INAPPROPRIATE POSTURE: DEVICE TO REGAIN AWARENESS ON POSTURES AND PREVENT TRAUMA

CASE STUDY: HOW CAN YOUNG ADULTS’ POSTURE BE MONITORED DISCREETLY BY SENSING AND MOVEMENT ASSISTIVE TECHNOLOGY

BY

AUSTIN CHEN

THESIS

Submitted in partial fulfillment of the requirements for the degree of Master of Fine Arts in Art and Design with a concentration in Industrial Design in the Graduate College of the University of Illinois at Urbana-Champaign, 2017

Urbana, Illinois

Adviser:

Professor Deana McDonagh, Chair
ABSTRACT

Muscular-skeletal injuries are not only lowering people’s quality of life, but also creating a massive monetary loss in the society. A considerable number of them result from fixation to incorrect postures and inappropriate forms when doing activities.

Unbalanced muscles are challenging bodies to hold appropriate postures. A certain group of people gained such chronic problems from habits in younger age.

As an appropriate solution, we realized that utilizing sensors that can be seamlessly embedded in everyday products could be a user-friendly way to deal with the problem. Aiming at increasing the participation in daily life of people with traumas that result from poor postural habits, we are convinced that our innovation can be acknowledged as assistive technology.

KEYWORDS

Posture, wellness, trauma, sensing technology, industrial design
ACKNOWLEDGEMENTS

First, this thesis was majorly supported by committee members at the University of Illinois at Urbana-Champaign (UIUC). They are: Dr. Deana McDonagh (Committee chair), Professor David Weightman from Department of Industrial Design, and Dr. Elizabeth Hsiao-Wecksler from Department of Mechanical Science and Engineering. I thank them for their advice along the way and for all the opportunities I was given to conduct my research and further my dissertation. Their specialty in relevant areas was a great support in bringing this project to an elevated level.

Second, I would like to thank my research team members, Prateek Garag and Gary Luo, for their wonderful collaboration. As this being a multi-disciplinary team, I learned a lot from those 2 talented yet hardworking engineers. I am glad that we made this project work.

Third, credits should be given to colleagues and professors who provided design and engineering support to this project. They are members from the Human Dynamics and Controls Lab at UIUC, Master of Fine Arts studio colleagues, Professor William Bullock, and Professor Suresh Sethi from Department of Industrial Design. Their insights, comments, and expertise have greatly assisted the research.

I would also like to show my gratitude to experts who were involved in the consultation for this research project: Zezhao Chen, Randy Ballard, Jeannette Elliot, Dr. Yih-Kuen Jan, and Dr. Adam
Johnson. It was their pearls of wisdom in biomechanics and muscle training that provided us with academic support.

Last but not least, I would also like to acknowledge other supporting individuals: Connor Goetten, Shannon Chang, Zack Zlevor, Stella Chu, Danni Wang, Shuang Bi, and Joyce Park. I am gratefully indebted to their valuable comments on this thesis.
**TABLE OF CONTENTS**

CHAPTER 1: INTRODUCTION ......................................................................................... 1
  1.1 BACKGROUND .................................................................................................. 1
  1.2 PROJECT INTRODUCTION ................................................................................ 3
  1.3 RESEARCH ROADMAP ..................................................................................... 6

CHAPTER 2: CASE STUDY – PART 1 ............................................................................ 7
  2.1 DATA-GATHERING METHODOLOGIES ............................................................. 7
  2.2 LITERATURE REVIEW ...................................................................................... 9
  2.3 PROBLEM IDENTIFICATION .......................................................................... 22

CHAPTER 3: CASE STUDY – PART 2 ......................................................................... 28
  3.1 DESIGN-DEVELOPMENT METHODOLOGIES .................................................... 28
  3.2 IDEATION ........................................................................................................ 30
  3.3 COMPETING PRODUCTS .................................................................................... 38
  3.4 PROTOTYPING AND TESTING ......................................................................... 44
  3.5 Refined SOLUTION ............................................................................................ 51

CHAPTER 4: LIMITATIONS AND RECOMMENDATIONS ........................................ 69
  4.1 LIMITATIONS ................................................................................................... 69
  4.2 RECOMMENDATIONS ....................................................................................... 70

CHAPTER 5: CONCLUSION ........................................................................................ 73
REFERENCES ........................................................................................................................................ 75

APPENDIX A: CORRESPONDENCE LETTER – ADAM JOHNSON.................................................. 79

APPENDIX B: TARGET GROUP SURVEY – POSTURE AND TRAUMA....................................... 81

APPENDIX C: IRB APPROVAL........................................................................................................... 83

APPENDIX D: SUPPLEMENTARY FILE ............................................................................................ 84
CHAPTER 1: INTRODUCTION

1.1 BACKGROUND

According to the report published by Bureau of Labor Statistics and the National Academy of Social Insurance, we are convinced that back injury is the most harmful trauma in workspaces, jeopardizing the ability to work among a large population in the US. Chronic pain being one of the parameters to define injuries, chronic back pain is the number one cause of days away from work with 298,000 cases in 2016. Back injuries are affecting 4.6 million people and causing 1.8 million emergency department visits per year, making itself by far the number one cause of nonfatal disabling work injuries (2016: 3).

Figure 1: Back Pain Statistics (Based on Safety Ambassador, 2012: 3)

As a matter of fact, doctors, back specialists and orthopedic surgeons will openly admit that the cause of back pain is frequently a mystery (Brennan, 2012), as the causes for it can vary.
However, it is said that there is always an underlying cause, and when that is addressed, the pain or discomfort will gradually disappear (Brennan, 2012). Defined as a “body’s cry for attention”, painfulness indicates certain injuries in either muscles or bones (Mahtani, 2015).

Having become a severe situation, a great number of back pain patients has misaligned joints or fixated muscles in a poor position. Scientists are tracing the root cause of most pains to bad posture – faulty body dynamics in routine activities and also while exercising (Mahtani, 2015). In other words, these could result from their postural habits in daily life. For example, slouching could put up to 85% more pressure on the intervertebral disc, which in long term could lead to bone spurs and herniated discs (Perry, 2015). Therefore, it is believed that postural corrections can massively eliminate the uneven pressure. Recent research has begun to shed new light on the importance of correcting sitting posture for the prevention and reduction of back pain, especially in the workplace. In clinic, the greatest challenge is not in teaching a patient to learn the “correct” posture, but in teaching the patient to be aware of when they lose the “correct” posture (Johnson, 2016). In this case, understanding what a “correct” posture is and exploring the effective methods to achieve it can be vital.

Are you aware of your posture change? As a matter of fact, statistics from interviews and observations are indicating that most people in workspaces tend to hold certain postures until they feel physical pain or phasic. Amy Lansky, the author of Active Consciousness: Awakening the Power Within, once said:
Part of it is our general detachment from our bodies. We are spending most of our days sitting in front of computers, televisions, on couches, in cars, or on punishing assembly lines. If we were more in touch with our bodies, with nature, and with the natural functions, the situation can be changed (Lansky, 2015).

Via literature search and review, 5 key factors were concluded as leading to fixation in inappropriate postures. There are internal factors such as goal oriented body movement, and faulty sensory appreciation. According to evidence, it can be true that human brains are not constructed in a way where a person can focus simultaneously on his/her posture and other ongoing tasks. Body forms tend to compromise to more dominated tasks the individual is working on. Other factors include body functionalities that are affected by both internal and external factors, which can be specified as muscle imbalance and inadequate slow-twitch muscle memory. Finally, the feature of seat surfaces serves as one of the external factors that affect postures. The nature of human bodies decided that postural issues are unrecognizable in most cases. Each of the 5 factors will be elaborated in the following chapters.

1.2 PROJECT INTRODUCTION

This project focuses on calling on awareness of chronic muscular-skeletal injuries, by analyzing the correlation between postural habits and injuries, defining key factors that result in poor postures, and in the end presenting solutions from a design approach.

In light of the fact that people are neither fully aware of what is influencing their health, nor having a constructed plan on self-improvement, we believe it is of significance to call on
awareness of postural health, and provide people with feasible solutions that can assist them to gain a better postural habit.

Owing to the fact that postural habits can lead to muscle imbalance and in long-term result in chronic injuries, it is vital for office workers to maximize the amount of time utilizing appropriate postures. Since the human body lacks functionality to alert postural habits, external assists could be helpful.

To be more precise, the project is targeting the 18 to 35-year-old user group. This group is in their postural stabilization period in their life: reaching peak bone mass and establishing a decisive stage of muscle building. Moreover, their lifestyle is changing during this period of time from being more physically active to doing sedentary deskwork.

Dr. Renu Mahtani, a practicing physician in holistic healing and founder of Param Yoga, wrote in her book The Power of Posture: “Good posture is not only about straightening up, but also about how we sustain our body in different positions and movements (2015: 343).” Based on her study, the goal for postural health appears to be removing fixated muscle position, and achieving maximized range of motion.

To tackle this goal, a multi-disciplinary team was gathered. Industrial designer Austin Chen (the author of this thesis paper) initiated this topic in November 2015. He is a Master of Fine Arts (MFA) candidate in the Industrial Design program at University of Illinois at Urbana-Champaign
(UIUC), practicing human-centered design. Mechanical engineer Prateek Garag, a senior undergraduate researcher at UIUC, started collaboration in January 2017. With his contribution, the mechanism of this design was eventually built. In February, Gary Luo, a software engineer at Yahoo in Champaign, Illinois, joined and took on software development for this project.

Specializing in different fields, each team member took charge of an individual area, but also collaborated to assemble this project together.
The technology development primarily took place in Human Dynamics and Controls Lab at UIUC, which focuses on assistive device development and locomotion biomechanics. This project was also assisted by the researchers in this lab with their specialty in biomechanics, relevant literature materials, equipment, and research methodologies.

1.3 RESEARCH ROADMAP

![Research Roadmap Diagram]

Figure 3: Research Roadmap
CHAPTER 2: CASE STUDY – PART 1

2.1 DATA-GATHERING METHODOLOGIES

From November 2015 to October 2016, we conducted 2 phases of data-gathering research. The first phase, November 2015 to January 2016, was a preliminary research stage. We focused on reviewing literatures for persuasive statistics and inspiring insights in the field of posture awareness and wellness. The second phase of research, March 2016 to October 2016, was practiced after a critique and design experiment stage. In this stage, the direction appeared to be clearer so the team aimed at studying intensively on the area of focus. The specific methodologies were concluded and elaborated in the following table.

Table 1: Data-gathering Methodologies

<table>
<thead>
<tr>
<th>Methodology</th>
<th>Definition of Approach</th>
<th>Expectations</th>
<th>Outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td>Literature search</td>
<td>This approach is to gather and analyze information found in the existing related literature, to evaluate the need of the design that we are going to make, serving as a theoretical base for other approaches (The Writing Center, 2003).</td>
<td>Expectations are to determine: 1) What is the problem that needs to be solved? 2) Who is in need? 3) Why does the problem need to be solved?</td>
<td>The problem was located, and the significance and necessity for improving postural wellness were clear. The researchers outlined the severity of this problem in the society, and the factors that resulted in this.</td>
</tr>
<tr>
<td>One to one interview and survey</td>
<td>This is survey and conversations that includes questioning, answering, doodling, storytelling, or any forms of activities that could help expressing ideas (Trochim, 2006).</td>
<td>Expectations are to get the story behind people' experiences, so as to objectively confine their needs, especially the underlying ones.</td>
<td>The researchers got insights on the characteristics and needs of people in the targeted group, and later located the design opportunities.</td>
</tr>
</tbody>
</table>
**Table 1 (cont.)**

<table>
<thead>
<tr>
<th>Methodology</th>
<th>Definition of Approach</th>
<th>Expectations</th>
<th>Outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td>Observation and Empathic modeling</td>
<td>It is a technique that we, as researchers, put ourselves in the position of target users (&quot;Empathic Modeling&quot;: 91).</td>
<td>Expectations are to let researchers understand the users' need in a more direct way.</td>
<td>The researchers developed a deeper understanding of the problem that users are facing.</td>
</tr>
<tr>
<td>Expert reach-out</td>
<td>We reached out to acquire advises from experts in academia and industry in relevant fields.</td>
<td>The researchers are to learn:</td>
<td>Design direction and requirement.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1) How can postures be corrected in the best way?</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>2) What other factors are there that need to be considered?</td>
<td></td>
</tr>
<tr>
<td>Patent search</td>
<td>This is to reach out and find research works that are previously done in the same area, to critique their approach, and to avoid intellectual property rights violation.</td>
<td>It was expected to find out the existing solutions for the same problem, as well as area for improvements.</td>
<td>Not only products but also techniques that are in the market for correcting postures were found. Analyzing the pros. and cons. of each solution, the researchers managed to accurately confine the design opportunity. Pictures and videos for presentations and publications.</td>
</tr>
<tr>
<td>Photograph and videotape</td>
<td>This is to record the research process, especially when it involves human interaction.</td>
<td>The researchers will clearly record visual and audio information that are necessary, and inform the participants the use of these files.</td>
<td></td>
</tr>
</tbody>
</table>

This table concludes the methodologies that were taken throughout the 2 research stages from November 2015 to October 2016. Conclusively, the methods for data gathering includes both quantitative research and qualitative ones. Throughout the process, the researchers managed to visualize the significance and necessity of this project, understand the current situation, and figure out the direction for solutions.
2.2 LITERATURE REVIEW

2.2.1 Back Injury – a wicked problem

Employees can get injured at workplace for various reasons. According to 2016 Bureau of Labor Statistics report, 24% of the injuries in US workforce are back injuries, including spine and vertebrae in the back.

Table 2: Most injured body parts (Based on Health and Safety Authority 2014: 26-27)

<table>
<thead>
<tr>
<th>Body Part</th>
<th>All N</th>
<th>All %</th>
<th>Workers only N</th>
<th>Workers only %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Back, including spine and vertebrae in the back</td>
<td>1,790</td>
<td>23</td>
<td>1,776</td>
<td>23.9</td>
</tr>
<tr>
<td>Finger(s)</td>
<td>726</td>
<td>9.3</td>
<td>707</td>
<td>9.5</td>
</tr>
<tr>
<td>Leg, including knee</td>
<td>637</td>
<td>8.2</td>
<td>606</td>
<td>8.1</td>
</tr>
<tr>
<td>Hand</td>
<td>542</td>
<td>7</td>
<td>531</td>
<td>7.1</td>
</tr>
<tr>
<td>Ankle</td>
<td>449</td>
<td>5.8</td>
<td>473</td>
<td>6.4</td>
</tr>
<tr>
<td>Shoulder and shoulder joints</td>
<td>481</td>
<td>6.2</td>
<td>433</td>
<td>5.8</td>
</tr>
<tr>
<td>Arm, including elbow</td>
<td>436</td>
<td>5.6</td>
<td>416</td>
<td>5.6</td>
</tr>
<tr>
<td>All others, including unknown</td>
<td>398</td>
<td>5.1</td>
<td>334</td>
<td>4.5</td>
</tr>
<tr>
<td>Total</td>
<td>7,775</td>
<td>100</td>
<td>7,443</td>
<td>100</td>
</tr>
</tbody>
</table>
As statistics are showing, the back is the most injured body part and therefore very vulnerable. These injuries would typically drive employees away from work and towards hospitals. Another report from Bureau of Labor Statistics in 2016 shows the major causes of employees’ absence.

**Table 3:** Distribution of injuries and illnesses by event or exposure, 2015 (Bureau of Labor Statistics, 2016)

<table>
<thead>
<tr>
<th>Event or exposure</th>
<th>Number of days away from work cases</th>
<th>Percentage of days away from work cases</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overexertion and bodily reaction</td>
<td>376,190</td>
<td>32.6%</td>
</tr>
<tr>
<td>Falls, slips, trips</td>
<td>309,060</td>
<td>26.8%</td>
</tr>
<tr>
<td>Contact with object, equipment</td>
<td>269,910</td>
<td>23.4%</td>
</tr>
<tr>
<td>Violence and other injuries by persons or animals</td>
<td>75,720</td>
<td>6.6%</td>
</tr>
<tr>
<td>Transportation incidents</td>
<td>63,210</td>
<td>5.5%</td>
</tr>
<tr>
<td>All other events</td>
<td>59,400</td>
<td>5.1%</td>
</tr>
</tbody>
</table>

As indicated on the table, overexertion and body reaction is causing the most cases of workforce absence comparing to all other incidences. This type of injury is often chronic and result from overuse of body parts. Therefore, finding out the most overused body part became crucial for identifying the problem. Supporting statistics were found in a report by Health and Safety Authority in 2014.
Overwhelmingly, over half of the overexertion cases, as much as 52%, were from the overuse of back, which indicates that incorrect use of the back is the number 1 cause of absence from work. Statistics from other sources are also showing back injury as the number 2 non-fatal injury, affecting over 4.6 million people, costing $23,000 per case in average for hospital or physical therapy visits (Safety Ambassador, 2014, P. 3).

According to medical study, back injuries and exertions are largely correlated with inappropriate postures (Hargrove, 2014). Dr. Adam Johnson, physical therapist at Carle Spine Institute (Urbana, Illinois) and teaching faculty at American Back Pain Center (Ira Township, Michigan), says:

“Low back pain is the no.1 issue to miss work in America. It is the costliest medical condition in our society. Slouching could put up to 85% more pressure on the intervertebral disc. A simple correction could eliminate the pressure by
40-85%. Recent research has begun to shed new light on the importance of correcting sitting posture for the prevention and reduction of back pain, especially in workplace.”

Appendix A: Johnson A (2016) in correspondence with author via letter

Commonly seen poor postures at workplaces include: hunching over, leaning back, looking down the lap, leaning on armrests, crossing legs, focal point being too low, sitting too low, sitting too high, and feet dangling. Each type of poor posture could contribute to different types of uneven pressure on our bones and muscles (Narins, 2014). Besides poor posture itself, people tend to hold these postures for too long, which increases the tendency of muscle fixations.

Figure 5: Commonly seen poor postures at workspace (Based on Narins, 2014)
2.2.2 The targeted user group

Who needs to be helped the most? To optimize the effect in improving postural health in the society, audiences need to be clearly identified since people in different age groups would have different demands and preferences. A figure laying out the growth of bone mass helps visualize the user group selection.

![Graph showing bone mass growth phases](image)

Figure 6: Anticipated audiences (Based on Drzal-Grabiec, Snela, Rykała, Podgórska, and Banaś, 2013)

The anticipated audience is people from 18 to 35 years in age. This group of people are in the postural stabilization period in their life, reaching peak bone mass, and in a decisive stage of muscle building. Moreover, their lifestyle is changing during this period, from being more physically active to being sedentary at a desk job. Our society has transformed into an
information processing society in which more employees are transacting business while proper sitting posture suffers for long periods of time (Mandal, 2016).

It is believed that precaution is better than cure. Before developing poor posture into chronic diseases, the young adult population can learn how to live a healthy life.

For a certain generation, the product they use can be a “culture input” in their lifestyle. For people who are 18 to 35 years old, they are living on products such as contact lenses, iPhones, and Facebook. It’s not hard to foresee that they will continue being users of these products even after they grow beyond 35 years of age.

Therefore, we are aiming at people who are from 18 to 35 years old, abled body, and participants should be within body height and weight ranges that encompass US statistics 5% to 95% percentile. That is male subjects should be 5’5” (165cm) to 6’2” (189cm) in height, and 122lbs (55kg) to 210lbs (95kg) in weight, and female subjects should be 5’ (153cm) to 5’8” (173cm) in height, 102lbs (46kg) to 182lbs (83kg).

Figure 7: Body size range
2.2.3 What factors can result in poor postures?

1) Goal oriented body movement.

Most postural body movements happen unconsciously. Poor postures can easily occur without being noticed when a person is focusing on certain task. In physical and rehabilitation therapy, “goal oriented movements” is a term describing those motions intended to result in an outcome, as distinguished from those enacted in reaction to a stimulus or need (Mosby's Medical Dictionary, 2009). In other words, human body is functioning in a way that all body parts work together to achieve one primary goal.

2) Muscle imbalance

Agonist and antagonist muscles are always in pairs, known as extensors and flexors. (Wikipedia) They need to be balanced in strength and volume. As a matter of fact, muscle imbalances occur when one muscle is stronger than its opposing muscle. The overused muscles tend to be shortened, pulling the joint tilting to one side. Therefore, overuse of muscle on one side of a joint is one of the factors that result in postural fixation. For example, if you sit all day at a computer or overwork your mirror muscles (like the chest and abs), your shoulders are likely pulled forward creating a strength imbalance between the front of your body and the back (DuVall, 2015).
3) Faulty sensory appreciation

People recognize their postures through sensory information from the external environment such as objects and sounds, and also internal sense. However, faulty Sensory Appreciation comes about when we do not receive accurate sensory feedback about our physical condition and use. This feedback comes to us through our kinesthetic and proprioceptive sense mechanisms (King, 2007). The following figure gives an example.

![Figure 8: Faulty sensory appreciation](image)

This figure is showing a case where a person is slouching. However, as he might not be able to sense his posture accurately, he would picture himself sitting up straight in his mind. In other word, scientific study indicates that human brains are not capable to accurately tell what posture the person is actually holding.
4) Pelvis tilting caused by external factors

Various types of seat surfaces are making a difference in posture. These are serving as external factors. The following figure serves as an infographic illustrating how this factor can influence postures.

![Figure 9: Pelvis tilt](image)

Studies on seat surface angle by the Back Centre LTD (Ivybridge, U.K.) show that sitting with the legs at 90° or less to the body causes strain in the hip joint. This is relieved by a backward rotation of the pelvis. This in turn flattens out the natural inward curve (lordosis) of the lumbar spine, putting increased pressure on the inner surfaces of the lumbar disks in particular. Seat wedges can help to reduce this problem by encouraging a more open angle between body and upper leg (Back Centre LTD, 2009).

5) Fast twitch muscle versus slow twitch muscle
Quoting personal trainer Zezhao Chen, muscles in 2 different types function differently. The fast twitch muscles can help you to lift heavy weight in high velocity, whereas slow twitch muscles give you stamina in holding strength. The following figure helps elaborate the difference between these 2 types of muscles.

![Figure 10: Fast-twitch muscle versus slow-twitch muscle](image-url)

As highlighted in the figure, slow-twitch muscles, owing to their capability in resistance to fatigue, are crucial. However, people tend to ignore them when building muscles. As a matter of fact, certain type of exercises is dedicated for slow twitch muscle improvement purposes. In light of that, people need to be educated to understand such body mechanisms.

To solve the postural problem according to the 5 major factors that result in poor postures, we need to tackle each one of them specifically. There are a few questions are raised from
literature research. If our brains are not doing a very good job alerting us, what else can help?

Can we make a better surface angle? How do we train the slow twitch muscles in everyday life?

These are the factors that we are considering in seeking solutions.

2.2.4 Current solutions

Various types of approaches were taken for correcting postures. The existing solutions can be concluded into 4 categories. Evaluated on their effectiveness and goals, they were placed in a figure with 2 axes.

Figure 11: Current solutions
1) Training and curing methods

Among all the solutions for correcting posture for long term benefits, it is assured by scholars and experts that body training and injury curing is the most beneficial, but the fact is that the current working class barely has enough time to participate in this. There being not a designed product for this purpose, trainers usually need to assemble their own equipment for the postural practice. For an everyday non-professional population, such activities are very difficult to do at home.

2) Products for massaging and taping effect

Muscle fatigue and pain often comes along with poor postures. Therefore, pain relieving products are being massively used. Despite their effectiveness, these products are not dedicated directly to purposes of posture-building in a long term, as they have barely any influence on muscle memory.

3) Physical assistive products

There are also physical assistive products such as belts and rigid-shaped seats that can hold your posture in a certain form. But the fact is that these items take over the role of muscles to hold the posture for you, jeopardizing muscle growth. Having the tendency to recklessly rely on them, the users would find products in this category addictive.
4) Sensing and alerting technology

Sensing and alerting technology is at its early stage of development with great potential for postural alerting. However, most of the designs in the market are focusing on short term effects. Some features are frustrating, making users tend to discard them after a while.

Conclusively, these designs took different approaches for the purpose of correcting postures. However, being either a brand-new item or replacement for the users, they usually require a life habit change to use them. From the perspective of user psychology, this could be another layer of difficulty in getting the users to accept those products. Based on the research, it is reasonable that a new generation of postural assistive design needs to balance effectiveness and adaptability.
2.3 PROBLEM IDENTIFICATION

2.3.1 Observation and interview findings

To better understanding user needs, a target group survey and a follow-up interview was conducted with each of the 36 individuals (14 male, 22 female), whose occupations include student, office worker, service industry worker, lecturer, freelancer, and so on. The questions are majorly about their activities and habits on a daily basis. Statistics were collected and analyzed for creating the following figures.

![Observations & Interviews](image)

Figure 12: Observations and interviews (Based on Appendix B - Target Group Survey Posture and Trauma)
Thanks to the participants, we found that most of them hold postures around 7 to 8 hours in a typical day. It is very common among this group to not move and stretch unless they feel pain. Moreover, even though 82% of them graded their postures lower than 5 on a scale of 1 to 10, 1 being poor 10 being good, none of them had a clear idea on what they are supposed to do to improve it.

Concluding such insights from observations and interviews, we believe that there’s a clear unsatisfied need in this area from this group of people, which is an obvious opportunity for development.

2.3.2 Following research on muscle development techniques

As illustrated in the literature review, current existing products are not perfectly satisfying the need to correct postures for long-term benefit. Thus, the researchers reached out to experts and practitioners in relative fields, trying to learn the appropriate techniques to form a healthy posture.

PhD candidate, personal trainer Zezhao Chen, Dr. Yih-Kuen Jan, director of Rehabilitation Engineering at UIUC, and Randy Ballard, athletic therapist for USA national volleyball team, shared their theories on how body forms and postures can be acquired.
It is commonly believed in both academia and body-training industry that focused muscle training that strengthen the core - the abdominal and low back muscles is the way to form appropriate postures (Ratini, 2015). Most skeletal muscles are attached to two bones across a joint, so the muscle serves to move parts of those bones closer to each other (Taylor, 2012). Therefore, to form a posture, a person needs to have muscles working in pairs to tilt or align the body part that is connected to the joints, and to hold it still. Each muscle fiber consists a few motor units, and it is innervated by them. More importantly, it can also “remember” the amount of motor units to activate when doing a specific movement repeatedly, which is known as “muscle memory”. Muscle memory has been used synonymously with motor learning, which is a form of procedural memory that involves consolidating a specific motor task into memory through repetition (Wikipedia, 2010).

Therefore, to a certain extent, postural habit is an appearance of a series of muscle memory. Just like a system needs to be coded to function desirably, muscles that are responsible for posture-holding need to be trained specifically to gain the muscle memory, which happens when exercised in repetitions.

So, in what way can a person build postural muscle memory? As explained in the literature review, fast-twitch muscles and slow-twitch muscles are functioning and trained differently. For the purpose of posture holding, people need to build slow-twitch muscles more specifically.
Fast-twitch muscle training helps build volume and power, which usually needs dynamic exercises involving weight-resistance and repetitive muscle-contraction. However, the way to build slow-twitch muscles is isometric training, which is a type of muscle training where joint angle and muscle length do not change during contraction. This type of activities enables joints and muscle fibers to be held at a certain angle and length for a relatively long time. The following photographs are showing a demonstration given by Zezhao Chen on 2 different types of training for the same back muscle area.

Figure 13: Demonstrations on fast-twitch back muscle training - dynamic training

The figure above shows a typical technique for exercising the fast-twitch type of back muscle, known as “back fly”. Practicing this, the person needs to:

1) hold free weights in both hands;
2) lower his/her chest to as parallel to the ground as possible;
3) keep elbows at 90 degree angles;
4) contract the back muscles quickly to raise the weights until arms are parallel to the ground, and lower them back after a short pause;
5) breathe out when pulling the weights and breathe in when lowering them back (Dumbbell Exercises, 2008).

Such instant muscle contraction builds explosive power and strength in repetitions. As a result, the muscles would grow size and weight. These techniques are usually adopted for sport performance related purposes.

![Figure 14: Demonstrations on slow-twitch back muscle training - isometric training](image)

This is an exercise focusing on back muscles in slow-twitch type, known as “wall angel”. The person needs to:
1) keep the tailbone, lower back, upper back, and head against the wall;

2) move feet out from the wall and tuck chin in;

3) keep elbows and hands on the wall;

4) keep elbows at 90 degree angles;

5) breathe steadily and evenly (Martin, 2014).

Comparing to dynamic trainings, such isometric training generates a different effect. It improves stamina in joint and muscles for holding postures.

From the demonstration, it is indicated that corresponding muscle memory can be built by maximizing the amount of time one can hold an appropriate posture. Doing it repetitively, one can change a postural habit vigorously.
CHAPTER 3: CASE STUDY – PART 2

3.1 DESIGN-DEVELOPMENT METHODOLOGIES

There are 2 design experiment stages that have taken place throughout the process. The first stage was from January 2016 to March 2016. In that period, rough ideas were brought to experiments based on assumptions from preliminary literature research. After another round of in-depth research, from October 2016 to March 2017, design ideas got refined and the final concept was brought up.

Table 4: Design-development methodologies

<table>
<thead>
<tr>
<th>Methodology</th>
<th>Definition of Approach</th>
<th>Expectations</th>
<th>Outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brainstorming</td>
<td>Brainstorming is a group creativity technique by which efforts are made to find a conclusion for a specific problem by gathering a list of ideas spontaneously contributed by its members (MindTools, 2013).</td>
<td>The expectation was to generate as many ideas as possible to solve the problem.</td>
<td>Within 1 hour, 11 designers and 1 professor (Prof. William Bullock) worked individually in a meeting and came up with a total of 53 preliminary design concepts based on Austin Chen’s research findings.</td>
</tr>
<tr>
<td>Idea visualization</td>
<td>It involves techniques such as concluding, abstracting and sketching, to create images or diagrams to better explaining the concept (Kehoe, 2017).</td>
<td>The expectation was to communicate the ideas via visual languages, in order to organize and categorize ideas.</td>
<td>Ideation roadmap.</td>
</tr>
<tr>
<td>Competing product search</td>
<td>The search is to find out, understand, and learn from the competitors who have similar products in the market (Dahl, 2011).</td>
<td>The expectation was to find out and understand the competitors so as to find out directions to design the product competitively.</td>
<td>More in-depth and underlying requirements for design should be brought up.</td>
</tr>
</tbody>
</table>
Table 4 (cont.)

<table>
<thead>
<tr>
<th>Methodology</th>
<th>Definition of Approach</th>
<th>Expectations</th>
<th>Outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td>Computer aided design (CAD)</td>
<td>Use computer software for design objects in 3D precisely (Rouse, 2011).</td>
<td>The aim is to visualize and modify the form in 3D.</td>
<td>CAD models were built and finalized.</td>
</tr>
<tr>
<td>Prototyping &amp; testing</td>
<td>It is to rapidly make low-fidelity model of an idea to explain the concept, from which more refined forms and details can be developed (Rouse, 2005).</td>
<td>The researchers aim at creating a mechanical function model to test the assumption of utilizing sensing and alerting technology.</td>
<td>Several variations of testing models were fabricated. All other developments were based on the results from this stage.</td>
</tr>
<tr>
<td>Demonstration &amp; feedback gathering</td>
<td>This is to display the models and explain concepts to a small circle of people and acquire their opinions and suggestions.</td>
<td>Physical models as well as other visual aids are prepared for presentations and exhibitions. Feedbacks in various forms are taken.</td>
<td>The physical models functioned as expected in display, and feedbacks from various perspectives were collected.</td>
</tr>
<tr>
<td>Model making</td>
<td>According to the nature of the designed product, this process involved activities such as computer numerical control (CNC) routing, polyurethane molding, sewing, woodshop machining, soldering, and various types of measuring.</td>
<td>The team is collaborating to deliver the final functioning model. Industrial designer Austin Chen and mechanical engineer Prateek Garag are collaborating in this process.</td>
<td>The final model was assembled, with all appearance parts and electronics.</td>
</tr>
<tr>
<td>Coding and programing</td>
<td>This is the process of assigning a code to the smart device system for the purposes of displaying and better realizing the purpose of design.</td>
<td>Software engineer Gary Luo takes the role of programing the interface that can communicate with the hardware. The process is coordinated by industrial designer Austin Chen.</td>
<td>A functioning user interface was programmed in IntelliJ.</td>
</tr>
<tr>
<td>User evaluation</td>
<td>Similar to the demonstration and feedback-gathering process, we bring the product to more audiences to uncover how a person perceives it before, during and after interacting with it (Usability, 2013).</td>
<td>It is expected to get user evaluation feedbacks from 30 subjects, on the functionality, performance, expectations, and user experience.</td>
<td>Applications for further research on human subjects are being processed.</td>
</tr>
<tr>
<td>Photograph and videotaping</td>
<td>This is to record the design process, especially when it involves human interaction.</td>
<td>The researchers will clearly record visual and audio information that are necessary, and inform the participants the use of these files.</td>
<td>Pictures and videos for presentations and publications.</td>
</tr>
</tbody>
</table>
3.2 IDEATION

3.2.1 Design brief

Based on the evidence found in the previous research, it is determined that the solution, from the perspective of industrial design, needs to satisfy the following criteria that we concluded.

Repetition being the key for building postural muscle memory, maximizing the percentage of time in healthy postures is believed to be the main goal for design.

Besides, multiple secondary goals were confined after the current solution analysis and users need evaluation.

1) Positive reinforcement

The motivation of the users to improve their postures is one of the decisive factors that can determine the successfulness of this design. Psychologically speaking, if users can receive rewards when a favorable behavior occurs, it is very likely that the behavior will occur again in the future. So, the behavior will be strengthened.
2) Severity indication

Despite the accuracy, the effectiveness of an alert system can be very limited if it doesn’t indicate the severity or providing any information on posture adjustment. Therefore, a more user-friendly system is needed, instead of one that only judges “good” or “bad”.

3) Easy decision for users

Items in large volume or with a large value are very hard to be replaced because it could be a hard decision to make. Similarly, new products that people are not using currently everyday could also challenge people’s acceptability. We aim at making our product an easy decision for people, especially first-time users.

4) Long-term benefits

As we understand that agonist and antagonist muscles come in pairs, we would set a goal for this design to help achieve some long-term wellness goals for the users, such as regaining or building muscle balance, building capability to optimized range of motion, removing fixated muscle position, and preventing postural injuries.

3.2.2 Brainstorming

Based on the research findings, the team came up with a total of 53 preliminary design concepts. Later, these ideas were organized into 4 major categories: software solution, games/activities, fun design, wearables, and furniture.
Figure 15: Ideation roadmap
After careful selection, 4 major directions were highlighted for potential development.

Figure 16: Software solution

1) Software solution

As the mutual characteristics of target users being that they are living on screen-based devices such as computers and smart phones, it is reasonable to take those devices that they are using everyday as an existing platform, and build solutions upon it. Considering achieving positive
reinforcement and visualization, the team came up with the idea of utilizing motion sensors to investigate postures, and displaying a real-time posture indicator on the screen.

Figure 17: Games/ fun design

2) Games/ fun design

This design direction aims at optimizing users’ motivation to do postural exercises. Adapted from muscle training techniques, some movements can be transformed into games at workplace. With products designed specifically for these purposes, office workers could be motivated to reduce their sitting time and get core muscles exercised.
3) Wearables

For the purpose of designing a light, portable, and seamless product, the anticipated solutions could be technologies embedded in garments and accessories. Within the feasibility of current technologies, these items could serve as alerting as well as sensing devices simultaneously. Aiming at a hands-off functioning product, wearables for postural correcting could be a design direction with potentials.
4) Furniture

The office workers need to interact with office furniture constantly for typically 7 to 8 hours a day. The chairs, desks, floor mats, etc. can all be potentially re-designed with added value for posture assisting. Changing the form and materials of a product can change the affordance, which is the way people interact with it. Embedded sensing and alerting technologies can add even further value to it.
3.2.3 Evaluation

The next step was to evaluate the advantages and disadvantages of each direction based on evidence and reasons.

Table 5: Pros and cons

<table>
<thead>
<tr>
<th>Ideas</th>
<th>Pros</th>
<th>Cons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Software Solution</td>
<td>It can be plausible for technology users.</td>
<td>Without physical interaction, the users’ motivation could decrease.</td>
</tr>
<tr>
<td>Games/Activities/</td>
<td>Design in this type can provide an immersion experience. Users can</td>
<td>The audience could be limited. It could be distracting at the</td>
</tr>
<tr>
<td>Fun Design</td>
<td>form a more emotional bond to it.</td>
<td>workspace.</td>
</tr>
<tr>
<td>Wearables</td>
<td>It could be light, portable, and seamless.</td>
<td>As an optional new item, people may find it a lifestyle changing</td>
</tr>
<tr>
<td></td>
<td></td>
<td>decision to make use of it.</td>
</tr>
<tr>
<td>Furniture</td>
<td>As an item with large volume and not requiring mobility, furniture</td>
<td>The scenario of usage can be limited.</td>
</tr>
<tr>
<td></td>
<td>may have more possibilities for design to play with.</td>
<td>It could be a big decision to make when it comes to making decisions</td>
</tr>
<tr>
<td></td>
<td></td>
<td>for buying/replacing an item with large value, which could be</td>
</tr>
<tr>
<td></td>
<td></td>
<td>unhealthy, speaking from the perspective of new product inventors.</td>
</tr>
</tbody>
</table>

The “pros” and “cons” with the consideration of various factors, helped clarify the “dos” and “don’ts” for the design. Bringing all factors into consideration and to achieve the goal of design, the team narrowed down the direction of forms to a physical product and a digital interface.

The aim was to add the value of postural assisting to an everyday item that is already commonly used by target users. Moreover, this item is envisioned to be in relatively small volume, and ideally with features that can bring joy to people.
3.3 COMPETING PRODUCTS

This section is a study on competing products for better identifying the design opportunities. Cases were selected to be studied for their similarities in form, functionality, and target user group to this project. These products are all utilizing sensing technology, aiming at helping users in daily office environment with their postures by real-time alerting.

3.3.1 Lumo Lift Posture Coach & Activity Tracker

The Lumo Lift is a sensory wearable device and an activity-tracking app for posture alert. Worn on the garment, it gently vibrates every time the user slouches (Lumo Bodytech Inc., 2016). The technology was a rechargeable battery powered inertial measurement unit, also known as IMU sensor, which is an electronic device that combines accelerometers and gyroscopes to measure a body's specific force and angular rate. A picture of usage scenario shows its features.
With a small attachment close to the collarbones, this device can sense the body movement, and sync the data to smart device for display. This product is currently available to be ordered online.

**Table 6:** Lumo Lift key features and price (Based on Lumo Bodytech Inc., 2016)

<table>
<thead>
<tr>
<th>Key Features</th>
<th>Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>Real-time alerting, activity tracking, history, Bluetooth wireless syncing</td>
<td>$69.99 ~ $99.99</td>
</tr>
</tbody>
</table>

The key features of this product were listed in the table above. However, even though this device is light, small and comfortable, the major limitation is that with its one sensor, it can only sense movements in the sagittal plane. In other words, it can only sense slouching, but cannot do much about the body tilting in coronal plane to the left and right. It is also challenged in
posture sensing accuracy, according to design commentator Sarah Mistroff’s comment:” The Lift app's offers too much design and not enough data (Mistroff, 2015).”

3.3.2 UpRight Posture Trainer

Similar to Lumo-lift, “UpRight” is a posture trainer that attaches to the lower back and vibrates when the user slouch. It also comes with an app for iOS or Android devices and Apple Watch as a personalized training program (Glassninja, 2015). The following figure shows the usage.

Figure 21: UpRight Posture Trainer (Wie Einfach, 2017)
UpRight uses a hypoallergenic adhesive for a closer contact and more accurate readings. Using the same type of sensor as Lumo-lift, it can however, be applied to more user scenarios as it is closely attached to human body which helps avoid misreading from clothes movements (Ci, 2014). However, the real-time vibrational alert could be an underlying frustration and a distracting feature for users as it can get triggered too frequently.

**Table 7:** UpRight key features and price (Based on UpRight, 2017)

<table>
<thead>
<tr>
<th>Key Features</th>
<th>Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>Real-time alerting, accurate posture sensing, automatic turn-off feature</td>
<td>$79.99 ~ $129.99</td>
</tr>
</tbody>
</table>

For battery saving purpose, this device knows when to automatically turn off as its stretch sensor senses the skeleton (Ci, 2014).

### 3.3.3 Darma

Another innovation in the market for posture correcting is Darma. They describe their invention on their website as: “It is a smart cushion that monitors your posture, sitting habits, stress level, and coaches you to sit better (Darma, 2017).”
In the form of a cushion, this product is dedicated specifically for office setups. Different to Lumo-lift, UpRight, or most of the other posture sensing devices in the market, Darma took a different sensing approach, Ballistocardiograph, to measure postures. Basically, this device measures the heart rate variability in certain body area to assess the pressure distribution. With this technology, Darma could accomplish the following features.

**Table 8:** Lumo Lift key features and price (Based on Darma, 2017)

<table>
<thead>
<tr>
<th>Key Features</th>
<th>Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sitting time reminder, habits report, stress level monitoring, stretching instructions</td>
<td>$199</td>
</tr>
</tbody>
</table>
The features are showing that this device focuses on the overall wellness of office workers, assisting not only the postures, but also spiritual health.

### 3.3.4 Insights

From analyzing related products, the researchers were able to better understand users’ expectations as well as capabilities and limitations of current technologies. Several new requirements were brought up from this research stage.

1) Assessing posture in both sagittal and coronal plane;
2) high accuracy in posture sensing;
3) seamless and easy to use;
4) energy saving;
5) minimizing discomfort and distractions at workplace;
6) overall wellness as a long-term goal.
3.4 PROTOTYPING AND TESTING

The major part of preliminary modeling and functionality testing took place from October 2016 to February 2017. Several variations of prototypes were made with a layout of pressure sensors to assess the change of sitting postures on a surface. The prototyping and testing were for the purpose of understanding the viability of this sensing and alerting system, before the team got down to design the form, appearances, tactile, and other details.

The first low-fidelity model was made in January 2017. It was a scared-down model with 6 pressure sensing units connected to an Arduino board. The purpose was to test if this type of sensors is capable for sensing the center of pressure excursion on a sitting surface.

Figure 23: Sketch models with pressure sensors

As shown in the photographs, 6 sensors were wired and taped on a piece of soft fabric and placed on an office chair in the first model. The researcher sat on it and tried to position his body to different postures, and recorded the changes in readings on each sensor. This model managed to sense the pressure change, although accuracy was limited by the rigidity of the
office chair cushion and the number of sensors. Some sensors would read zero when the body was not sitting exactly on top of it. Therefore, the next step for the researchers was to redesign the sensor layout and to add rigid materials to the sensor board to cope with the flexible seat surface.

The second variation of hardware was done after several modifications. This is a full-size model with re-engineered circuit board layout.

![Figure 24: Second prototype model soldering (left), layout (middle) and testing (right)](image)

In this model, a total of 12 pressure sensors were used. Via testing, 12 is believed to be the most suitable number of sensors for accurately sensing the postural pressure change. To cope with the reading error, the team came up with the idea of building a “sandwich” structure by placing sensors on a soft foam board in between 2 rigid acrylic boards. The structure is shown in the following sketches.
This new engineering solution helped distribute pressure on the surface and avoid sensors reading zero, and successfully decreased the errors when functioning on top of soft cushions.

Along with the hardware development, the team took several attempts to prototype and test the exterior model. The process started with sketches, clay models and digital models built in computer aided design (CAD) software.
For ergonomic comfort, the team hand-crafted a full-size cushion model based on body shape. It was later photographed and used as reference for CAD. The digital model was done and transferred to a CNC routing machine for accurately fabricating rigid foam model.
As the physical model was built, the researcher managed to physically sit on and interact with the full-size model. This prototype played a crucial role in form evaluation. Based on this model, the researchers made decisions on changes and modified the CAD model.

Meanwhile, the team decided to use polyurethane to create a flexible cushion. Second round of CNC routing took place for building a mold for expanding foam modeling.

Figure 28: FlexFoam-iT! X (Reynold’s Advanced Materials, 2014)
After comparison with different types of foam in density and flexibility, a strong flexible casting foam, FlexFoam-iT X, was selected for the best outcome. Liquid A and B being mixed together, this liquid foam was poured into a prepared mold that is shown in the following photograph.

![Figure 29: Cushioning material modeling: expanding foam modeling (left), cushion model (right)](image)

The liquid foam soon expanded and formed into a flexible cushioning shape as desired. Pulled out from the mold, the cushion model worked as a suitable housing for the hardware. Fabrics and zippers were later sewed to complete the prototype.
With the completion of the fabric case, a minimum viable model was done, concluding the prototyping and testing stage of this project. In this stage, the research team explored the possibility of the pressure sensing technology, and came up with several creative solutions for sensing posture excursion on seat surfaces.
3.5 REFINED SOLUTION

The solution got modified and refined from January 2017 to April 2017. At this stage, the team built final CAD models and renderings, modified hardware and software, made hi-fidelity models, and took videos and photographs.

The final design, PosturSense Cushion, is a re-innovated everyday product that utilizes pressure sensing technology, aiming at assisting users to regain awareness of postures to achieve a long-term wellness benefit. The design consists of a redesigned cushion and a posture indicator to be displayed on smart devices.

Figure 31: PosturSense Cushion overview
The 2 major features that this cushion has are posture improving, and a user-friendly way of alerting. In general, the users would receive postural correcting information from both tactile and visual assist.

### 3.5.1 Redesigned Cushion

The cushion is in a wedge-shaped form covered in a fabric case with non-slip silicon strips. As shown in the following figure, the footprint of this cushion is finalized to be 16 by 16 inch. The silicon strips layout is designed in a ripple form in response to the user interface graphics.

![PostureSense Cushion dimensions](image)

*Figure 32: PostureSense Cushion dimensions*
According to the market research, cushions in this size are predicted to be applicable to most office chairs. This dimension also assures adequate space for the hardware to be housed.

The wedge shape of PosturSense Cushion is designed to be approximately 13°. The result is supported by evidences from ergonomic studies.

Studies by Etienne Grandjean indicate that VDT operators have preferred 13-15-degree backward incline (Grandjean, 1980). At this angle the pressure on the intervertebral discs is minimal. Based on the study result from the Back Centre LTD (Ivybridge, U.K.), the angle assures a more open angle between body and upper leg, preventing the inward curve of lumbar spine being flattened out.

The contour on the top of the cushion helps support the pelvis in a healthy position which is avoiding either anterior or posterior tilt.
As shown in the figure, the biomechanical structure of human pelvis determines that even a small inward or outward tilt can cause the spine to be positioned in an overhyped angle, increasing pressure in the inner surface of each vertebrae. The contour of the cushion was designed specifically to position the pelvis in the neutrally upright position so as to ensure spine maintaining a natural curve, offsetting the negative influence created by seat surface angle to the spine.

Along with the upper contour, the cushion also has a groove that continues to the back of the cushion. This “cut out” design is dedicated specifically for coccyx (tailbone) comfort.
The natural suspension position of coccyx is that it rests lower than the buttock cheeks. A flat seat surface can put body weight on the coccyx and cause pressure. Therefore, a cut out design can set the tailbone at ease when sitting.

PosturSense Cushion is a modular system. The cushion itself can be transitioned as a back pillow as well, as the supporting contour for the back is the same as it is for the buttock.
With this feature, this product is providing users with options to choose their preferred way of interaction, and satisfying a larger variety of needs in the office environment.

The cushion is applicable to various occasions for posture correcting and training. The following photographs showed its usage on a car seat and a couch at home.
These are also scenarios besides office environment where people will sit and hold their posture for a long time. PosturSense Cushion can be used on various type of seat surface and function the same way.

### 3.5.2 Posture indication and smart alerting system

A corresponding algorithm was created for translating data from a layout of force-sensitive resistors to a center of pressure (COP) indication. In this way, the postures can be visualized and monitored.

When a sitting posture is changed, the COP should also change accordingly. Therefore, the COP excursion is correlated to the change of the angle between one’s body and the surface.
The graphic is illustrating the correlation between sitting postures and COP. When a person is sitting in his upright position, his/her COP should be in the center of the seat surface. As an acceptable range of COP movement, the “green zone”, being set, the system can send out alert when the moves away from this zone.

A posture indicator is designed to be displayed on the screen of a smart device. The system translates the COP excursion to info-graphics for the users to visualize their posture change.
This is the interface of the posture indicator on the screen. The dot represents where the COP is in the zone, and the color indicates the distance and duration of the COP being off-centered. When the person starts to either tilt to one side or slouch, the dot moves accordingly indicating where the COP is moving towards. The more severely the person is off-centered, the more orange the dot will turn. When an inappropriate posture has been held for over 2 minutes, the dot would turn red, and the device will send out a vibrational alert, suggesting that the person should either adjust his/ her posture, or leave the seat for a stretch.

Conclusively, this alerting system is hierarchical, showing the severity of one’s posture. Instead of simply judging a posture as “good” or “bad”, PosturSense Cushion functions in a relatively gentle way. With visualization features added to the system, the users can see how far they are off from a preferable posture, and get the directional information from the screen on how to move and re-align.

3.5.3 Usage scenario

1) Calibration

The user should first connect the device to a computer via cable or Bluetooth, then sit on it and click the “Calibration” button with the cursor. The small green dot will show up on the screen indicating the COP.
As the user calibrates, the posture he/she is holding at that moment will be taken as a centered upright position. It is going to be referred to as a desirable posture for adjusting. The window on the screen can be moved freely.

After sitting for a while, the user may start to tilt or slouch.
The dot will move accordingly to which direction the person is tilting towards. The color of it will change from green to orange as it moves away from the center. When an inappropriate posture has been held for over 2 minutes, the dot will turn red, and a gentle vibration will be sent out from the cushion.

Figure 42: Adjusting posture (left) or leaving the seat (right) when being alerted

Being alerted by either the tactile feedback or visual signal, the user will be guided to adjust his/her posture back to the calibrated upright position. He/she can also choose to leave the seat for a stretch. The device will automatically turn off when the user is not sitting on it.

To check the progress, the user will go the history page. Postural performance of each hour, day, week, and month will be recorded and shown in bar charts.
The entire design is aimed to be positively reinforcing so as to encourage users. The system would keep sending out positive messages, informing users of their appropriate postures, aimed at creating a satisfying experience. Observing the center of pressure excursion on the screen and trying to keep an appropriate posture could be as well a gaming-like experience.
3.5.4 Electronic components

The major sensing components for this device are the Force-sensitive resistors (FSR), which detected physical pressure, squeezing and weight. They are basically resistors that change their resistive value (in ohms Ω) depending on how much is being pressed (Adafruit, 2009).

![Diagram of electronic components](image)

Figure 44: Electronic components

The functionality was achieved by a total of 12 FSRs. The electronic signals from each FSR were collected by a Arduino Uno microcontroller. The data were then sent to the computer to
function the software. After processing, some commands were then sent back to the hardware. Receiving these, the microcontroller will function the vibration motors to alert.

For protecting the hardware and increasing the accuracy of data reading, the team finalized the concept that was tested during prototyping stage. That is placing one rigid acrylic board on each side of the circuit board to form a “sandwich” structure.

![Figure 45: Explode view of interior structure](image)

The 3-D rendered graphic is an illustration of the interior structure of this device. The protective shields were made from acrylic, a type of flexible yet stiff material. The entire hardware part is housed in between 2 cushioning foams. They are made from expanding polyurethane in a CNC routed mold.
3.5.5 Exhibition

The project was exhibited to the public at the 2017 Master of Fine Arts Show (University of Illinois, Urbana-Champaign, Illinois), which lasted for 2 weeks in April. The device was open to the attendees to try out.

![Figure 46: PosturSense Cushion demonstration at exhibition](image)

The demonstration showed the capability of this device to the audiences. From that, the team received feedbacks about different aspects. The committee faculties and major researchers of this project presented at the exhibition.
The exhibition affirmed the research value and potential market value of this product. The research and development of this project will be continued by the team.

3.5.6 Envisioning

The PosturSense Cushion is beyond being just a product. It could serve as an inspiration for postural technology and design research in the future. The product itself is envisioned to be a smart module that can have multiple applications of use.
In the future, products that assist human wellness will be needed in all aspects of daily life. Technologies are foreseen to be much seamlessly involved in people’s daily life. Information synchronization and interactions will occur among devices of different types for convenience.

![Multi-functional Module](image1)
![Mobile Application](image2)
![Functioning Independently](image3)
![Data Synchronization](image4)

Figure 48: Future extension

According to the foreseen future, the software will feasibly transform into applications on devices in various type of operating systems. A more advanced burnt-in operating system would even allow it to function itself, without another device being connected.

Such postural smart device could easily tackle the financial inefficiency of face-to-face interaction between doctors and patients. Thus, the patients would feel less stressful during physical therapy visits. As the postural performance data can be recorded and synchronized on doctors’ and patients’ devices, training and curing can be simply monitored.
Applicable in various occasions, this technology can be adopted by manufacturers of traveling gear, office applications, and even airline seating. They will assist postures in multiple different scenarios for a larger variety of audiences.
CHAPTER 4: LIMITATIONS AND RECOMMENDATIONS

4.1 LIMITATIONS

Constrained by various factors, researchers of this study did come across conditions and influences that cannot be controlled. The design solution also has certain shortcomings.

1. Performance and durability of sensors

The sensors (FSRs) being used in this design for device functionality were purchased from the market. They are not initially tailored for this device. Their performance and durability could be inconsistent to a certain extent.

2. Options on electronic components and materials

The current design being a practically viable model, there could be better options on electronic components. Some parts can be potentially customized for reduced volume and weight. As technology advances in the future, the product can be developed furthermore.

3. Underlying needs

This study is focusing exclusively on creating an efficient solution for the postural health problem. However, we won’t exclude the possibility that other user needs can be satisfied by this product, which generates possibilities for future research and development.
4. Individual characteristics of users
Because each human body has a different level of sensitivity on tactility, color, blinks, and so on, the effectiveness of this product can differ from person to person.

Conclusively, limitations on this study is subjected to several exterior factors that can’t be controlled by the researchers of this study. However, these may create opportunities for further research and development on this project.

4.2 RECOMMENDATIONS

Based on the current accomplishment, a future research plan was made by the team. The next step of this project will be as follows:

1. Design variations and modifications

As the research continues, the design should be modified based on new findings and context.

2. Human subject testing

To better assess the functionality of PosturSense Cushion, it is important to get the users involved in the testing, and compare the COP sensing accuracy of this device to a golden standard force sensing device. Therefore, the team submitted a functional assessment plan to
the Institutional Review Board (IRB) of UIUC, and received the approval in July 2017 for human subject testing. The testing set-up is as shown in the following photograph.

![PosturSense Cushion prototype on a Force Plate](image)

**Figure 49: PosturSense Cushion prototype on a Force Plate**

The cushion will be placed on top of a Force Plate, and human subject will sit on it and be asked to lean to certain positions. A total of 30 participants will be invited to the testing in July and August 2017.
3. Patenting

The researchers will search and ensure this invention has no conflict with existing patents. The team should apply for patenting to protect their intelligent property.

4. Publication

The research result and design concept should be published in academic journals and other platforms to get further exposed to public for optimizing the influence and academic value.
CHAPTER 5: CONCLUSION

Identifying an emerging postural health problem of 18 to 35-year-old office workers, the research team from UIUC visualized a solution, utilizing sensing technology in the form of a re-designed cushion with postural assisting and smart alerting features. It is a solution for discreetly monitoring young people’s posture by sensing and movement assistive technology.

As the research is showing, back injury is causing an enormous financial and workforce loss in society. Posture health is getting on people’s nerve and increasingly drawing people’s attention nowadays. This device is designed for improving people’s postural wellness to reduce such losses. For precaution instead of cure, this design is trying to let the young adult population learn how to live a healthy life before their poor posture turns into chronic diseases.

It is an anticipated area that the product can be a “culture input” in the young generation lifestyle, benefiting their future. It is almost predictable that, in the rest of their life, they will continue being users of those products that they got used to in early ages. As healthy posture can be acknowledged as an attractive culture, young people would tend to follow the trend and form good habits that benefit their future. The ultimate goal for this project is to form and strengthen this culture.

In conclusion, this thesis is in support of an assumption that, in the long term, sensing and assistive technologies would offer to improve people’s postural health by helping regain and
build muscle balance, remove fixated muscle position, and prevent trauma resulted from inappropriate postures.
REFERENCES


APPENDIX A: CORRESPONDENCE LETTER – ADAM JOHNSON

CARLE SPINE INSTITUTE
610 N. Lincoln Avenue | Urbana, IL 61801 | (217) 383-6555 | Fax: (217) 383-7069

1/22/16

To Whom It May Concern:

As the senior physical therapist at the Carle Spine Institute, Urbana, IL, I am excited about the idea of a postural garment that does not offer physical support, but rather postural feedback in real time. Rigid bracing and supports have failed low back and neck pain patients. They have proven ineffective in clinical trials and, save for a few specific spine conditions, have appropriately gone out of popular use in medicine. Moreover, back braces typically allow a spine patient to relax their muscles too much, resulting in weaker muscles over time; the end result is greater mechanical loads being transferred from the muscles to the damaged, painful spinal structures. However, if patients can strengthen and tone their postural muscles and maintain better postures throughout the day – especially when sitting – then irritating and potentially damaging mechanical forces can be taken away from the spine. I can foresee a wearable garment that alerts patients to poor postures not only helping tone and strengthening postural muscles but also improving the patients’ postural awareness. The ultimate goal would be improved postural awareness for good, lifelong postural habits.

Beyond the common cold, low back pain is the number one reason to miss work in America. It is the most costly medical condition to our society. It is the number one cause of long term disability in those under the age of 45 and one of the main drivers for disability insurance premiums. Recent research has begun to shed new light on the importance of correct sitting posture for the prevention and reduction of back pain, especially in the workplace. The American workforce is becoming progressively more sedentary (i.e., sitting jobs) and tends to sit slouched over, a posture that puts up to 85% more pressure on the intervertebral disc compared to standing. This also is the very position of the spine (flexion) that has repeatedly been shown to cause bulging and herniated discs. A simple correction of sitting posture will immediately reduce discal pressure by 40-85% and eliminate damaging forces. Currently, however, no one has developed a way to consistently keep a person in correct sitting posture. Worse yet, no one has developed a simple way of alerting someone when they lose their posture in all their various sitting environments. Yes, there are lumbar supports to attach to a chair which aid in reducing spinal flexion, but most of my patients are self-made experts at slouching even with a lumbar support.

In the clinic the greatest challenge we have is not in teaching a patient to learn the correct posture. It is in the patient being aware when they lose the correct posture. Their kinesthetic awareness -- the awareness of one’s own body position -- is simply lacking. Physical therapists have all sorts of tools and tricks to teach posture, but a spine patient can lose his/her correct posture in a matter of seconds. He/she can end up slouching to the nth degree in less than 1 minute, totally unaware and right in front of the therapist.

A spine pain patient’s progress with healing/relief is directional proportional to his/her compliance with sitting posture. The deck is already stacked against spine pain sufferers due to an innate lack of kinesthetic awareness. Couple this with the fact that insurance companies have reduced physical therapy visits. In recent years it has proven quite difficult to consistently improve our patients’ posture as they are only allowed to attend PT 2-4x/month; the window of training and correction for our patients has narrowed significantly. Decreased visits = decreased understanding = decreased patient compliance. This is akin to expecting an NCAA basketball team to make it to the Final Four, yet they
don’t get to see the coaching staff more than every 10 days during the season. Should a spine patient have consistent, daily training on posture, he/she could become world class in a matter of weeks. A garment that provides such daily, consistent postural feedback may just be the answer we are looking for in my profession, especially if it were able to be calibrated in the clinic, custom-tailored to the patient’s injury and needs.

A quick cost analysis: 15 minutes of neuromuscular education in the physical therapy clinic is billed at $115. Patients are seen for an average of 30-45 minutes/visit. That’s $230-$345 in postural education and exercise. At 1-2 visits per week the cost adds up quickly. The closest I can come to a wearable posture device is taping a patient’s spine. The tape can be worn for 2-3 days before the skin begins to break down. It costs $115 to tape the patient and the tape loses its effectiveness as it gradually loosens. I figure it really only gives good, real-time postural input for the first 4 to 8 hours. Hence, postural education and compliance per medical dollar is frustrating to say the least. A postural smart garment could easily (pardon the pun) knock the pants off my profession’s financial inefficiency. And it would open up greater windows of relief during physical therapy visits as more time could be spent on pain relieving exercise instruction, manual therapy, etc.

While I find sitting posture correction to be the greater challenge, standing and walking postures deserve attention as well. And a smart garment could easily address these. While I have seen a few creative ideas that give vibratory feedback in a chair (I’m not sure if they ever made it past the R&D phase), they did not cross over to standing and walking. A garment is the only device I can foresee that would cover all the loading modes of the spine: sitting, standing, walking. One device, 16 hours per day. That’s as good as it gets. Who knows; it could probably even be worn for sleeping posture correction. A lot of patients wake up in more pain due to bad positioning in bed.

Simply put, more is needed to further the cause in reducing and preventing spine pain. At the end of the day, patient independence and compliance are the keys to success for spine pain. A postural smart garment could significantly increase the odds of lasting relief and increased function.

Sincerely,

[Signature]

Adam Johnson, PT, Cert. MDT

Carle Spine Institute

Teaching Faculty, American BackPain Center
Target Group Survey
Posture and Trauma

How long do you sit/stand at your workplace?

Do you adjust your fixed posture during the length of your work?

What do you think you should do to make yourself comfortable at work?

On a scale of 1 to 10, how much do you care about the look in your posture, if not considering about other factors such as comfort.

What would you do to help you keep a good posture? (Choice of furniture? Reminder? Or just by feeling?)

What would you do once you feel pain?

If you feel pain, how do you relief it? If you never feel any, you can skip this question.
What do you do after the pain is relieved?

On a scale of 1 to 10, grade your own posture in a typical day of work.

What would you do to develop good postures?

Have you learned anything about muscle training can possibly help with postures?

Are you willing to purchase any product that is designated to help with posture at workplace?

What do you pay for the most at workplace?
APPENDIX C: IRB APPROVAL

University of Illinois at Urbana-Champaign

Office of the Vice Chancellor for Research
Office for the Protection of Research Subjects
805 West Pennsylvania Ave
Urbana, IL 61801

July 5, 2017

Deana McDonagh
Fine & Applied Arts Admin
143 Art and Design
408 E Peabody Dr.
UIUC Campus Mail, IL 61820

RE: Functional Assessment of PosturSense Cushion in Comparison with a Force Plate
IRB Protocol Number: 17831

Dear Dr. McDonagh:

This letter authorizes the use of human subjects in your project entitled Functional Assessment of PosturSense Cushion in Comparison with a Force Plate. The University of Illinois at Urbana-Champaign Institutional Review Board (IRB) approved, by expedited review, the protocol as described in your IRB application. The expiration date for this protocol, IRB number 17831, is 07/04/2018. The risk designation applied to your project is no more than minimal risk.

Copies of the attached date-stamped consent form(s) must be used in obtaining informed consent. If there is a need to revise or alter the consent form(s), please submit the revised form(s) for IRB review, approval, and date-stamping prior to use.

Under applicable regulations, no changes to procedures involving human subjects may be made without prior IRB review and approval. The regulations also require that you promptly notify the IRB of any problems involving human subjects, including unanticipated side effects, adverse reactions, and any injuries or complications that arise during the project.

If you have any questions about the IRB process, or if you need assistance at any time, please feel free to contact me at the OPRS office, or visit our website at https://www.oprs.research.illinois.edu.

Sincerely,

Michelle Lore, MS
Human Subjects Research Specialist, Office for the Protection of Research Subjects

Attachment(s): 1 Research Team Application, 1 Consent Form

c: Elizabeth Hsiao-Wecksler
    Ruixi Chen
    Prateek Garag
APPENDIX D: SUPPLEMENTARY FILE

The supplementary file [PosturSense Cushion Demonstration Video.mp4] is a 3-minute recording of an introduction to the final design. The video consists of an overview to this project, an elaboration of the design solution, and a usage demonstration of the working model.