SeatPlus: A Smart Health Chair Supporting Active Sitting Posture Correction

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Abstract. Nowadays, sedentary and poor sitting postures mainly cause lumbar spine-related diseases for office workers. According to the related medical theory of sitting posture correction, this paper presents a smart chair *SeatPlus* that actively corrects the poor sitting posture. To identify and address the issues in sitting posture correction, we iterated our prototype three times following Lean UX design method. We evaluated *SeatPlus* in terms of system performance and system usability. The accuracy of the sitting posture recognition is higher than 90%, and the effectiveness of correction exceeds 70%. The overall usability of *SeatPlus* is good especially in two usability dimensions, impact and perceived Ease of Use. Furthermore, we find that the effectiveness of correction positively influences some usability dimensions, while the frequency of correction negatively influences the perceived ease of use.

Keywords: Real-time monitoring · Active correction · Smart chair · Healthy sitting posture · Lean UX

1 Introduction

Cervical spondylosis of lumbar vertebra is ranked as the second most persistent ailment in the world by the latest World Health Organization. In China, more than 200 million patients suffer from this disease caused by sedentary and poor sitting postures. Most existing approaches of sitting posture correction work as a reminder, that is users adjust their postures based on the suggestions from the system. By contrast, "active" posture correction takes *dynamical* actions to stimulate users to *subconsciously* adjust poor sitting postures. Figure 1 illustrates the active correction enabled by the inflated airbags.

Following the Lean UX design method, we iterated the design of *SeatPlus* three times based on a minimum viable product (MVP). We use rapid experimentation and measurement to learn quickly how well (or not) our ideas meet

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our goals. In specific, we optimized data communication among devices, the algorithm of recognizing sitting postures, and the ergonomic design of the chair. In the end, we evaluated the system performance and system usability of the chair and analyzed relations between them.

Considering the S-shaped spine, the weight of the upper part of the spine will cause the pelvis to turn backward and the shrink of the curvature of the lumbar vertebra. When the body leans forwards the center of gravity moves forwards, which results in excessive pressure on the lumbar vertebra. In order to keep the stability of sitting after a long time, the waist muscles and lumbar muscles are going to be tight and strained. If the pressure cannot be relieved all the time, the intervertebral discs and nerves might be crushed, which will lead to severe pain. The good sitting posture requires users to keep upper body and waist straight, both legs parallel, both feet on the ground, and buttock flat.

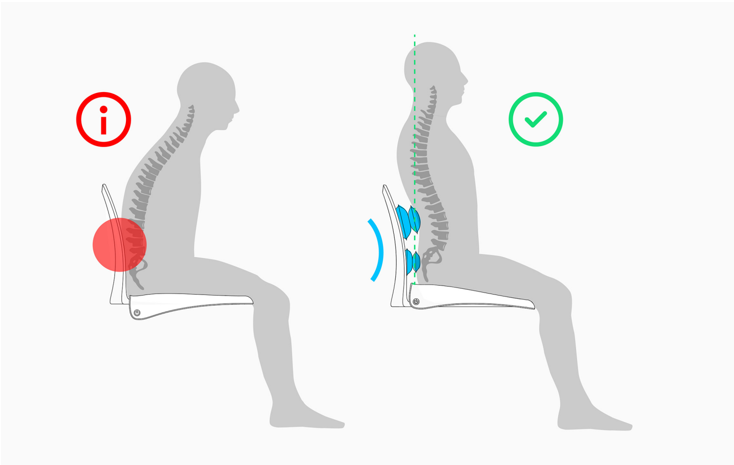

Fig. 1. Illustration of active correction

In this paper, we mainly collected 8 common sitting positions in the office, which includes good sitting posture, humpback, reclining, shallow sitting, cross-leg (left), cross-leg right, inclining to the left and right.

Before designing and developing the prototype, we first elaborated our research motivation from the social, economic and technical aspects by using SET factorial analysis [7].

Social Factors: According to the 2016 edition of the American Diabetes Association (ADA) guidelines, one-time sitting time should not exceed 90 min, and 58.6% of office workers sit for more than one hour at a time, of whom 39.3% sit more than 90 min. The 2019 white Paper on sedentary behaviors in the workplace points out that China has 140 million white-collar workers, of whom only 16.1%

can maintain a good sitting posture. More and more enterprises are paying more attention to employees' sedentary health investments.

Economic Factors: As living standards improve, the demand for health services is shifting from traditional disease treatment to disease prevention. In 2016, the China government issued the "2030" planning framework for a healthy China. It pointed out that the "treatment-oriented" policy should be transformed into a "health-oriented" policy. With prevention as the most important policy, the market of China's health care is estimated to exceed 1.1 trillion USD in 2020, and the market segment for waist care reaches 10 million USD.

Technical Factors: With the rapid advance in sensors and AI algorithm, sitting posture monitoring can be realized with high accuracy and fast response. At present, there are three major techniques for posture recognition: sitting duration monitoring, posture pressure monitoring, and posture image monitoring.

The contributions of this paper are threefold:

1. We proposed a way to integrate active posture correction into a smart chair.
2. We revealed the relationship between the system performance and the system usability. It is found that the accuracy of recognition positively influenced overall usability, while the frequency of correction negatively influences the perceived ease of user.
3. We summarized the practical experience of Lean UX based on research and development in an enterprise environment.

The rest of the paper is organized as follows. We will first discuss the related work followed by the description of the system design, design methodology, and user study. After that, we present the study results and conclude the paper with discussions about the user study and design methodology.

2 Related Work

In this section, we briefly review the related works about sitting posture recognition and correction.

2.1 Sitting Posture Recognition

So far, sitting postures recognition are mainly based on sitting duration, sitting pressure, and sitting posture images. The sitting duration approach reminds users to adjust their postures by sending notifications [10,16,26,29]; however, the users may ignore such an intrusive reminder [23] as it may distract users attention from the primary task. While the pressure-based recognition leverages various sensors to collect sitting pressure data such as load cells [1,3,17,18], accelerometers [19], etc. It is easy to train a good classification model having above 90% accuracy of recognition by using classic machine learning algorithms such as decision trees, SVM (Support Vector Machine), the higher accuracy can be achieved by using deep learning techniques [8,13]. Besides, several systems detect sitting postures by the images captured by an RGBD camera [5,22,30], the accuracy of recognition may be subject to the lightness of the environment and the area of body captured by the camera. Therefore, we decide to follow a pressure-based approach to implement the module of detecting sitting posture in our system.

2.2 Sitting Posture Correction

Based on the mechanism of correction, the correction approaches can be categorized into passive correction and active correction. The passive means the system does **not** take direct actions to improve postures. For example, the passive correction can be a reminder or ergonomic sitting back. Most existing correction systems present various ways to remind and guide users to good postures. For example, showing the sitting posture information on different personal devices [4,6,15], and providing haptic feedback by vibrators. Since these approaches are all intrusive, some non-intrusive corrections try to avoid distracting users from the primary task while guiding users to good posture, for example, a slowly moving robot arm for unobtrusive posture correction [25]. The representative products of ergonomic design for postures correction are chairs supporting lumbar [11], adjustable desktop platforms [9,20], and a cushion member for fixing sitting posture [28]. However, the user acceptance of these products may be subjected to the low comfortableness after long time use. By contrast, active correction means a system can dynamically adjust the physical form of a chair when it detects poor sitting postures [21]. As far as we know, most existing approaches of sitting posture correction still work in a passive way.

3 System Design

This section describes the hardware frame design, I/O design, algorithm design, App design, and the practice of Lean UX design method.

Based on the results of user research, *SeatPlus* has the following design requirements:

1. The sitting surface and the backrest need to support the waist and back;
2. The system can detect if the sitting posture of a user is wrong;
3. The system provides a corresponding intervention if a wrong posture lasts longer than a certain time.

3.1 Hardware Frame Design

The design of this hardware frame should be comfortable for sitting and effective for sitting data collection. Moreover, the hardware frame should prevent users from wrong sitting postures. The seat cushion and back cushion are made of memory foam material, which can disperse the pressure on the back, buttocks, and legs to a certain extent. According to the human latissimus dorsi and erector

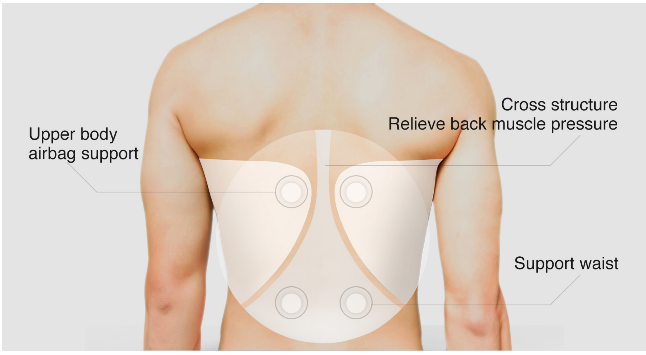

Fig. 2. Design of airbag support

rectus cross-shaped structure shown in Fig. 2, we employed back airbags to keep waist upright. The inflated airbags physically support lumbar spine and prevent lumbar spine from bending. The airbag design is the key to the active correction. We designed a specific action of inflating airbags by adjusting the air volume and inflating time for each of seven poor sitting postures.

3.2 I/O Design

As shown in Fig. 3, the hardware part is mainly composed of the mainboard, WiFi module, air pump, airbags, pressure sensors, ABS base frame. The type of mainboard is Arduino Mega2560, which is suitable for the design of multiple I/O systems, rapid verification, and iteration in the early stage of the product design. The range of the membrane pressure sensor is from 0 to 5 kg. Figure 4 shows the hip pressure map that illustrate the positions of placing 11 membrane pressure sensors on the cushion and back. The positions are determined based on the pressure distribution. After the system is powered on, the mainboard

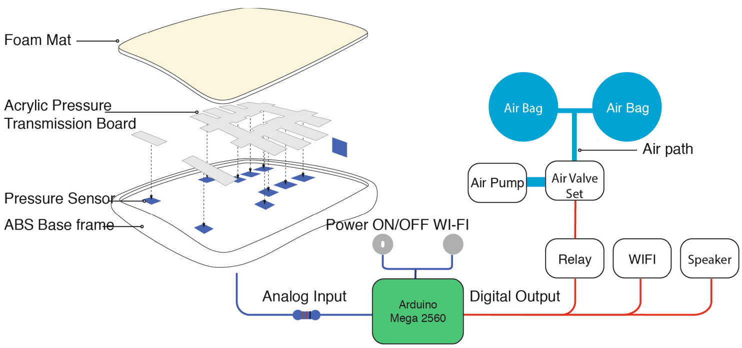

Fig. 3. Hardware frame of the chair

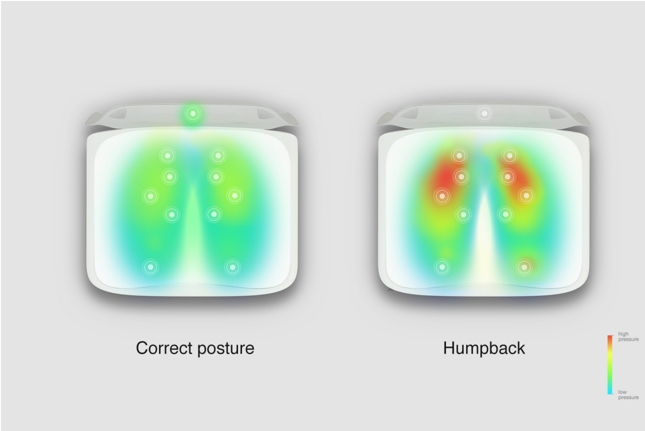

Fig. 4. The pressure distribution map of hip

will continuously receive the pressure data and then send data to the server via WiFi.

3.3 Communication Design

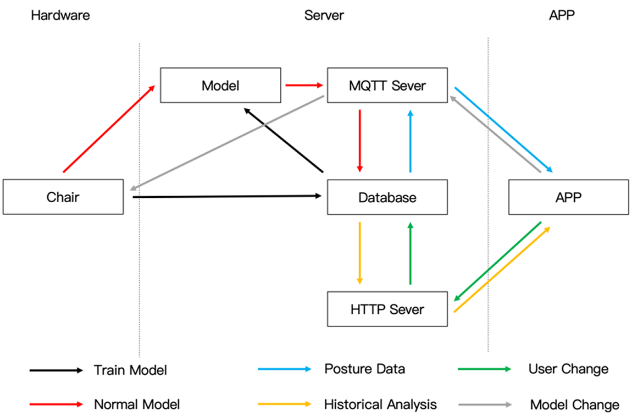

Fig. 5. Communication logic of chair

Data storage and processing are performed on the cloud server. Through WiFi connection, data can be quickly transferred among the chair, server, and App. The neural network algorithm enables the system to recognize different users and store their sitting posture data in the database. Meanwhile, through the Internet of Things network protocol MQTT (Message Queuing Telemetry

Transport) [14], other devices can be connected and controlled. The communication logic is shown in Fig. 5, which can be divided into three parts: hardware, server, and App. The MLP Classifier [27], a multi-layer perceptron, performed well in the classification problem. The chair sends the pressure data to the server for processing and predicts the user's current sitting posture. We stored pressure data and sitting posture data in the database, thus we can analyze and visualize user historical data and the development process of sitting posture habit. Moreover, users can create user profiles, switch working modes, and interact with the chair via a mobile App.

3.4 App Design

As shown in Fig. 6, the user client is an Android App, which can visualize sitting posture data. Continuous data monitoring and analysis facilitates the sitting posture health and provides lifelong health companions.

Fig. 6. The user interface of the mobile client

There are four working modes for the user: training mode, correction mode, relaxation mode, and entertainment mode. (1) Training mode: When someone first uses this chair, she/he needs to create an account by the App. At this time, the App will guide the user to switch between different sitting postures, collect the user's sitting posture data, and train a classification model for sitting postures. (2) Correction mode: The chair monitors the user's sitting postures in real-time. When a user maintains a poor sitting posture for a long period of time, the chair actively help the user adjust the current poor sitting posture by inflating airbags. (3) Relaxation mode: the chair will be inflated and deflated at a fixed frequency to give a massage for relaxation. (4) Entertainment mode: There are two ways to activate this mode. One is that when the user has been sitting for more than 45 min, a message will pop-up on the App to remind the user and recommend body exercises for relaxation. Another way is to click the game button on the App, and the a spaceship game will start. Users moves the body to controls the spaceship to catch the falling stars.

4 Design Methodology

Lean UX is the evolution of product design. We chose UX design method rather than other design methods, because of several advantages in product design that are "*1) it helps us remove waste from our UX design process; 2) it drives team members to harmonize our "system" in a transparent, cross-functional collaboration; 3) it is the mindset shift we gain from adopting a model based on experimentation.*" [12]. This method is to deeply involve users at each design stage and iteratively optimize products through user testing and user feedback. Besides, following Lean UX method also reduces enterprise development costs and improves development efficiency [12]. We iterated design prototypes three times to verify our product functions, develop low/high-fidelity prototype and finalize product design.

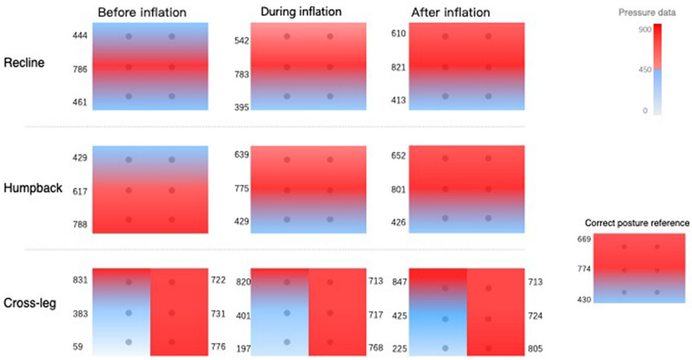

Fig. 7. Pressure distribution for different sitting postures (the first time prototype)

In the first iteration we mainly verified the feasibility of posture recognition and correction enabled by airbag inflation. The early prototype can obtain the average value of pressure distribution on the sitting surface and helped users maintain good sitting posture. Figure 7 shows that the sitting pressures produced by different sitting postures were significantly different. Among them, the sitting pressure graph of the semi-lying sitting posture and the hunched sitting posture after inflation is significantly improved, which is close to the pressure graph of the good sitting posture. It means that airbag inflation can effectively help users change recline and humpback postures. Although it was verified that the inflation reminder is helpful for improving sitting posture, the comfortableness, stability, and accuracy of the chair still need to be improved.

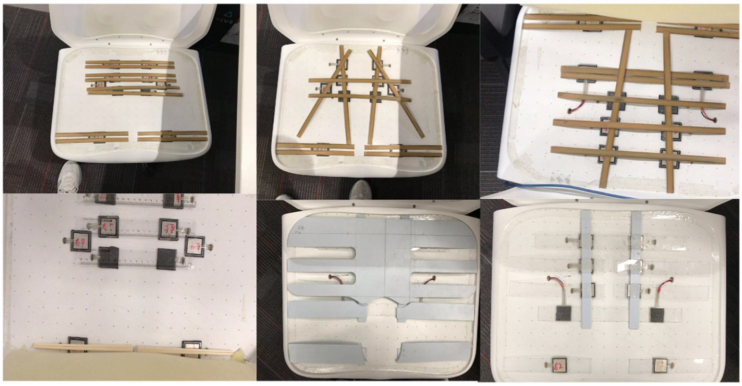

Fig. 8. The placement of pressure sensors (the second time prototype)

In the second iteration, we verified the ID design of the product and hardware system design. The prototypes is more integrated. All components are hidden in the back cover. A built-in rechargeable battery powers the entire system without additional wiring. In order to obtain more accurate sitting pressure data, we increased the sensors from 3 pairs to 5 pairs, as shown in Fig. 8. In order to accurately collect sitting pressures of different body sizes, we enlarged the contact areas by bridging independent touch points. We tried different ways and materials to determine a parallel sensor placement and bridge sensors by ABS material. In the end, we verified the usability of the finalized product. Through three times of iteration, the finalized design can meet the users' requirements and business requirements. On the basis of good system performance of the previous prototypes, we mainly optimized the comfortableness of the chair. The chair cushion is filled with memory foam material to improve comfortableness, and it will not affect the accuracy of the pressure data. The height and backrest of the chair can be adjusted to fit different users. The chair cushion has a triangular curved surface as a whole, which fits the curve of the buttocks and makes legs apart and stabilizes the sitting posture for better support. Besides, the sitting posture prediction algorithm is updated from SVM to MLPClassifier to achieve higher accuracy.

5 User Study

This section shows the system performance test and usability test for the third time of product prototypes.

5.1 Procedure

We recruited participants to test the usability of the chair in a real working environment. The steps of the user study are as follows:

1. We introduced the experiment purpose and process to subjects, then tell them how to use hardware and software.
2. The subjects were asked to perform different sitting postures upon the guidance of the App to train a sitting posture model.
3. The subjects were required to maintain each sitting posture for 30 s.
4. We asked the subjects to use the chair in a real work environment for 15 min.
5. We asked the subjects to fill in a post-study questionnaire.

5.2 Measurements

This test mainly uses a standardized usability questionnaire. SUS is a widely used questionnaire to measure system usability [2], but it lacks specificity in the test of healthcare products. So we employed the Health-ITUES questionnaire [24] that has good reliability and validity indicators. Health-ITUES consists of 20 questions, using a 5-point Likert scale, including four dimensions of influence, perceived usability, perceived ease of use, and controllability (Table 1). The overall score is the average scores of all question items, and each item has an equal weight. Besides, the questionnaire also contains three subjective questions (Table 2) to collect the experience of using the chair.

Table 1. The constructs of Health-ITUES [24]

Dimensions	Questions
Impact	1. I think the chair would be a positive addition for persons living with the issue of being sedentary
	2. I think the chair would improve the Quality of Life of persons living with the issue of being sedentary
	3. I think the chair has an important part of meeting my information needs related to self-management of sitting postures
Perceived Usefulness	4. Using the chair makes it easier to self-manage my sitting postures
	5. Using the chair enables me to self-manage my sitting postures more quickly
	6. Using the chair makes it more likely that l can self-menage my sitting postures
	7. Using the chair is useful for self-management of sitting postures
	8. I think the chair presents a more equitable process for self-management of sitting postures
	9. I am satisfied with the chair for self-management of sitting postures
	10. I self-manage my sitting postures in a timely manner because of the chair
	11. Using the chair increases my ability to self-manage my sitting postures
	12. I am able to self-manage my sitting postures whenever I use the chair
Perceived Ease of Use	13. I am comfortable with my ability to use the chair
	14. Learning to operate the chair is easy for me
	15. It is easy for me to become skillful at using the chair
	16. I find it is easy to use the chair
	17. I can always remember how to log on to and use the chair
User Control	18. The chair gives error messages that clearly and tell me how to fix problems
	19. Whenever I make a mistake using the chair, I recover easily and quickly
	20. The information (such as on-line help, on-screen messages and other documentation) provided with the chair is clear

Table 2. Subjective questions in the questionnaire

SQ1: Which factors do you think probably most influence your intention to use the smart chair, and why?
SQ2: Which situations do you think in which you would like to use the smart chair, and why?
SQ3: What do you want to suggest and ask for the chair?

The evaluation contains both subjective measurement and objective measurement. The subjective measurement employs a questionnaire Health-ITUES; and objective measurement considers three indicators: accuracy of correction[1], frequency of correction[2], and effectiveness of correction[3].

5.3 Subjects

In total, we recruited 12 subjects from a high-tech company. Half of them are female; 11 are between 26 and 35 years old, and one is older than 35 years old. All of them are office workers. Figure 9 shows the sedentary situation realized by the subjects. Besides, three-quarters of users (9) have experience in using the products that remind users of sedentary behaviors.

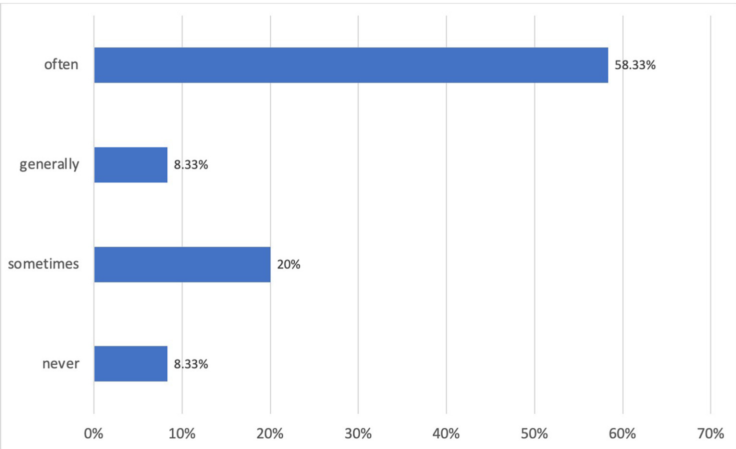

Fig. 9. The subjects' experience of using posture correction products

[1] Accuracy of Recognition = number of correctly recognized sitting postures/total number of recognized sitting postures.

[2] Frequency of Correction = the total number of inflations within 15 min.

[3] Effectiveness of Correction = number of the corrections that stimulate users to change the sitting posture/The total number of corrections within 15 min.

6 Experimental Results

This section shows the results of the performance test and usability test and summarizes the subjective feedback of users.

6.1 System Performance

Figure 10 shows the result of system performance. In specific, the accuracy of recognition stands at a satisfying level that is above 90%, and the effectiveness of correction is above 70%, which indicates the usefulness of active correction implemented in our system. The average number of correcting posture is 13.33 (SD = 5.48).

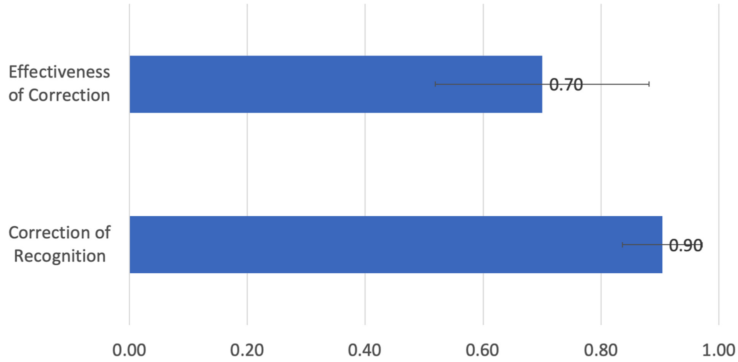

Fig. 10. System performance of smart chair

6.2 System Usability

We employed the questionnaire of Health-ITUES consisting of 20 questions to measure the overall usability of our chair. The average score of usability is 3.81 (SD = 0.68) out of 5. Figure 11 shows the scores of four dimensions related to usability. According to 5 point-Likert scale (1: Strongly disagree, 2: Disagree, 3: Neutral, 4: Agree, 5: Strongly Agree), if we consider 4 is a cut-off value for a satisfying level, our chair performed well on two dimensions of *Impact* (Mean = 4.12 SD = 0.91) and *Perceived Ease of Use* (Mean = 4.11 SD = 0.53). The scores on Perceived Usefulness (Mean = 3.81 SD = 0.95) and User Control (Mean = 3.73 SD = 0.70) are also satisfied.

6.3 Correlation Analysis

Furthermore, we performed correlation analysis between three objective indicators of system performance (accuracy of correction, frequency of correction, and effectiveness of correction) and four subjective indicators of system usability

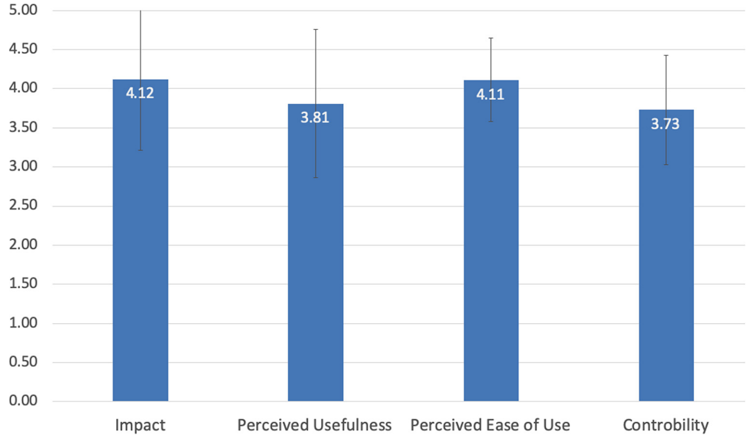

Fig. 11. Scores on four usability dimensions

(Impact, Perceived ease of use, Perceived usefulness, and User control). Figure 12 plots three correlations showing a statistical significance and one correlation that tends to have a statistical significance. In specific, we found correction effectiveness positively correlates with overall usability ($r = 0.600$, $p < 0.05$) and it also positively correlates with two dimensions of usability, Impact ($r = 0.530$, $p = 0.08$) and the Perceived of Ease of Use ($r = 0.692$, $p < 0.05$). Interestingly, we find that correction frequency negatively correlates with perceived ease of use ($r = -0.609$, $p < 0.05$).

6.4 Subjective Feedback

Moreover, the questionnaire contains three subjective questions. For the first question *"SQ1: Which factors do you think probably most influence your intention to use the smart chair, and why?"* One-third of subjects think comfortableness most influences the intention of use, and they also pointed out the importance of safety, noise, and price. For the second questions *"SQ2: Which situations do you think is suitable for using the smart chair, and why?"* 11 out of 12 users say that they tend to use the chair in the office because the sedentary issue often occurs in the office, while one subject thinks she would like to use the chair at home in leisure time rather than in the office because of the noise of pumping air cushion. Toward the last question *"SQ3: What do you want to suggest and ask for the chair?"* Two subjects think the noise of pumping air cushion distracts them from the working task. Besides, user attention to the sitting data and reminders shown on the tablet screen may distract her. Therefore a non-obtrusive way of giving feedback is more desired, for example, reminding by voice in a situation.

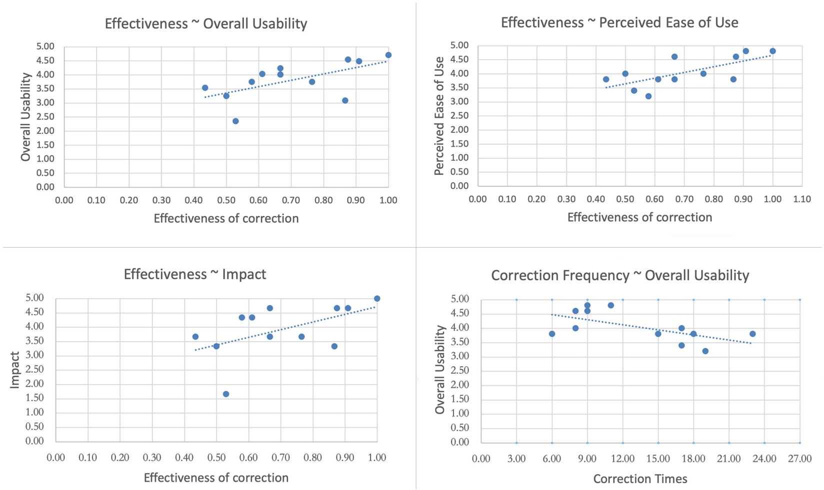

Fig. 12. Correlation analyses between system performance and system usability

7 Discussions

This section mainly discusses the results of user study and the lessons learned from the practice of lean UX methodology in the process of designing and developing the chair.

7.1 System Performance and Usability

The results of the system performance test indicate that the smart chair performs well in terms of accuracy of recognition and effectiveness of correction. The performance can still maintain at a satisfying level when adapting to different body shapes. The high effectiveness of correction (above 70%) proves the advantage of *active correction* over passive correction. The results of Health-ITUES questionnaire show that the overall usability of our chair is good and some dimensions of usability are particularly highly rated by subjects such as Impact and Perceived Ease of Use.

The results of correlation analysis manifest that the effectiveness of correction has a significantly positive impact on overall system usability and two dimensions of usability: Impact and Perceived Ease of Use. Therefore, it may also suggest the positive effects of active correction on system usability. However, the correlation results do not show a significant correlation between accuracy of recognition and system usability. Arguably we suggest that **designers of the smart chair should focus more on increasing effectiveness of correction when the accuracy of recognition reaches a satisfying level**. Also, the negative correlation between the frequency of correction and system usability indicates that frequent correction may undermine system usability. Too frequent actions of correcting sitting postures may aggravate the disturbance of noise made by pumping air cushions. Thus we suggest that **designers of smart chairs should balance the frequency of correction and system usability**.

7.2 Practice of Lean UX

We designed and developed our smart chair following the methodology of Lean UX. We briefly summarize the lessons learned from this practice in our project.

1. Lean UX is particularly suitable for enterprises that follow the bottom-up design approach. It enables the research development team to generate innovative concepts based on the feedback from real customers and then transfer the concepts to product functions.
2. Considering the limited resources of enterprises, the practitioners should prioritize the requirements collected from the communications with customers in production.
3. To ensure the project advances smoothly, we should break down a workflow into fine-grained tasks and set a priority and a deadline for each of them.
4. Compared with software design, the modification in hardware design is much more expensive. Thus, the Minimum Viable Product (MVP) is useful because it allows us to rapidly test our ideas even if the MVP may sacrifice the system performance to a certain extent in the early phase.

8 Conclusion

This paper presents a new smart health chair that supports active correction for the poor sitting postures. The chair can recognize the sitting postures in real-time. We describe how we followed the Lean UX design method in our project and summarized the practical experience of Lean UX. Moreover, we evaluate our smart chair in a real working environment. In specific, we measured the system performance (accuracy of recognition, frequency of correction, and effectiveness of correction) as well as system usability. The correlation analyses reveal that **effectiveness of correction** significantly influences overall usability and several usability dimensions, while the frequency of correction tends to undermine system usability. As we know, developing sitting habits usually takes a long time. To better verify our results, we may need to run a longitude study. Thus, we plan to evaluate our chair by conducting a longitudinal user study with more subjects in a classroom in the future. Overall, we think the approach of active correction and the study results shed light on the design and development of the smart health chair.

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