StraightenUp: implementation and evaluation of a spine posture wearable

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Abstract. Human posture and activity levels are indicators for assessing health and quality of life. Maintaining improper posture for an extended period of time can lead to health issues, e.g. improper alignment of the vertebrae and accelerated degenerative disc. This, in turn, can be the cause of back pain, neurological deterioration, deformity, and cosmetic issues. Some wearable prototypes have been proposed for spine posture monitoring, however, there has not been enough consideration for the users' experience with these devices, to understand which characteristics are central to acceptance and long-term use. This paper presents a prototype of a low-cost spine posture wearable, along with its preliminary evaluation, which aims both to confirm that the wearable can measure spine posture and to evaluate user experience with this device. The results show that the wearable was comfortable, causing a sensation of security, and that feedback to users would be needed to help improve posture. Further work is required to make sure the device is easy to put on and remove, and discreet enough to be worn in public.

1 Introduction

Human posture and activity levels are indicators for assessing health and quality of life. This type of information may be monitored remotely [1]. Information such as the number of walking steps per day, and the curvature of the spine, may be used to help users improve posture and activity levels. Maintaining improper posture for prolonged time can result in pain and discomfort [2], which can disrupt health, daily activities and family life [3].

Some portable computing devices have been proposed to measure posture and trunk motions, e.g. a lumbopelvic motion monitor [4], a system of dynamic monitoring and orthopaedic imaging [5], and textile sensors for upper body postures [6]. These wearable devices are sometimes voluminous and visible to others. User experience, user requirements, cultural context, and aesthetics must be considered as a central factor when designing wearable devices. Therefore, further study is needed, not only to properly and accurately monitor these conditions, but also to understand how to provide a positive user experience. This paper aims to focus on understanding factors that affect user experience with these wearables. To accomplish this goal, we designed, implemented and evaluated a low-cost wearable device to monitor spine inclination. This device measures angles in the sagittal plane continuously in real-time by using three 3-axis accelerometers placed along on a wearable device. Thirty participants tested the prototype to evaluate its usability and design.

This paper is organized as follows: first, we discuss related work, regarding how spine posture has been monitored and research on user experience regarding wearable devices. Then, we present the design and implementation of our device, called *StraightenUp*. The fourth section describes the evaluation of the device, followed by our results and conclusions.

2 Related Work

2.1 Monitoring spine posture

The systems for measuring human postures, especially related to the torso, have been classified based on the position of the sensors (transmitter) and the sources (receiver), as follows. Systems may be *outside-in*, when the sources are on the body, but the sensors are elsewhere (e.g. movement is tracked through cameras), *inside-out*, when the sensors on the body, but the sources are elsewhere (e.g. accelerometer-based systems), *inside-in*, when both sensors and sources are on the body (usually used as wearables for longer-term use), or *outside-out*, when both sensors and sources are not on the user's body (e.g. x-rays) [7].

Some systems that can be used for dynamic monitoring of the spine are portable devices that are embedded with accelerometer, gyroscope, and GPS, which have proven to be effective and are gaining popularity [8]. The characteristics which have made them successful are their small size, low cost, and integration capabilities [9].

Activity recognition may be used to improve patient care, or to understand behavioral changes for healthy users [10]. For instance, a mobility monitoring system for older adults that used two accelerometers (one on the trunk and the other on the thigh) and a small data-logger, was used to distinguish between static and dynamic activities, and to detect sitting, standing and lying activities [11]. A portable smart garment, designed specifically for posture monitoring, was used to monitor trunk postures during daily activities, finding that it may help improve kyphosis (forward rounding of the back) [12].

There are several approaches and initiatives that seek to monitor postures through technology; however, most research has focused on the technology (accuracy, sensitivity and specificity) itself [13]. Our work aims to consider the technological factors as on par with the user experience factors; i.e., we consider that just as important as being able to accurately monitor posture, is how the user experiences the monitoring device.

2.2 User experience with wearable technologies

The rapid advances and innovations in mobile, ubiquitous and pervasive computing have changed how users and designers perceive and employ these technologies. For example, the quantified self movement [14] has pushed for technologies that monitor every aspect of users' lives, through mobile and wearable technologies - and many users have started using popular wearables to track information about their lives (e.g. FitBit, Misfit, Apple Watch, Garmin Wearables).

The most important factor in the acceptance of wearables is their usefulness [15]. Other factors such as ease of use, usability, quality and connectivity affect use rates [16], but few research has focused on the factors that affect user behavior and adoption [17].

3 StraightenUp: a wearable device to monitor spine inclination

We designed and implemented a wearable device to monitor spine inclination. This device continuously measures the angle in the sagittal plane in real-time by using three 3-axis accelerometers (LilyPad Accelerometer ADXL335) placed on a modified back support brace. This data is sent to the computer (see Fig. 1).

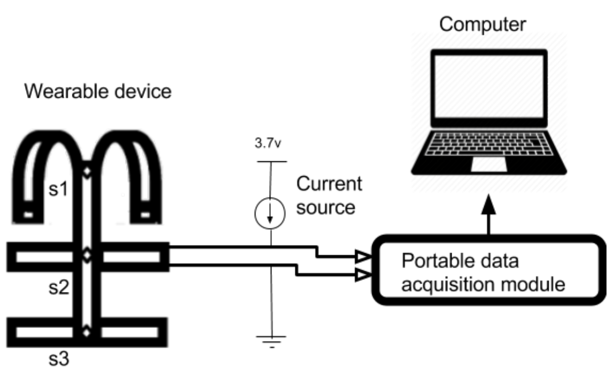

Fig. 1: Scheme for monitoring spine inclination

The modified back support brace was built out of several back support and pregnancy support belts, to be adjustable (through velcro straps) and fit tightly to the body, to minimize differences in orientation between the sensors (sewn on the brace) and the user's body. The three sensors were attached to the brace on the upper trunk, central trunk and lower trunk (see Fig.2). The sensors were connected by cable to a data acquisition system using Arduino Leonardo (ATmega32U4 microcontroller with built-in USB), Bluetooth module HC-05 and a 1000mAh battery. These components were put into a small, 3D-printed box, to be carried by the subjects (or stuck on the side of the brace with velcro).

Fig. 2: StraightenUp: end result of brace with sensors, and controller box

4 Methodology

4.1 Participants

Our participants were 30 higher education students (7 women and 23 men). The weight of participants ranged from 43 to 106 kgs (average: 68.5), and their height ranged from 1.51 to 1.83 meters (average: 1.68). 14 of the participants reported they suffered back pain. On average, they reported to spend 9.4 hours per day sitting (min=4, max=14), and standing on average 3.3 hours (min=1, max=8).

4.2 Data collection

We used mixed methodologies to collect data from the experiment. Quantitative information was collected through a questionnaire and data captured by the *StraightenUp* prototype. Semi-structured interviews were applied at the end of the experiment, each lasted about 10 minutes. To evaluate the prototype the participants used the *StraightenUp* prototype and they did six different positions with their body. The type of information collected was:

1. AttrakDiff is a 28-item questionnaire that measures pragmatic manipulation, hedonic stimulation, hedonic identification and attraction of software products [18]. We used the English version and online questionnaire [19].
2. *StraightenUp* prototype collected information from the three accelerometers for each position performed by the participant. In total six positions were executed.
3. Audio recordings from the interviews.

4.3 Experiment

The experiment was performed during April 2017 in Santiago, Chile. For the experiment, the participants first read and signed an informed consent form. Then, the experiment was carried out in two phases:

Phase I: At this stage participants wore the prototype on the upper body (trunk). Then, participants were instructed to assume the different postures. Each posture lasted for approx 20 seconds (50 measurements were taken during that period) in a predefined sequence of six positions in the sagittal plane: back, straight and rigid, straight and relaxed, tilted in 60 degrees, tilted in 30 degrees and tilted as low as possible (see Fig. 3).This sequence was selected to test the precision and accuracy of the sensors, as the measurements from the device could be compared to a known standard. In each position, the participant had his/her back straight and his/her eyes facing the front. The angles and positions were marked on the wall for reference.

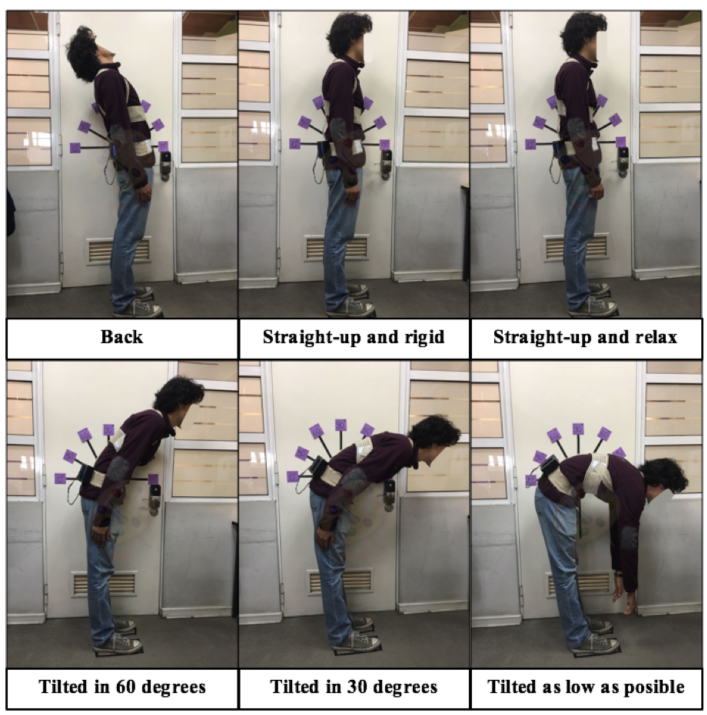

Fig. 3: Evaluation of *StraightenUp* with six positions.

Phase II: In the second part the AttrakDiff questionnaire was applied to assess the usability and the design of the prototype. For this, participants completed the online questionnaire. Finally, an interview was done to know the participant's opinion about *StraightenUp*. The interview focused on knowing: (1) the aspects that the user liked or disliked about the prototype, (2) situations or moments where the participants would use the prototype, and (3) what improvements they recommended to the prototype.

4.4 Analysis

The data obtained from the accelerometers were analyzed by descriptive statistics, for which the R program was used [20]. For the analysis of the data collected from the AttrakDiff questionnaire we used the results obtained from the AttrakDiff site [19]. We also used thematic analysis to code and analyze the data [21] of interviews, which were recorded and transcribed. Each interview was assigned a code (P1 to P30). Some quotes from participants are provided in the results (translated from Spanish).

5 Results

In this section, first we discuss the results from StraightenUp for posture classification. Then, we perform qualitative analysis of the individual interviews, and finally we discuss the user experience results.

5.1 Body posture classification:

Influence of sensor position: An analysis of the positions of individual sensors showed that the data distribution for the back, tilted in 60 and 30 degrees, and tilted as low as possible (flexion) are more strongly grouped (see Table 1). On the other hand, for the rigid and relaxed positions, the sensor located in the middle part of the back (s2 in Fig. 1) produced more variable measurements. We believe that the variability that occurs in s2 is due to the body type and build of the participants, leading s2 to be tilted at different angles for each participant. However, this does not necessarily mean that measurements from s2 are incorrect or not useful. The sensor located in the upper part of the back (s1 in Fig. 1) is affected by orientation errors caused by the movements of the head for the back and flexion/low tilted positions.

Influence of type of posture: We input the data collected by the prototype into the Weka software[3] to assess whether the sensors were accurate enough to automatically classify a measurement into one of the six body postures. To assess the performance of the classifier we used a set of 9000 instances collected from 30 participants with 50 data points for each posture. Using all three sensors, 99.5%

[3] Weka, available at: http://www.cs.waikato.ac.nz/ml/weka

Table 1: Descriptive Statistics (M=mean, SD=standard deviation)

Postures	Sensors					
	s1		s2		s3	
	M	SD	M	SD	M	SD
Back	−56.62	14.92	49.32	57.38	−47.36	52.27
Rigid	−45.72	5.27	−36.68	70.37	−60.26	28.92
Relax	−42.94	4.38	−29.00	78.41	−60.88	29.33
60 degrees	−20.24	6.52	−59.51	5.73	−48.35	11.83
30 degrees	−4.96	9.45	−33.82	15.81	−35.07	12.66
Flexion	11.78	24.27	−0.62	17.04	−13.37	14.71

of instances were classified correctly. Given the variability of data that occurred in s2, we also removed it from the analysis, finding that the rate of classification decreased to 97.5%, so we decided to keep data from all three sensors. The confusion matrix in Table 2 shows that the results had high precision, with very few instances of missclassified information. There was a minor amount of confusion between the classes rigid, relax and back only. This confusion is due to the fact that the three postures (back, rigid and relax) are highly similar. This relatively consistent pattern indicates that the statistical classification model is robust and capable of discriminating accurately between six body postures.

Table 2: Confusion matrix for global sagittal alignment classification

	Back	Rigid	Relax	60°	30°	Flexion	TP Rate %	Precision %
Back	1490	6	3	0	0	0	99.3%	99.7%
Rigid	2	1485	13	0	0	0	99%	99.1%
Relax	2	7	1491	0	0	0	99.4%	98.9%
60°	0	0	0	1496	4	0	99.7%	99.9%
30°	0	0	0	1	1498	1	99.9%	99.7%
Flexion	0	0	0	0	0	1500	100%	99.6%

5.2 Analysis of individual interviews:

1. *Perception of device:* Overall, all participants liked the wearable concept and found it useful and practical. They described the overall interaction with the StraightenUp wearable as very comfortable, and liked that it is like a garment and fits the body, causing a sensation of security: “I liked the fit very much [...] it gave me a sensation of security, that’s what I felt”. Most participants stated that it was difficult to put on because of the number of straps: “It’s comfortable but I think you’d need help putting it on - I can’t

imagine putting it on myself, I wouldn't know how to use it on my own". They also suggested that you could conceal the box by reducing the size "The box that is on the back should be smaller, otherwise I think that if you sat down, having a box on the back would be uncomfortable".

2. *Motivation of use:* Participants agreed that the information provided by the device can improve posture habits and reduce discomfort in the spine. "For example, I'm trying to remember all the time that I have to fix my posture to reduce the pain I feel. If there was something that could help me do that, it would be good". A participant stated that he would not like to use the device because of its appearance: "Generally, because of aesthetic concerns, I think body awareness could be improved in less artificial ways".
3. *Frequency of use:* About the appropriate place to use the device all participants stated that they would like to use it in the office (workplace) during the hours they are sitting. "The time I'm at work basically, since I spend so much time sitting and that is when I have more pain, then I would use it when I'm at work".
4. *Device expectations:* All participants stated that a feedback signal is needed to alert if they are using bad posture "It should give me feedback, when I'm slouching I would clearly prefer if it warned me". About half of the participants would prefer that the alert be a vibration in the device "It should simply vibrate and warn you without having to communicate with the cellphone necessarily", while the others prefer to receive notifications in their cell phone "Send me a notification to my cellphone, everyone is always carrying their cellphone".

5.3 User experience results:

Overall, AttrakDiff scores were generally favorable, i.e. the overall user experience of StraightenUp was rated as positive (although there is still much room for improvement). In all four dimensions, StraightenUp was rated as moderately good, with best ratings in attractiveness (ATT; M 0.92), pragmatic quality (PQ; M 0.89) and hedonic quality - stimulation (HQ-S; M 0.89). The weakest score was in the hedonic quality - identity (HQ-I, M 0.49) category, which means that StraightenUp is perceived as a non-presentable device, i.e. it does not have the appearance of a finished product. Fig. 4. shows a diagram of the mean values on a scale of -3 to 3. Overall, the results show that users feel StraightenUp would be useful, but that presentation must be improved.

5.4 Discussion

Testing of StraightenUp revealed its ability to distinguish between the following positions: back, rigid, relaxed, tilted in 60 degrees, tilted in 30 degrees and flexion with a high degree of accuracy. Some studies [22, 23] indicate that the performance of these systems differs for many reasons, such as the different ways of evaluating, the number and type of sensors used, the location and attachment of the sensors to the body, and the number of the recognized postures. In our

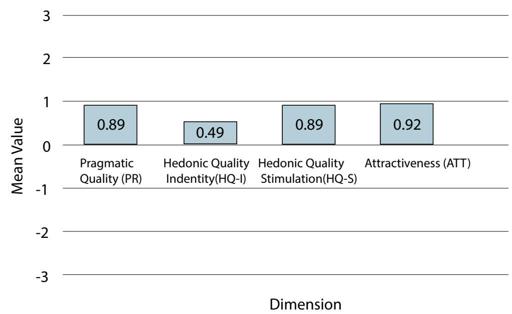

Fig. 4: AttrakDiff mean values for each category

case, the possible positions were classified accurately, although they were very discrete, that is, further testing must be done to assess to what degree we could detect smaller shifts in the angle the back is tilted, for example.

Our results agreed with previous research stating that wearable devices should be discreet and not voluminous. There is still a necessity for wearable devices and prototypes that can integrate more seamlessly with users' lives and aesthetics.

Our experiment suggests that one of the possible factors that hinder the adoption of wearables is the difficulty of putting on and taking off the device. Some previous researchers [24] have detected this inconvenience and have tried to solve it. They have used a modular design in smart garments showing that this design has great potential for precision and comfort to make the system useful in context and accepted by its users. Another indicator for the adoption of wearables has to do with the perceived utility of these devices [25]. Most participants indicated that the use of alerts in the body (trunk) in real time may be a technique that helps improve posture habits. In this sense Ribeiro [26] points out that the provision of a constant postural feedback influences the postural behavior. This could generate a greater adhesion of these devices.

The participants of this experiment were healthy people with spinal discomfort (since they spend a large part of the day sitting down). Other back issues (e.g. deformation of the spine, sagittal balance) will need further testing with the particular demographic that is suffering from those medical conditions.

6 Conclusion

The experience of using a device that classifies real-time human postures detected with three triaxial accelerometers attached to the trunk was positive. The evaluation was performed through an online questionnaire (quantitative data) and individual interviews (qualitative data) that were complemented to give greater meaning to these results by providing a better understanding of the feelings and attitudes towards the device of the participants. Results indicated that StraightenUp was comfortable to use and could potentially be useful for controlling spinal posture by receiving real-time postural alerts. Future steps are aimed at improving and evaluating the experience of using the portable device in a clinical context to support the diagnosis of sagittal imbalance in elderly patients suffering from chronic pain due to deformation of the spine.

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