm.

1.2 Intended Audience

The intended audience of this document includes but is not limited to the members of Meerkat Biotechnologies and potential stakeholders of this product. This document shall be used by all the team members as a guide for the system requirements throughout the development. Potential stakeholders shall refer to this document to evaluate the progress and verify the functionality of the product.

1.3 Project Background

VertAlign is a posture correction device which aims to promote healthy posture in individuals such as office workers with the aim of preventing chronic back pain later in life. Current back pain treatments are inadequate, and aside from invasive procedures such as surgery, only seek to control and alleviate symptoms after they appear. Many such devices have been proposed to combat this issue - the most noteworthy being the Lumo Lift [4], which is magnetically clipped onto an article of clothing. However, certain aspects of the Lumo Lift such as reading accuracy, as well as price, present issues that we aim to resolve to our fullest extent.

VertAlign is simple and intuitive in its usage. The user simply activates the device and wears it around their neck. It is accurate in that, unlike the Lumo Lift, the readings are obtained directly from the shoulder and neck, both major anatomical markers of upper-body posture.

Comfortable enough to be forgotten when worn, VertAlign acquires the positional data in real-time using multiple accelerometers and performs subsequent analysis. The device notifies the user about their bad posture and issues a reminder in the form of gentle vibration to return to good posture.

1.4 Classification

Throughout this document, the following convention will be used to define a requirement:

[Req a.b.n - p]

Where a.b represents the section number, n denotes the functional requirement number and p indicates the priority of the documented requirement in roman numerals.

The priority of the functional requirement is defined as follows:

i -- High priority: this requirement is very essential for the product. A proof-of-concept must meet this requirement.

ii – Moderate priority: this requirement is vital for the marketable product. A prototype must meet this requirement.

iii -- Low priority: this requirement is applicable to iterations of development after delivering a working prototype.

2. Functional Overview

2.1 Ergonomics

In the human factors and usability textbook, it is quoted that "designers need to make things that satisfies people's needs, in terms of function, in terms of usability, and in terms of their ability to deliver emotional satisfaction." [5]. For the requirements to be satisfied, we must consider the ergonomic factors of hardware, cognitive, and human compatibility.

Hardware factors are associated with human-machine interfacing. For example, the location of interface components like buttons and feedback components like visual displays and markings (static and dynamic) must be considered to maximize functionality and ease of operation. Furthermore, we must address other hardware concerns such as the thermal stress of the device enclosure from the battery discharge and recharge. The enclosure must not grow hot enough from the battery that it causes burns or discomfort from the heat. Lastly, the vibration module should not cause discomfort during notifications.

Cognitive ergonomic factors aim to minimize human-perception-related errors, thereby increasing usability, functional reliability, and safety. The feedback provided from the device must be clear and useful to the operation of the device. In our product, the mobile application will provide feedback, collect posture data, and provide positive psychological feedback in the form of metrics and charts that show a user's progress on correcting their posture while using the device.

Lastly, human ergonomic compatibility factors are critical in our design considerations as we are developing a wearable device that must fit with the consumer's body size and shape. VertAlign's current design is shown in figure 2.1 below. The device is 15.25 cm (H) x 16.50 cm (W) x 1.90 cm (D), and is designed, with the average human neck radius in mind, to be worn comfortably around the user's neck. [6] The soft silicon plastic casing allows the device to flex and it will allow users with above average neck thickness to wear it without any excess pressure. Also, we have distributed internal hardware across the entire device to evenly spread the weight across the entire the device. The device itself is made up of light materials and will not exceed a weight of 150 grams. This will minimize strain on user's neck and back from long term usage of the device, which would be detrimental to the posture-correction goals of the device.

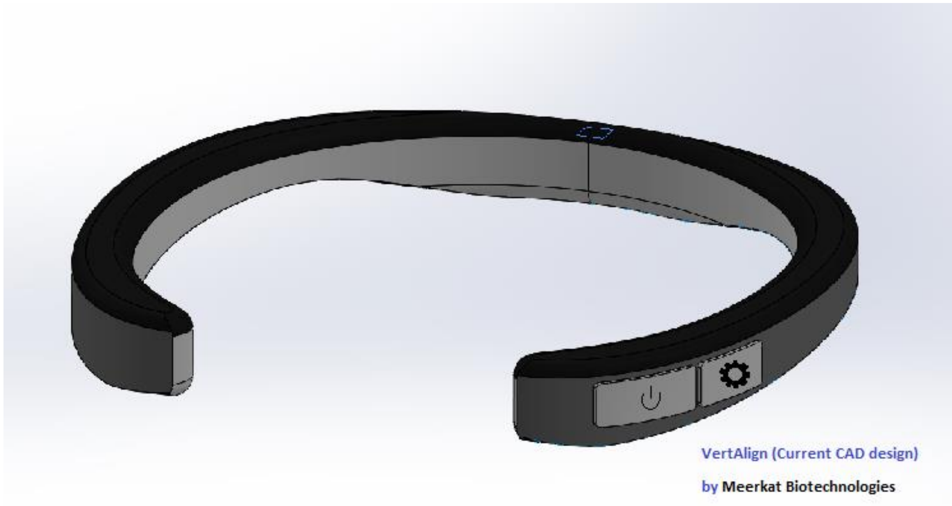

Figure 2.1: CAD Model[1]

[1] current CAD design may not reflect perfectly with the device control configuration outlined in the user interface appendix. The CAD model will need to be modified with changes made in the future design iterations.

2.2 Accelerometers & Gyroscopes

A triple axis accelerometer is a very versatile sensor used to analyze the dynamics of an object. Accelerometers have a wide range of applications including gaming devices, medical instruments, handsets, Hard Disk Drive (HDD) protection and Industrial instrumentation. The gaming industry has demonstrated the use of an accelerometer to determine the spatial orientation of an object with remarkable success.

When the object is sitting still, the acceleration due to earth's gravity (g) is the only acceleration acting on the object. As shown in figure 2.2 below, we will acquire –g in the z-direction from the sensor when the ø and θ angles are zero. In a static setting, if the sensor is oriented with non-zero ø and θ values, g will be given by the vector components of the three principal axes. A triple axis accelerometer measures the three vector components as a separate voltage values. A digital accelerometer then uses an Analog to Digital Converter (ADC) to provide raw data values corresponding to the spatial orientation of the device. Digital raw data is calculated using the formula given in equation 2.1.

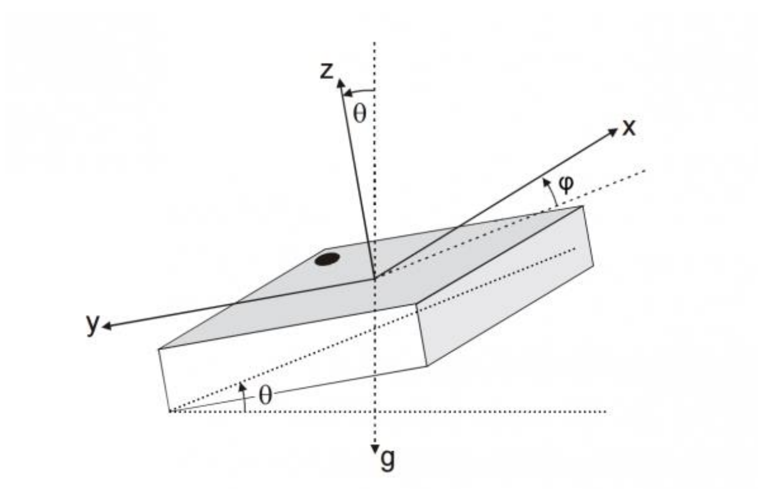

Figure 2.2: Accelerometer Orientation Sensing [7]

$$\frac{Resolution\ of\ ADC}{System\ Voltage} = \frac{ADC\ Value\ (Raw\ Data)}{Analog\ Voltage\ Measured} \tag{2.1}$$

Gyroscopes measure the rate of rotation about an axis with respect to the Earth's surface. Using the key concepts of angular momentum, gyroscopes determine the orientation of an object. A gyroscope is well-suited to record the orientation of a body with high frequency movements like an airplane. An accelerometer is unable to determine the orientation of an object when it is accelerating from anything but gravity, meaning that a gyroscope is more accurate for high frequency movements, and an accelerometer only for objects that stay relatively constant. For the VertAlign, what is important is general trends over a period of minutes, so orientation data from an accelerometer is appropriate for our requirements.

3. Proof-Of-Concept Design

A few fundamental changes in the design have been made since outlining the requirement specification of the VertAlign. We initially proposed implementing three gyroscopes, however in our proof of concept we have implemented 2 accelerometers. Figure 3.1 below illustrates the position of the sensors in the design. Due to a technical limitation, only two sensors were used. This limitation is explained later in the section 3.1.

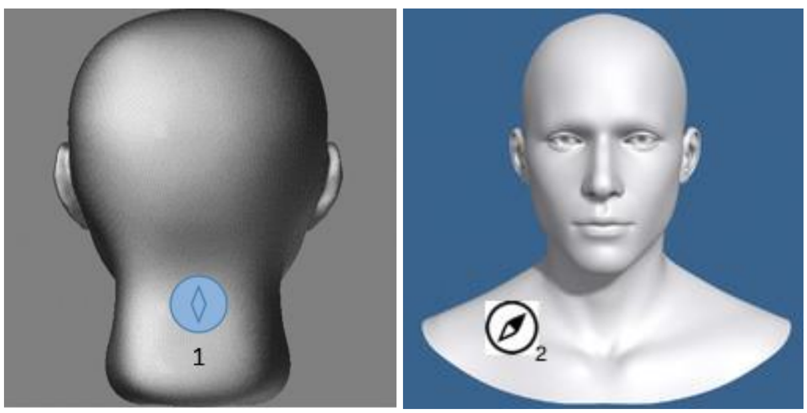

Figure 3.1: Accelerometer Positions [8] [9]

3.1 Hardware Design

VertAlign's proof of concept is a simple design. As shown in Figure 3.2, the two ADXL345 accelerometers embedded in their individual breakout boards are connected to a microcontroller Mega 2560. Both the sensors are powered by a 3.3V DC supply via microcontroller.

ADXL345 is a triple axis MEMS (Micro Electro Mechanical System) type digital accelerometer. Per the datasheet, ADXL345 has a sensitivity of 0.25 degrees in X, Y and Z directions [10]. ADXL345 has a fixed resolution of 10 bits to measure $\pm 2g$. However, a user can scale the resolution to 13 bits to measure $\pm 16g$. Measuring $\pm 2g$ with the given precision and accuracy will meet the requirement specification

[11]. Raw data we have received from the sensor is the ADC Value obtained using the equation 2.1. Since ADXL345 is a digital accelerometer, ADC has been implemented within the IC.

We are sampling the data every 50ms, giving the device an operating frequency of 20 Hz. At this operating frequency, the current which flows through the circuit is restricted between 40µA and 145µA [10].

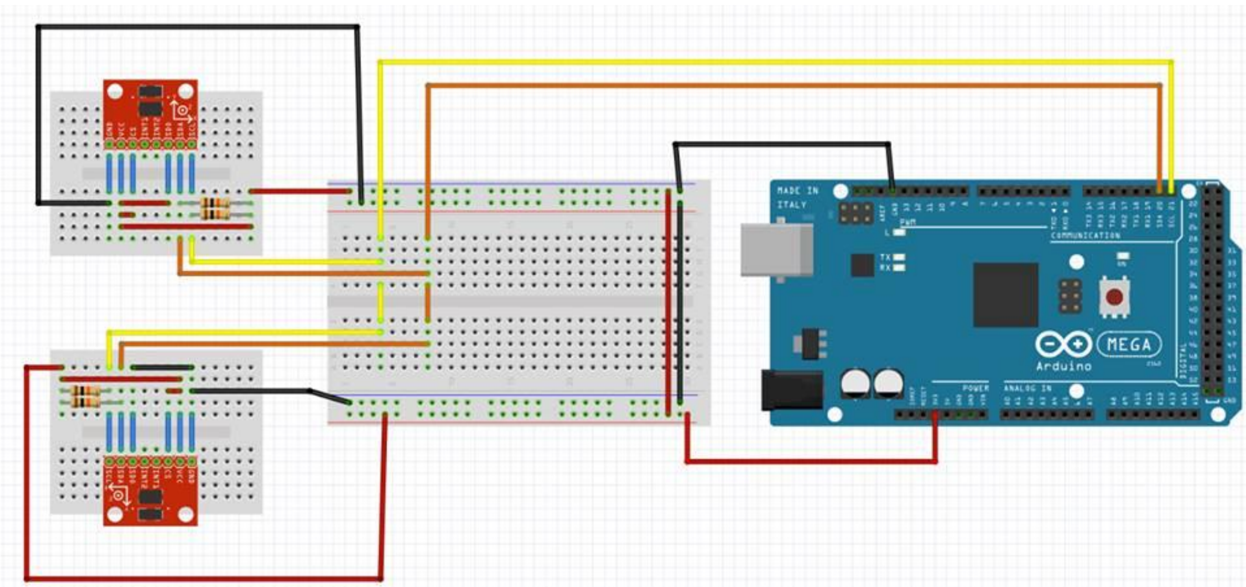

Figure 3.2: Proof of Concept Circuit

The ADXL345 breakout board we have used in the design has the following pins:

BREAKOUT BOARD PINS	DESCRIPTION
GND	Ground
VCC	Supply Voltage (2-6 V DC supply)
CS	Chip Select
INT1	Interrupt 1
INT2	Interrupt 2
SDO	Serial Data Output
SDA	Serial Data Input
SCK	Serial Clock

Table 3.1: ADXL345 Breakout Board Pins [10]

The Chip Select signal enables communication with the master bus and must be high for a sensor to operate. In the design implementation, the CS pin is directly connected to VCC for constant operation.

To control the sensors via master bus, we had a choice between Serial Peripheral Interface (SPI) and Inter-Integrated Circuit (I2C). In an SPI topology, a master device is connected to each slave via four unidirectional wires. One wire is used by a master to send a wake-up signal. Two separate wires are used to read and write data to a peripheral. Since the communication is a synchronous process, the last wire is used for a clock signal. This allows for a very high-speed data transfer rate between the peripheral and the master bus. In general, the SPI protocol transfers data at 100Mbps. If multiple peripherals are connected to a microcontroller, this topology results in a lot of pins during its implementation.

I2C is an elegant communication protocol used for multi master slave communication in a system with only 2 signal wires: serial data (SDA) and serial clock (SCK). Each peripheral has a unique address which is used by the master for identification. The device address for ADXL345 is 0x53. When the desired peripheral is identified, a handshake signal is sent via bi-directional SDA to wake up the device. The same wire is further used to send and receive data from the master. The SCK signal is a clock generated by the master to simply synchronize the data transfer. Since a single wire is used for both reading and writing the data, I2C provides much slower data transfer rate than an SPI protocol, but requires less wires and pins to implement. Furthermore, we implemented pull-up resistors in both SDA and SCK signal lines for proper I2C operation. If multiple peripherals are connected to the same I2C bus, nominal operating voltage in both SDA and SCK signals lines must not exceed 0.3V hence requiring pull-up resistors [11].

To minimize the pins required for SoC design in the next iteration of development we decided to implement the I2C protocol. The only shortcoming of implementing I2C over SPI is reduced data transfer speed. Data transfer rate is usually 100kbps for I2C when a 10k pull-up resistor is used, and our design operates at 20Hz. To meet our design requirements, we must therefore send under 5kb per clock cycle.

Per the datasheet, ADXL345 has two device addresses: 0x53 and 0xD1 [11]. The initialization of either address is determined by the SDO pin on the breakout board. In our implementation, one ADXL345 responds to 0x53 by pulling the SDO pin down to ground. By connecting the SDO pin on the second ADXL345 to VCC, the address is read as 0xD1. To implement a third ADXL345 with the same microcontroller there is no unique address to decipher its data. There are two workarounds to this limitation. First, we can implement a MUX to select among the three sensors, however this implementation would mean taking two clock cycles to read input from the sensors. The second workaround would be to introduce another microcontroller into the design. Both solutions require additional hardware leading to a higher cost.

3.2 Hardware Enclosure

The two accelerometers are currently enclosed in an airplane pillowcase, which provides a good mock-up for the demonstration of the proof-of- concept and for further development of the product. The flexibility of the fabric allows for the sensors to conform to the user's upper torso and produce accurate readings. The two sensors are insulated in a container to prevent any static charge buildup due to the pillow's fabric. Since the current configuration is tethered, long extension cables are used to mitigate any accidental disconnection of key components. Figure 3.3 shows a user wearing the proof-of-concept. The sensors have been mounted strategically to duplicate the configuration illustrated in Figure 3.1 above. The first sensor rests on the neck and second sensor rests on right collar bone. Counterweights have been placed in the left arm of the pillowcase to increase comfort.

Figure 3.3: Proof of Concept Hardware Enclosure

3.3 Requirement Specifications

Due to the implementation of accelerometers instead of gyroscopes, some requirement specifications have been modified. Table 3.2 and Table 3.3 below outline the specifications that have been revised and met during the design process respectively.

Requirement Specifications	Previous revision	Current revision
[Req 2.3.23 - i]	The gyroscopes must be triple axis	The accelerometers must be triple axis.

[Req 2.3.24 - i]	The gyroscope's sensitivity must be 250 DPS	The accelerometer's sensitivity must be at least 1 degree.
[Req 2.3.26 - i]	Both Bluetooth module and gyroscopes shall have a 16 bit DAC resolution	Both Bluetooth module and accelerometers shall have at least 10 bit DAC resolution

Table 3.2: Revised Requirement Specifications

Requirements Met	Description
[Req 2.2.2 - i]	The device shall be mounted on the user's neck.
[Req 2.2.4 - i]	The device shall solely monitor sitting posture.
[Req 2.2.5 - i]	The device shall be minimally intrusive to the user.
[Req 2.2.6 - i]	The user shall be able to use the device either with or without the companion application.
[Req 2.2.11 - i]	The device shall not emit radiation harmful to its users, including from excessive heat.
[Req 2.2.12 - i]	The device shall not interfere with the operations of any other devices.
[Req 2.2.13 - i]	The device shall not emit toxic fumes or produce any environmental hazards.
[Req 2.2.14 - ii]	The device shall not contain sharp or rough edges.
[Req 2.2.15 - i]	The device shall not produce any unnecessary pressure points on the user's body.
[Req 2.2.16 - i]	The device shall contain hypoallergenic components.
[Req 2.3.3 - i]	The device shall be housed in a semi-rigid case.
[Req 2.3.5 - ii]	The device shall have equal weight distribution.
[Req 2.3.15 - i]	The device shall have an operating temperature range of 0C – 40C.
[Req 2.3.19 - i]	The current required by the system should be less than 25mA.
[Req 2.3.23 - i]	The accelerometer must be triple axis.
[Req 2.3.24 - i]	The accelerometer's sensitivity must be at least 1 degree.

Table 3.3: Specifications met by Proof of Concept

In the proposal, we stated that the number of sensors required along with their positions is subject to modifications. In an iterative design process, we want to test multiple configurations to optimize for performance and cost. The two-sensor configuration has provided adequate measurements showing the success of the proof-of-concept design. The next section outlines some results we obtained when we performed tests on five external subjects using the current two-sensor design.

4. HUMAN TRIALS

To better refine the algorithm for processing, testing was done on five subjects to obtain values for the following postures, as outlined in Table 4.1. With each posture, we included neck movements to obtain the full range of values that could exist. Experiments contained 10 seconds allocated for overhead.

Posture	Routine Description and Timing	Total time
Baseline	Back straight, unmoving	20s
Back Straight	Back straight, start head straight, 15 seconds looking up, 15 seconds looking down, repeat once	70s
Slouch	Normal comfortable slouch, identical look up/down routine	70s
Leaning forward	Elbows and forearms resting on desk, identical neck routine	70s
Leaning sideways	Begin at baseline, lean left 15 seconds, lean right 15 seconds, repeat once. Subject assumes they are using a mouse that is too far left or right.	70s
Standing up	Begin sitting, stand up after 15 seconds, sit down after 15 seconds. Repeat once.	70s

Table 4.1: Descriptions of test routines for initial human trials

It should also be noted that test subjects were instructed to lean sideways in whatever way they wanted, as long as the position was comfortable. Because the baseline itself consists of a straight back, the trials of interest only included the subsequent slouch, lean, and stand routines. The following table outlines the procedure used to quantify the obtained data.

Posture	Processing Procedure
Slouch	Subtract all Y and Z values from their respective baseline, then average
Leaning forward	Subtract all Y and Z values from their respective baseline, then average
Leaning sideways	Repeat above. Also, subtract all X values from the baseline, average all positive values, and average all negative values.
Standing up	Note any simultaneous spike above a threshold in both Y and Z

Table 4.2: Descriptions of processing procedures for initial human trials

Some of these procedures are self-explanatory - a forward-leaning and slouch posture would not produce any tangible change in the X axis, so only the Y and Z axis would be considered. Conversely, for the sideways lean, the focus would be on the X axis, with a smaller emphasis on the Y and Z axis values.

The standing up procedure utilized a different approach. The standing motion involves a relatively rapid motion in both the Y and Z axis direction, because it involves the user leaning forward to move their center of gravity above their legs, while conducting the rising motion itself.

The preliminary results are as shown below in Figures 4.1 and 4.2:

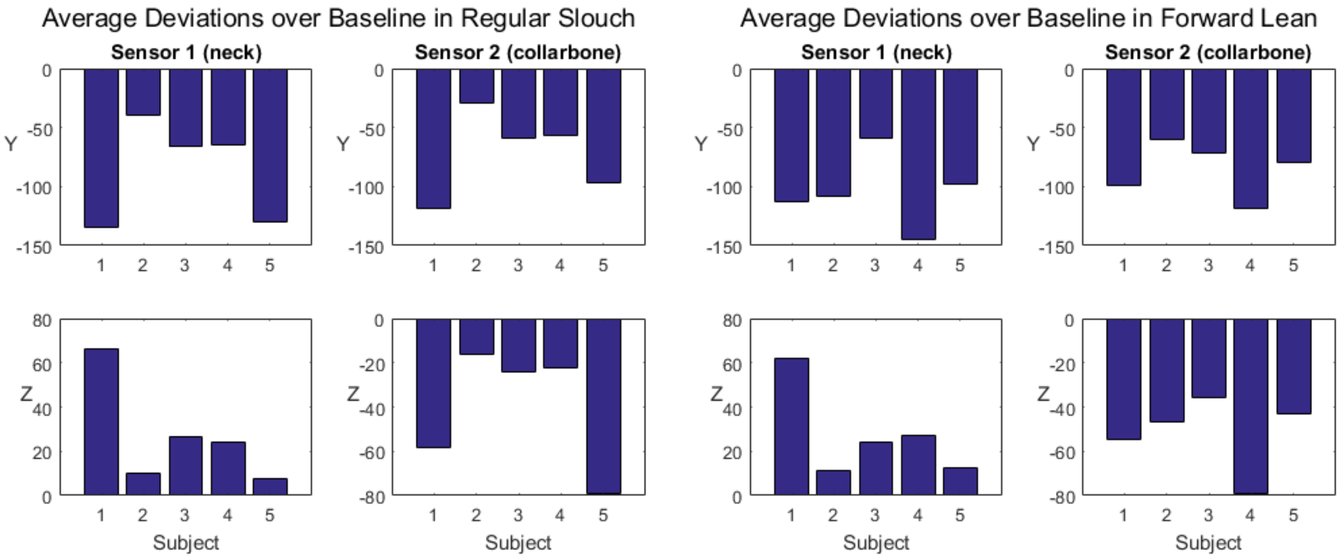

Figure 4.1: Preliminary data for slouching and forward leaning positions

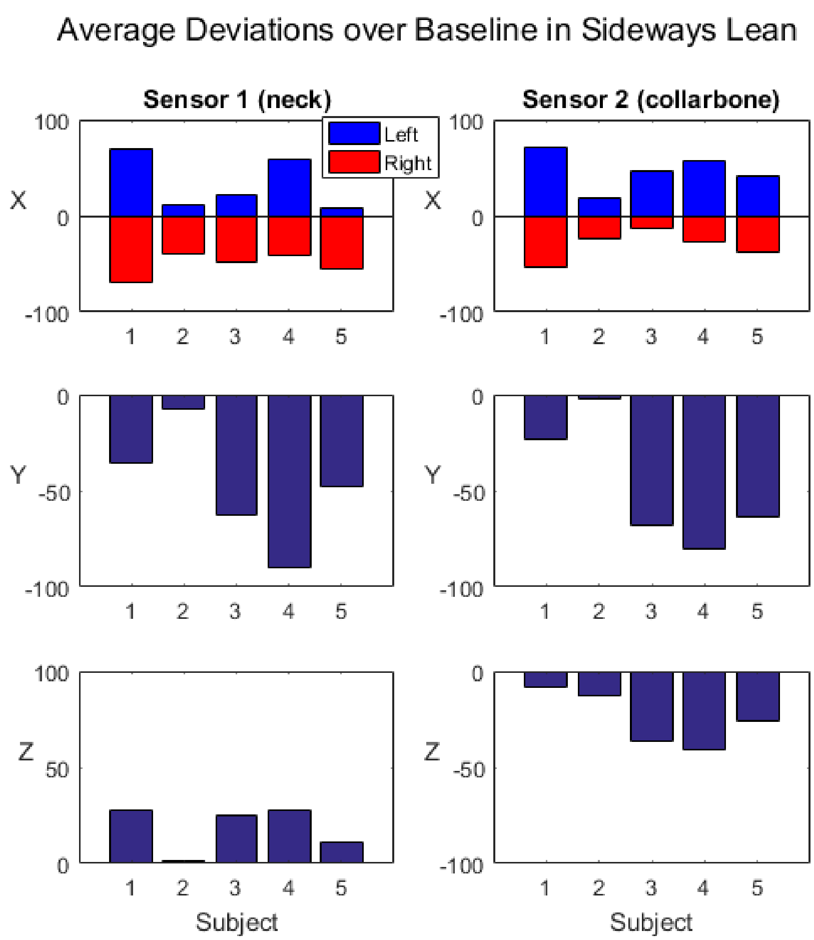

Figure 4.2: Preliminary data for sideways leaning positions

To preface an explanation of the data, it is necessary to point out the Z axis inversion, as observed in Sensor 1, for both figures. Because the sensors' configuration is such that they are on different sides of the upper torso, this meant that at least one of the X, Y, or Z axes in one sensor would produce an inverted value when compared to the other. We determined early in the design phase that X and Y axis rotation would take precedence, and this is reflected in the above figures.

Figure 4.1 shows a general negative trend in both the Y and Z axes, except for the positive trend in the Z axis for the neck sensor. As expected, the negative offset increased in magnitude when the user sat in a forward-leaning position instead of a simple slouch. Because the Y and Z magnitudes seem to correlate, quantifying this in future trials is a high priority in the development of the notification algorithm, and having multiple confirmation points will help remove falsehoods.

Figure 4.2 shows the offset produced during left and right-leaning postures. The difference in magnitudes in left offset versus right offset in some subjects suggests that the user's dominant hand may change how he or she leans sideways. This would also be worth exploring further in future trials as we can isolate the movement near the sensors. Although the testing routine needs to be further refined, the values prove promising as we move towards the main notification algorithm.

5. Design Iterations

The status of VertAlign has been outlined comprehensively in Section 3 and 4. A mockup has been developed to test the theory and refine the algorithm to be used for detecting when to alert the user.

The next iterations of the device will advance from the Proof of Concept stage, and begin to meet physical (e.g. casing dimensions and weight) and software requirements (e.g. saving data and broadcasting state). Further testing with users will be done at each stage to ensure the device remains comfortable, intuitive, and accurate.

The prototype stage will be the first stage to have a purpose-built casing that meets our weight and dimension requirements. This stage will also introduce calibration as an action available to the user. The prototype must contain and be powered by a rechargeable battery that lasts for at least 8 hours. The Android app must also begin development at this stage, and should be able to interface with the device and receive information on current posture state. All requirements for vibrations and status LEDs listed as requirements for the proof of concept will now be incorporated during the various prototypes developed during this stage.

Once all prototyping requirements are met, design will move onto the requirements of a marketable product. This will cover the remaining requirements from our requirements specification, as well as the necessary steps of marketing the device and planning distribution.

5.1 Future Considerations

As mentioned in section 4, the data was obtained through a preliminary routine that has substantial room for improvement. Having noticed trends in the obtained data, in particular the dominant hand-related findings in the sideways-leaning postures shown in Figure 4.2, additional testing procedures need to be designed and executed to better understand these behaviors. By doing this, we can further refine our notification algorithm to ensure the greatest robustness and accuracy.

In addition, the accelerometers themselves contain many configurable options for us to consider. Further research will be done on these in hopes of increasing the accuracy of our readings.

6. CONCLUSION

The VertAlign is on track to achieving the functions previously set for it. Some tradeoffs were made during the development of the proof-of-concept. Priority was placed on getting familiar with use and configuration of accelerometers and beginning human trials to gather data. We deemed LED indicators for the proof-of-concept to be low priority and decided to forgo them for now. Another important design decision was to use accelerometers exclusively rather than include any gyroscopes. The reasoning behind this is because the VertAlign is a device which focuses on sensing posture in a sitting position at constant velocity. For this application, movement is generally classified as low frequency and better detected by accelerometers over gyroscopes.

The VertAlign is currently capable of monitoring the angles of a user's neck and shoulders. Results from human trials showed promising data in terms of determining postures. Future designs will add levels above data capture, and implement an algorithm that processes the raw data into a decision on whether current posture is good or bad and then notify the user of the result. The Android application will interface with the VertAlign and allow for calibration, timer setting modifications, and data/metric tracking.

References

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A1. Test Plan

PHYSICAL DEVICE

Requirements to meet	Steps to Test	Pass/Fail
[Req 2.2.3 - i], [Req 2.3.15 - i]	Repeat all tests for operation in rooms of temperatures varying from 0°C to 30°C, vary by 10°C. Check temperature during operation to ensure it does not go above the required limits.	
[Req 2.2.9 - i]	Ensure the LED colour matches the current state of the device. (Confirm time to posture warning matches current setting)	
[Req 2.3.7 - ii]	Press the calibration button and ensure calibration begins.	
[Req 2.2.10 - ii]	Confirm calibration takes less than 10 seconds	
[Req 2.2.7 - ii]	Present a new user the system and basic instruction, and observe if they can use it within five minutes of being introduced.	
[Req 2.3.16 - ii]	The device must last for at least 8 hours when turned on. Leave the device on for 8 hours to confirm.	
[Req 2.3.12 - ii]	Drop the device from 2m high. Check device operation.	
[Req 2.3.8 - iii]	Press the settings button and confirm both the LED and the actual device state update.	
[Req 2.4.3 - i]	Sit in “proper” posture for more than the current timer length. Confirm no alert. Sit in an improper posture for more than the timer length. Confirm the user is alerted.	
[Req 2.4.4 - i]	Place the device on a chair (or wear it and sit) for half an hour. Confirm the device gives the alert to stretch.	

ANDROID APPLICATION

Requirements to meet	Steps to Test	Pass/Fail
[Req 2.5.1 - ii]	Confirm that the application pairs up to the device.	
[Req 2.5.2 - ii]	Confirm app runs on multiple versions of Android. Repeat all software tests for 4.4, 5.0, 6.0, 7.0	
[Req 2.5.4 - ii]	Confirm application resumes from where the user backed out after going to home screen.	
[Req 2.5.5 - ii]	Confirm calibration starts when selected on the app, and confirm calibration properly finishes and applies to the device.	
[Req 2.5.6 - ii]	Confirm that data is stored on the device and can be retrieved after using the device for a session.	
[Req 2.5.7 - ii]	Confirm the applications graphs are accurate to saved data, and there are no graphical or data bugs visible to the user.	

A2. UI Appendix

A2.1 Introduction

The User Interface Appendix provides an overview of the user interface elements of the VertAlign and its method of operation from a usability standpoint. It is divided into five sections containing user and technical analysis, engineering standards, and analytical and empirical usability testing regarding the VertAlign device. Careful consideration has been made to ensure that our usability design decisions have been dictated by our usability requirements.

In user and technical analysis, we discuss the physical and intellectual requirements of our users as well as the *Seven Elements of UI Interaction* as they apply to our device. The seven elements, taken from Don Norman's *The Design of Everyday Things,* are discoverability, feedback, conceptual model, affordances, mappings, and constraints.

Engineering standards outlines the specific standards which the device will comply to, such as RoHS, CSA, and various IEEE standards. These standards apply to limits on the use of hazardous materials, physical safety, and environmental impact, which are crucial factors considered in the design of our product.

Usability testing details our plan for testing the various iterations of our device with users and with respect to learnability, efficiency, memorability, errors, and satisfaction. It also addresses how to perform safe operation of the device and discusses possible errors that may occur with users and their solutions.

A2.2 User Analysis

Aside from the VertAlign mobile app, the device does not include a navigation screen or menu. This means the level of required user knowledge is relatively low for this device. The possible actions include turning on and off, changing timing setting, activating the Bluetooth module, and calibrate. All of these actions can be controlled using two buttons and one switch.

The user should understand the application of long press or press-and-hold in order to make full use of button functionality. Powering on by using a long press is a common function present in most smart phone models today. The VertAlign is easily accessible to almost all of the population due to its simple operation and low number of required inputs. Users with severe joint conditions in the hands and fingers may have trouble operating the device due to pressure caused by resistance in the button mechanism.

Users with prior experience with wearable devices will find the VertAlign easier to use compared to other popular wearable devices such as Fitbit products. These products contain many more features, necessitating a more complex control layout. For the initial iteration of the VertAlign with a low number of features, the simple two button, one switch layout is a cost-effective solution. It is welcoming for newcomers to the wearable market, as well as users who are not technologically savvy.

It is important to note that the VertAlign can function as a completely standalone device. It is not required to pair with a mobile phone. Users who are less knowledgeable about technology are able to ignore the Bluetooth and mobile app features entirely if they wish to do so. Although this will limit their ability to access product features such as posture graphs and day-to-day posture tracking.

Users should be aware that there are mechanical restrictions regarding the VertAlign. The arms of the structure will be flexible in order for users to be able to place the device around their necks. The flexible arms should not be flexed past a certain angle, as this may damage both the casing and the sensitive electronics within the device. The flexibility is only enough to allow for the device to be drawn past the thickest part of the neck and then return to its original shape to hold on.

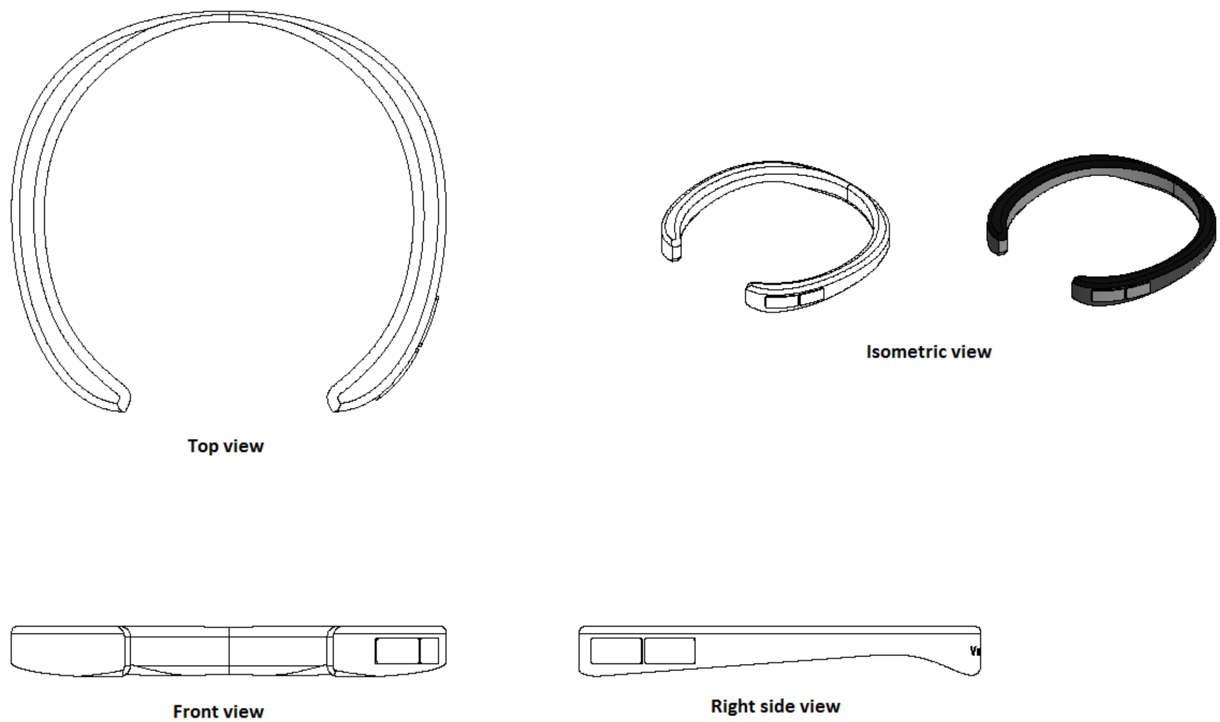

Figure A2.2: VertAlign Plan View and Isometric View

A2.3 Technical Analysis

This section will discuss the Seven Elements of UI Interaction as they apply to the VertAlign: discoverability, feedback, conceptual model, affordances, signifiers, mappings, and constraints. Definitions for each term are provided and taken from Don Norman's text (as studied in ENSC 304), The Design of Everyday Things.

A2.3.1 Discoverability

"It is possible to determine what actions are possible and the current state of the device."

The current state of the device will be visually shown by three separate LED indicators: on/battery, Bluetooth, and timing setting. Possible actions will be discoverable through two buttons: power and setting.

Some discoverability is sacrificed by using the same button for two different actions based on the length of the button press. For short presses, the settings button will change the preset timer length for alerts. The timing functionality fulfills [Req 2.5.12 - ii]. For long presses, the settings button will begin calibrating the device. The power button will not be similarly overloaded, and will only ever initiate power on and power off.

A2.3.2 Feedback

"There is full and continuous information about the results of actions and the current state of the product or service. After an action has been executed, it is easy to determine the new state."

As stated above, visual feedback will be provided by three LED indicators. Our prototype will also have the ability to provide tactile feedback via vibration module. A change in the device state will be indicated by a change in the LED colour as well as the on/off status of the LEDs.

The LEDs will indicate the current power state (on or off), as well as timer settings. The power LED starts at green, and will turn red once the low battery threshold has been reached. Tactile feedback is also required in tandem with visual feedback since the device's LEDs will not be visible while worn. We plan to have the device vibrate lightly whenever a button input is registered.

Familiar icons will be used for power, Bluetooth, and settings. As well, conventional colour-coding will be used to indicate battery status. These features are in alignment with [Req 2.5.10 - ii].

A2.3.3 Conceptual Model

"The design projects all the information needed to create a good conceptual model of the system, leading to understanding and a feeling of control. The conceptual model enhances both discoverability and evaluation of results."

The main function of the device is to alert a user when their posture needs correction, or they have been sitting too long and need to take a break. These functions are easily understood. The device is controlled through two buttons on the casing, with some options available through the Android application. The first button is a power button, which users will all have past experience with.

The second button is the settings button, which changes the amount of time before an alert is issued and when held will initiate calibration. The indicator for timing settings will be a set of three circles backlit by LEDs. The shortest timing setting will have one lit circle, the middle timing setting two, and the longest timing setting three. Pressing the settings button will cycle from one lit circle to two to three and back to one. This overflow from maximum back to the lowest should already be familiar to users as it is used by many systems relying on a single button to cycle.

A2.3.4 Affordances

"The proper affordances exist to make the desired actions possible."

Due to the relatively simple operation of the device, only two buttons are required for all possible actions with one toggle switch to control whether Bluetooth is currently active. The device will turn on and off with long presses of the power button. Long presses are required to avoid accidental activation/deactivation of the device from coincidental impact with the power button.

Currently we are using the settings button to change the timing setting, but also to calibrate the device on a long press without having to pair to an Android device. We are considering adding a third button in future iterations that would only be used to perform calibration.

A2.3.5 Signifiers

"Effective use of signifiers ensures discoverability and that the feedback is well communicated and intelligible."

Since the user cannot see the LEDs on the device when wearing it, we have chosen to use the vibration module alongside the LEDs to provide signifiers that are intuitive. When the settings button is pressed, the vibration module will give as many short pulses as there are circles active on the indicator. In this way, the user can feel which timing setting they have switched to without having to take off the device and look at the indicator visually.

When the device is first turned on, the battery indicator will light up and the vibration module will give one long pulse. Calibration will start a long vibration pulse when it begins, and another long vibration when calibration concludes. Bluetooth will be controlled by a toggle switch that will show "ON" next to the switch when in the ON position, and solid black when in the off position. The Bluetooth icon will be visible beside the toggle switch for clear identification of purpose.

A2.3.6 Mappings

"The relationship between controls and their actions follows the principles of good mapping, enhanced as much as possible through spatial layout and temporal contiguity."

Since our device will have only two buttons, the mapping will be relatively simple. The power button should have the recognizable power symbol on it, and ideally it should be located under the battery LED indicator. Likewise, the settings button will be located under the timing indicator. The Bluetooth switch will be located on its own at the back of the device, clearly labelled by the Bluetooth symbol above to avoid any possible confusion.

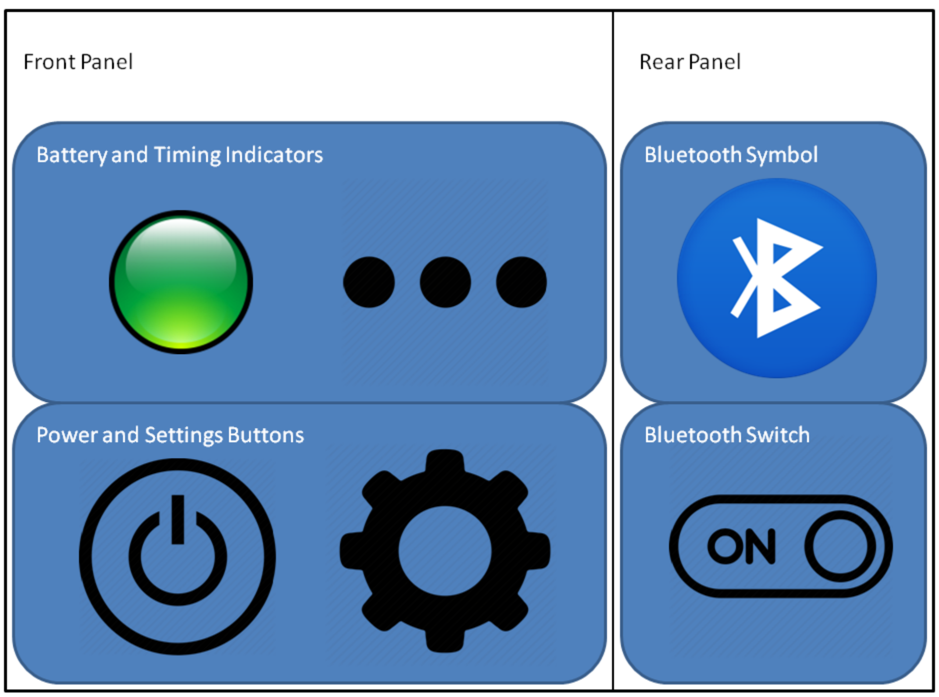

Figure A2.3.6: VertAlign Control Layout

A2.3.7 Constraints

"Providing physical, logical, semantic, and cultural constraints guides actions and eases interpretation."

Our device does not have any other mechanical or moving parts aside from the power and settings buttons, so there are no real needs for physical constraints. As for logical constraints, if the user holds down the power button and the settings button, the power off will supersede the calibration input and the device will power down without initiating calibration. Powering down after calibration begins will be allowed, since the case of the battery dying during calibration should be addressed regardless. Changing timer settings could be locked out during calibration, but as these have no effect on calibration there is no reason to do so.

A2.4 Engineering Standards

This section will outline in detail the engineering standards applicable to the VertAlign user interface, their purpose and relevance. These standards follow from the requirement specifications.

[Req 2.6.2 - ii]
The RoHS standard restricts the use of hazardous substances such as lead, mercury, and cadmium. Because the device constantly and physically interfaces with the user's body, compliance with this standard is essential for the success of the product. This standard is also important because it aligns with Meerkat's goal of improving the health of its users.

[Req 2.6.3 - ii]
IEEE 1621 is the standard for user interface elements in power control of electronic devices employed in office/consumer environments. This standard primarily covers the use of terms, symbols, and indicators in regards to power control.

A2.5 Analytical Usability Testing

Our team met with biophysical kinesiology professor Max Donelan to ask for feedback on the design of the VertAlign. Professor Donelan has experience in wearable technologies. He recommended a device with high learnability which could work right out of the box with minimal effort.

Our device has a multi-functional settings button that may have a negative effect on learnability. Initially it may not be clear to a user that the settings button can be held down in order to start device calibration process. To alleviate this potential issue, calibration will be made an optional feature. Preliminary data from posture testing with the mock-up model yields noticable trends in good and bad posture that arise even among subjects with varying heights and body types.

VertAlign's efficiency is high due to being a set-and-forget device. The device setup is the only non-automated process of the device. Once the user has become proficient in setup of the device, posture detection and alerts can take place without further human intervention.

For the same reason, VertAlign also has good memorability. The setup process itself involves only a few simple steps: turn on, set timing, and calibrate. The calibrate and timing steps are interchangeable, in that they do not have to happen in a specific order. This eliminates any errors that may occur due to incorrect sequencing of steps. Calibration is also an optional feature.

A2.6 Empirical Usability Testing

Currently no empirical usability testing has been conducted with users for our product mock-up. Our plan for usability testing for future iterations of our prototype include working closely with potential users to gain feedback on our initial design decisions. The feedback will address the following questions: "Is the device functioning as described?", "Is it comfortable to wear?", and "Is it easy to use?".

The feedback will be collected through a survey which asks the test subjects to rate certain aspects of the device such as learnability, memorability, and satisfaction. Another round of usability testing and surveys will be conducted after analyzing feedback and making appropriate design changes. This process will be part of our iterative design progress procedure.

One user mistake that concerns us is the possibility of improper calibration. This could lead to some users inadvertently reinforcing poor posture habits using the VertAlign. A possible way to minimize this error is to introduce a constraint on the calibration window. A limit can be placed on the maximum angles which are acceptable for calibration. In this case we would need an easily understandable way to inform the user that calibration has failed and they need to try again.

A2.7 Conclusion

Major design decisions regarding the physical control layout of the device have been agreed upon. These design decision are tentative and subject to change. Improvements to future iterations are to be made after further discussion and analysis of empirical usability testing feedback. Our design includes some sacrifices in learnability since the user cannot rely on visual indicators while wearing the device. This could introduce some difficulty in the calibration process.

Remaining work includes development of the mobile app and its user interface. Although we have agreed upon what features the app should support, design decisions regarding the software layout specifically have yet to be made. We will also need to perform usability testing on the app. Test subjects' should try installing and using the app, and gauge their experience pairing with the device.

As we proceed with development of the mobile app, it is important to keep in mind the usability requirements previously set for the app. At this point they are not subject for revision:

[Req 2.5.9 - ii] The application shall contain a minimalistic interface for simplicity.

[Req 2.5.10 - ii] The user interface will follow conventions that allow users to already be familiar with certain features, e.g. settings icons.

[Req 2.5.12 - ii] The user shall be able to configure the threshold for bad posture sending a notification.

A2.8 References

[3] Aggarwal, Kushank et al. *Requirements Specification For A Wearable Posture Correction Device*. Vancouver, B.C.: SFU, 2017. Web. 30 Mar. 2017. ENSC 405W Assignments.

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[A2.8.2] I.-S. C. Policy, "IEEE SA - 1621-2004 - IEEE standard for user interface elements in power control of electronic devices employed in office/consumer environments," 2005. [Online]. Available: https://standards.ieee.org/findstds/standard/1621-2004.html. [Accessed: Mar. 30, 2017].

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