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A Vibro-Haptics Smart Corset Trainer for Non-Ideal Sitting Posture

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ABSTRACT

This study aimed to develop a vibro-haptics feedback based smart corset to stimulate humans to be in ideal posture by monitoring the spline in thoracic vertebrae of T5-T12 levels, and provide a vibro-tactile stimuli to human's skin at lumbar L3 level. A corset contains a microcomputer, sensors and an actuator was implemented on 12 participants for 2 cases to determine its efficiency. In the first case, tactile stimuli was not provided to the participants, while in the second case tactile stimuli was ensured. The results showed once the vibro-tactile stimuli was represented to the participants, their posture regime improved significantly with a value of 53.13±23.14 %. Moreover, it was also observed that their non-ideal postural duration significantly decreased. These results suggest that the corset provides vibro-tactile feedback that encourage humans in seated posture to beneficial postural habits while using computers.

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KEYWORDS

Smart corset, sitting posture, spinal curvature, vibro-haptics, actuator/ sensor

1. INTRODUCTION

Incorrect or non-ideal posture is a problem that becomes increasingly widespread in today's world. This can be affected by daily activities, physiological and living conditions, and it has a great role in decreasing the quality of life. It can also cause musculoskeletal problems which are the second most common and costly spinal disorder [1]. Low back pain is one of these problems [2] which contributes to many factors such as physical [3-4], psychological [5], biological [6] and genetic factors [7]. One of the most usual strategies used by physiotherapists to the management of low back pain is providing advice to the patients on spinal postures. There are widely accepted clinical beliefs concerning ideal or non-ideal posture [2]. However, there is not any consensus upon an ideal posture during sitting [4]. An unbalanced posture can affect the person's posture while standing and walking [8]. In slump sitting, the intervertebral disks are subjected to compressive stresses at the anterior part of the fibrous ring, posterior migration of the nucleus [9] and an increase in these stresses may cause damages to intervertebral disks [10]. It has been reported that an increase in lumbar flexion in slump sitting can cause lower back pain [11] due to higher compression stresses created in the spine compared to the "neutral" sitting [4, 12]. These stresses may produce intervertebral disk degeneration as well as damage and misalignment of vertebrae. Hence, the correct posture is the principal factor for the health of the spine [13]. Some authors have suggested lordotic seated postures in sitting can prevent this damage [14, 15]. Furthermore, it has been reported that a sitting posture which complied with the natural curvature of the spine, and appeared comfortable

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without excessive muscle stretch includes advantages [2].

Some instruments such as inclinometers [13, 16], radiographic images [17], 3D electromagnetic tracking systems [4], photographs [2], camera [18], motion capture systems [19], laser scanners [20] have been widely deployed to measure and to analyze the curvature of the spine. However, many of these expensive systems used in clinics and labs may be costly and not fit to monitor day to day conditions for the users. In order to monitor and control the posture for daily uses, haptic stimuli has been performed in various studies [8, 21]. This type of sensory stimuli has largely been explored in postural control using the principles of sensory substitution by the neuroscience community. Sensory substitution refers to a multitude of different processes of reorganization within the brain, each of which the way information is processed and may ultimately result in behavior change [22]. Typically, vibration actuators with an array have been implemented as vibrotactile feedback devices due to the fact that they can provide additional information without interfering with the basic functions like hearing or seeing [8,21,23,24]. To monitor and to improve the posture for daily regular users, several portable and haptic feedback-based devices have been proposed [25]. For instance, Zhang et al., embedded force sensors to the chair to determine the sitting posture and used vibro-tactile feedback to encourage the users to correct their postures [26]. Barone et al., performed flexible strain sensors to monitor the thoracic spinal angles and provided visual feedback during flexion and extension [21]. A network of three inertial measurement units were used to determine the thoracic and lumbar angles and provide auditory feedback to encourage users to a neutral standing position [19]. In brief, fiber optic [27], inertial [28] and flexible strain [21] sensors are the most typical sensors that have been suggested to monitor the posture. In addition to the studies performed by academic researchers, wearable posture trainers have also attracted the commercial markets such as Jins Meme, Alex+, Nadi X, Sense U, Upright Go posture trainer and Mevics [29]. However, the details about the determinations of posture using these devices are not available since they are for commercial purposes. The majority of these devices are built with processor, microcontroller, accelerometer, gyroscope, magnetometer, inertial sensor and feedback instruments. The feedback is provided via vibrotactile cues allow tracking and logging the posture via app-based graphics and mostly attached to the skin or garment via adhesive clips or pins. Most of them determine the posture from a single node. Hence, it is not certain whether they have a capability to assess the relative joint angle using a single node.

In this study, we aimed to design a corset made of fishline breathable stretch fabric, assembled with a low weight and low-cost instrument to improve the users' postures in sitting by allowing them vibro-haptics feedback. Different from the majority of the available devices, the sensors can be located to the place specifically for the user's spine, and the smart corset fits the user's abdomen, and allows to measure joint angle. The idea here is once the user's posture exceeds slouching posture angle limit, the vibro haptic motor is actuated to encourage humans to adjust his/her posture. The main goal is to evaluate how such a smart corset with vibrotactile feedback could improve the sitting posture of the user.

The study is organized as follows. First, textile material used in smart corset device is demonstrated. Next, the hardware and software framework of this device is described. Then, the results obtained from participants are presented. Finally, the performance of the device is summarized and discussed in terms of participants' posture improvement rate.

2. MATERIAL AND METHOD

2.1 Textile material

Various fabric samples such as fishline sketch and knitted fabric containing 92%PES 8%EL were supplied from various manufacturers. The goal is to choose a fabric that provides reasonable properties in terms of comfort, moisture transfer and air permeability. Since the PES / EL blended fabric does not wrap the body tightly as the gutted fabric, it leads to undesirable consequences such as changing the position of the sensors/ actuator and making a bulge at the sensor's location. Therefore, fishline stretch fabric (Misineteks Tekstil, Turkey) was preferred due to its sensitivity of transfering the vibrotactile stimuli to the human body. Various experimental tests such as air permeability and moisture transmission were performed on fish line samples to characterize the fabric [30, 31]. For the weight per unit area (g/m^2) test, the measurement was performed on 5 samples in accordance with ISO 3801 standard [32]. Those samples were cut with a grammage stencil with an area of 100 cm^2 and weighed in precision balance. For the measurement of air permeability, the test was performed for 10 samples, and each has an area of 5 cm^2. The test was carried out using Fx 3300 Instrument at pressure of 100 Pa in accordance with ASTM D 737 [31]. For the determination of transmission properties, a moisture management tester instrument was implemented for 5 samples, and each has dimensions of 8x8 cm^2. The fabric has a plain weave that includes 70 denier polyamide warp yarn, 1200 number gipe yarn (150 filament polyester coated over elastane) and polyamide fishline yarn with a thickness of 0.15 mm and 200 dtex. The weft and warp density of the fabric are 12 and 25 threads/cm, respectively. It is 100% flexibile, and a typical weave plan of the fabric is shown in Figure 1.

Once the fabric was characterized, the next step was to sew the corset using a lockstitch machine. Velcro fasteners were used on the corset for upper straps, waist region and placement of electronic devices. The corset's fabric and velcro bands were stitched with 100% PES sewing. The corset consists of four main components which are upper straps from the right and left, back and belt parts. Note that, it is not covering the body completely, but only a part of it. The front and back straps have a length of 6 cm while the waistband has 13 cm (Table 1). Three different corset sizes for female and male were manufactured. They fit on users' abdomen comfortably and help them not to be in extreme slump posture. Furthermore, the corsets do not have to be in touch with the body's skin directly, and could be worn on the specific user's garment. Velcro fasteners were used on the corset for upper straps, waist region and placement of electronic components.

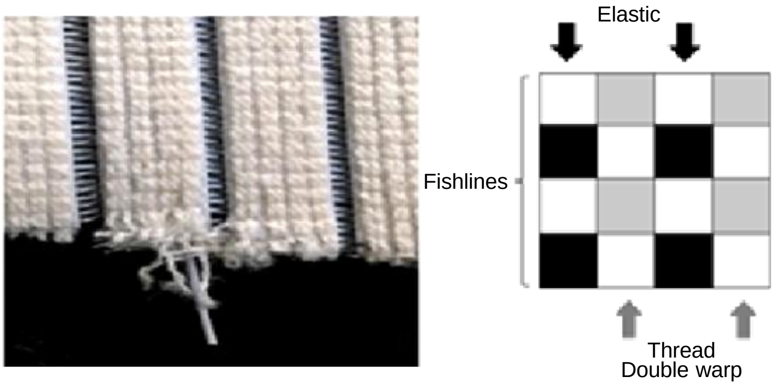

Figure 1. Fishline stretch fabric and its weave plan

Table 1. The dimensions of the corset

Strap	Female		Male	
	Length (cm)	Width (cm)	Length (cm)	Width (cm)
Front	62	6	78	6
Back	39	6	45	6
Waistband	84	13	102	13

2.2 Hardware and software setup

The instrument developed in this study consists of two absolute orientation sensors (BNO055, Bosch, Sensortec, Germany), a microcomputer (Raspberry Pi Zero, Raspberry Pi Org, UK) and a vibro actuator (Precision Microdrives, UK). Total weight of the instrument is 145 g. These components are powered by 2 x 1550 mAh Lipo batteries. Since 1S2P LiPo battery's voltage level is 3.7 V, a 5 V step-up boost converter was used to supply the orientation sensors and the micro-Computer. The vibration actuator is powered with a rail from 3.7 V LiPo battery directly without any regulator. The intensity of the vibro actuator can be adjusted using PWM (Pulse-width modulation), while it is excited with constant current. The device, orientation sensors and vibro-haptic actuator are enclosed in two different 3D printed boxes that have dimensions of 94 x 84 x 23 mm, and 30 x 28 x 9 mm. Each of these units is attached to the corset with velcro; so the region of each enclosed unit can be modified for users. Although there is not any general indicator that describes the ideal sitting posture with quantitative data [4], it is reported that a posture which matches the natural shape of the spine and appears comfortable without excessive muscle stretch has advantages [2]. In this study, T5-T12 levels were assessed as reference landmarks [33]. Therefore, one enclosed absolute orientation sensor was located at T5, and the other at T12 (Figure 2). It is noted that, while these sensors can measure lateral bending and extension-flexion angles of the spine, the instrument is adjusted to collect only the flexion- extension measurements with a sampling rate of 5 Hz. The enclosed vibro-tactile unit is attached to the L3 level of the user via velcro, and excited when the threshold exceeds. The reason for choosing this level is to allow a person to sense the vibro-actuation stimulus noticeably and may also avoid noises due to environmental effects [8]. The communication between the microcomputer and the orientation sensors are performed using I^2C (Inter Integrated Circuit) protocol. The reason for preferring this protocol is that it allows communication with multi sensor nodes with a single data cable on 8-bit address system. The processing unit includes an expansion unit to store the data in MicroSD. Moreover, it also includes a modem to transfer the data over Wi-Fi. The device can be recharged with a micro-USB cable. In power consumption tests, it has been observed that the device can operate about 6 hours continuously with 2x1550 mAh LiPo rechargeable battery.

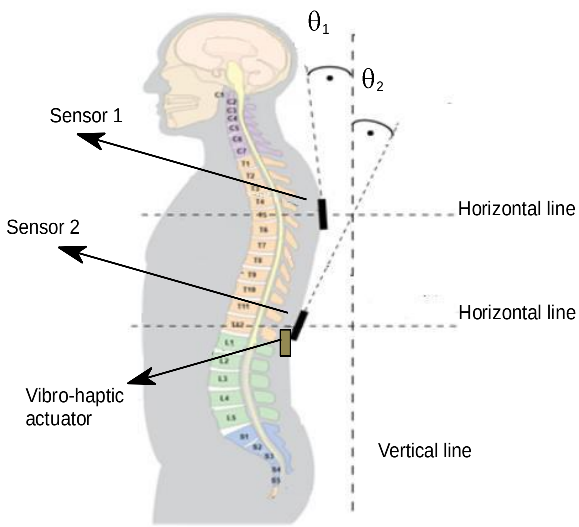

Figure 2. Placement of sensors and actuator

Once the hardware setup is completed, the next stage is to develop an algorithm that monitors the posture and determines the incorrect posture (Figure 3). It starts when the micro-computer is powered on and then it checks the sensors' status by trying to acquire sample data from them. Here, θ_1, θ_2 and θ_r refer to the 1st, 2nd, and relative angle (θ_1-θ_2) of the two sensors. If the process is successful, it waits for the operator's command for calibration (Figure 3). In this process, the user is instructed to pose upright verbally. Then the angle θ_r is saved for later calculations as an offset value θ_o. Next, the user is instructed to pose in a non-ideal posture which makes the user uncomfortable by slouching his/her spine. Then, the angle difference for this position is measured again and stores as θ_r. By subtracting the offset value θ_o from this angle θ_r, the algorithm computes a new value and stored it as a threshold value θ_t. Once the calibration process is completed, the program enters an infinite while loop. The algorithm subtracts the offset value θ_o from the θ_r and stores the new induced angle difference value as θ_i. This θ_i value is logged with a time tag and stored as time series in the MicroSD card. Next, if θ_i is lower than θ_t the algorithm assumes that there is no anomaly "ideal posture", and it returns to the first step in the loop and continues. On the other hand, if θ_i is higher θ_t, there is an anomaly "non-ideal posture", and it alerts the user. Then it creates a warning event by using θ_i value with time info and then logs the event in the MicroSD card. The final step is to transfer the data. If a WiFi internet connection is available, then the device sends this event to the remote server over TCP/IP. If not, it logs the event in the MicroSD card in a separate file to send it later. Finally, the process returns the first step of the algorithm loop. The algorithm embedded in the micro-computer was developed using PYTHON 3.

2.3 Human test procedure

Twelve healthy participants (9 females 27 to 58 yrs, 3 males 32 to 40 yrs) from academic staff and graduated students have enrolled in the study. The clinical ethical review board of the Ege University approved the study with a designated document ID of 103-2016. All participants provided written consent to participate to study. First, the participant wears the corset that is suitable for him/her (Figure 4). Then, the enclosed 1st, 2nd sensor, and vibro-haptic actuator are adjusted to be on user's T5, T12, and L3 landmarks. Second, the participant sits in front of his/her own computer. We encouraged each user to arrange the height of the chair and computer before the tests. Third, we asked to sit what he/she considers to be an ideal and non-ideal for the calibration process and determination of range of motion (ROM) with the directions of the physiotherapist. If the participant slouches to a limit out of ROM threshold, the vibro-haptic actuator warns the user to correct his/her posture.

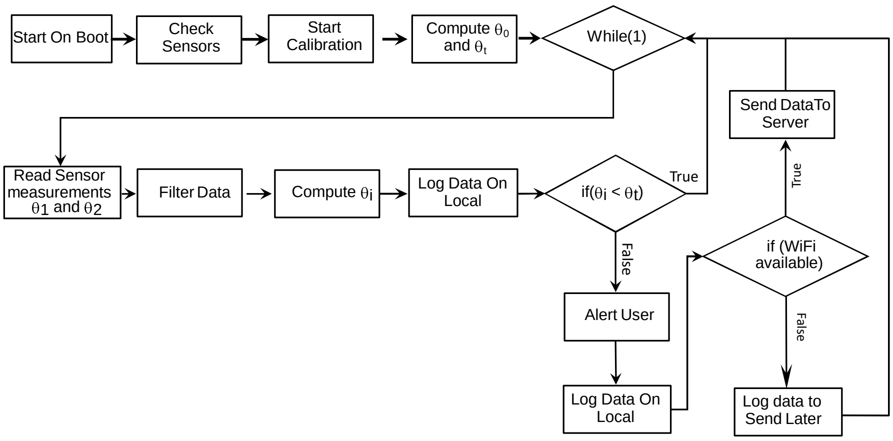

Figure 3. Flowchart of the algorithm used in microcomputer

Figure 4. A participant with a vibro-haptic corset from various views

The investigation was implemented for 2 cases to figure out the efficiency of the smart corset. In the first case, tactile stimuli was not provided to the participants while in the second case tactile stimuli was ensured. The idea of the first case was to determine the user's habitual daily sitting posture, while in the 2nd case was to investigate how well the vibro-tactile stimulation could rehabilitate the user's posture by changing his/her cognitive attitude. The duration of each test case was one hour and performed from 2:00 PM to 3:00 PM to ensure the same daily conditions.

2.4 Statistical assessment

Statistical differences between case 1 and 2 were investigated through one-way analysis of variance and paired *t*-test by imposing a confidence interval of 95%. Differences between the cases are significant for *p*-value is lower than 0.05 level. The statistical assessments were performed using SPSS 22.0. Furthermore, the participants' scores were processed using receiver operating characteristics (ROC) curves to determine how well their results in case 1 and 2 could be discriminated using MATLAB 2012. ROC curves summarize any possible classification between groups' datasets. They are typically established by plotting the true positive rate (TPR) against the false positive rate (FPR) at various threshold settings. For a curve close to the TPR left vertical axis, the classification score increases, while it is close to the FPR horizontal axis the score decreases. Therefore, the best possible classification would yield a point in the upper left horizontal corner point (0,1). The performance of the curve is assessed via area under curve (AUC) and critical optimum point (COP). The best performance is observed for AUC=1, while the worst is for AUC =0.5. Generally, an AUC of 0.5 is considered "no separation" between groups, 0.6 to 0.7 is "sufficient", 0.7 to 0.8 is "acceptable", 0.8 to 0.9 is "very good", and higher than 0.9 is outstanding.

3. RESULTS

In this study, a vibro-tactile feedback-based corset was developed to stimulate humans to be in ideal posture. Initially, various experiments have been performed on corset's textile to investigate whether it provides reasonable comfort properties in terms of wetting time, absorption rate, maximum wetted radius, spreading speed, accumulative one-way transport capacity and overall moisture management capacity. The overall moisture management capacity (OMMC) is the combination of one-way transportation of liquid, moisture absorption and spreading rate inside the fabric [34]. Typically, this value represents the liquid that effectivity transferred from top surface to the bottom [35]. The higher OMMC resulted in higher spreads of liquid. The results showed that fish line fabric has an advantage such that it can prevent any possible textile bulges during human daily activity. The weight per unit area and air permeability values of this fabric are 479.4 g/m^{2}and 710.7 L/m^{2}s, respectively. It was obtained from comfort tests that the selected fabric allows air and moisture to pass through. The overall results suggest that the corset's fabric is reasonable and promise comfort to the user (Table 2).

In the next step, the smart corset efficiency was determined on participants. Typical raw measurements that show the relative angle of motion for a participant is represented in Figure 5a. The red horizontal dashed line refers to the threshold line while the red vertical line shows the separation band between the two cases. The sampling rate of the measurement is 5 Hz. Each case measurements include 18K data points that yield 60 min. It is observed that the number of data points that exceeds the threshold line (16.34^o) is found to be higher in case 1 than the second case. The raw measurements were also investigated using the box plots (Figure 5b). In brief, the box plot is a standard method of distribution of data samples corresponding to the features using boxes and whiskers. It represents the inter quartile range of samples while the whiskers refer to a multiple of the first and third quartile of any variable. Any data points that are placed out of this limit are considered as outliers. The inter-quartile values for case 1 and 2 range from 4.92^o to 13.30^o and 6.11^o to 11.11^o, respectively (Figure 5b). These results suggest that the range of motion (ROM) due to slouching was decreased in case 2 and indicate that the participant's posture was improved when stimulated by vibro-haptic actuation. The reason for higher outliers encountered in case 2 may have occurred due to participant's sudden motion to correct the posture once they feel the vibro stimuli.

Table 2. Moisture management results of the fish line stretch fabric

Variable	**Region**	**Result**	**Scale**
Wetting Time (s)	Top	4,9687	Fast
	Bottom	4,9167	Fast
Absorption Rate (%/s)	Top	33,7898	Medium
	Bottom	34,6331	Medium
Maximum Wetted Radius (mm)	Top	16,6667	Medium
	Bottom	16,6667	Medium
Spreading Speed (mm/s)	Top	3,0496	Fast
	Bottom	3,1412	Fast
Accumulative One-Way Transport Capacity (%)	Top- Bottom	33,3048	Bad
Overall Moisture Management Capacity (OMMC)	Top- Bottom	0,3394	Very bad

In order to observe and determine all participants' performance, the results are plotted via bar and scatter graphs (Figure 6). The colored circular disk represents the performance and its value as well as the color scale distribution is located at the right of the graph. The performance is computed via $(p_1-p_2)/p_1 \times 100$, while p_1 and p_2 refer to the non-ideal posture number for case 1 and case 2, respectively. The mean non-ideal posture numbers for case 1 and case 2 are 694.66 and 272.25, respectively. In addition, the mean non-ideal posture duration for case 1 and 2 are 147.02 s and 62.18 s, respectively. The highest posture improvement is obtained in the 2nd participant (81.11 %), while the lowest in subject 6 (11.68 %). One possible reason for the low performance of this 6th participant is that he/she may not feel the vibro-haptic stimuli well. The average posture improvement percentage for all participants is 53.65 ± 23.14.

One way ANOVA test assessment was performed for each participant's raw time measurement series to determine the efficiency of vibro-tactile stimuli. The postural angles of all participants in case 1 and 2 are $23.25^\circ \pm 3.44^\circ$ and $20.81^\circ \pm 4.51^\circ$, respectively. The ANOVA test results demonstrate that there is a significant difference between the two cases. ($p<0.05$)

The relative angle measurements obtained for all subjects are combined as two-dimensional vector datasets to investigate the inter quartile range for each case. The size of these datasets is 192K x 2 and the 1st and 2nd dimension refer to case 1 and 2, respectively. The inter quartile relative angle for case 1 is in a range of -3.29° to 5.33°, while for the 2nd case is -2.1° to 2.96° (Figure 7a). It is observed that the range of the box in the 2nd case is lower than the 1st one which indicates that the range of motion due to slouching decreases in case 2.

The subjects' scores were further assessed using receiver operating characteristics (ROC) curves to determine how well all participants' results for two cases could be discriminated against (Figure 7b). The size of the raw measurements for each case is 96Kx2. In addition, the size of the non-ideal posture number and posture duration is 12x2. Note that, the first two dimensions refer to the 1st and 2nd case data. Area under curve (AUC) value obtained for the raw measurements is 0.6531, and critical optimum point is located at (0.2833, 0.4807). These results show that the raw measurements in each case could be separated with a sufficient score. However, acceptable AUC values are obtained for non-ideal posture number (AUC = 0.7083) and non-ideal posture duration (AUC = 0.7361). The overall ROC curves results indicate that once a user is stimulated via vibro-haptic stimuli his/her posture regime changes to a lower slouching range.

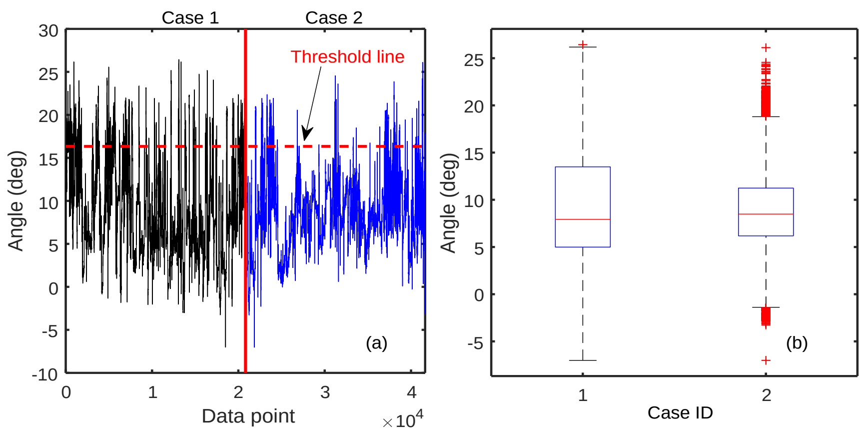

Figure 5. Typical measurements obtained for a participant. (a) Raw measurements, (b) Box-plot of the raw measurements

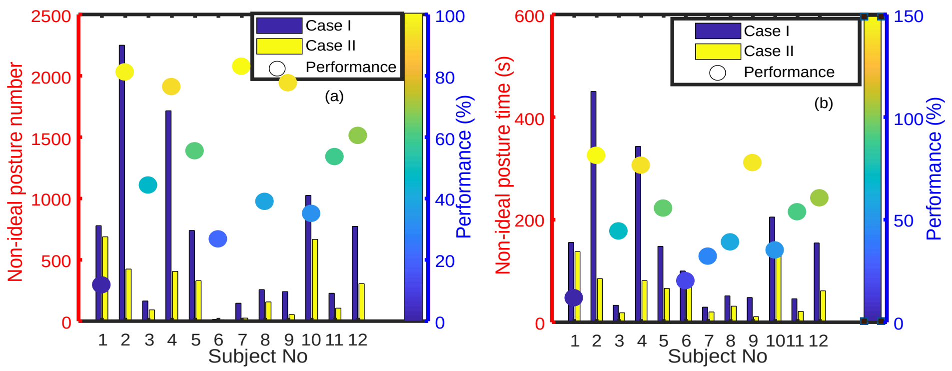

Figure 6. The performance of human subjects for the two cases (a) Non-ideal posture numbers, (b) Non-ideal posture duration

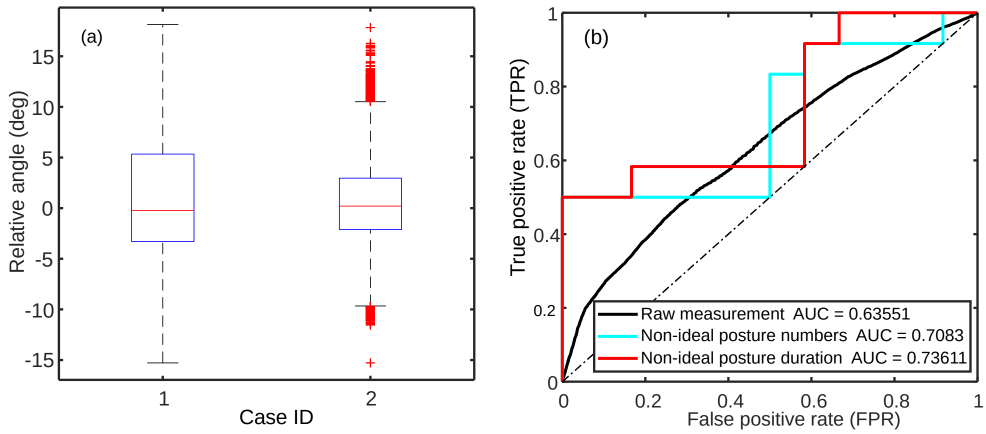

Figure 7. All participants' results. (a) Box-plots, (b) ROC curves

4. DISCUSSION AND CONCLUSION

This study aimed to develop a vibro-haptic corset that stimulates humans to be closely in an ideal posture. Initially, an appropriate fabric textile that provides reasonable properties for the human's comfort was chosen. Then, two orientation sensors and a vibro-haptic actuator were attached to the corset via at T5-T12 and L3 level, respectively. An algorithm was developed to perform some features such as monitoring the posture, calibrating the sensors, storing the raw measurement, determining the critical non-ideal posture threshold angle, acquiring the non-ideal postures as well as the duration, and transferring them over a Wi-Fi connection to the server. Then, two test cases were implemented on 12 participants for the case duration of one hour. In the first case vibro-haptic stimulation was not provided to participants while in the second case it was ensured. The results obtained for participants are given in the previous section. In order to summarize the efficiency of the corset, the participants' results are represented in Figure 8. A paired t-test is implemented on these results to figure out whether there are statistical differences between case 1 and 2. The results show that there is significant statistical difference between them ($p<0.05$) which indicates that the vibro-haptic corset improves the posture. The improvement is around 53%, and their non-ideal posture duration was significantly decreased showing that their motor learning could be encouraged.

We believe that the use of adjustable velcros fasteners ensure appropriate placement of sensors and actuator to each specific subject's spine anatomy. Furthermore, the instructions provided to participants prior to the tests were sufficient and prevented any misalignments. All of them completed the two case tests successfully. A Likert type survey was arranged for subjective evaluation of the participants to figure out how well they were satisfied by using such a smart corset. Statements and results of this survey are given in Table 3, and they show a favorable response for this corset. The subjective evaluation also showed that the corset's fabric and electronic components are suitable, their size fits on each participant and they feel their self comfort. In addition, 91 % of all subjects agree that it aids to improve posture and they want to use it for their daily life. Their responses are also visualized with bar graphs (Figure 9). In overall, the participants' sentiments are mainly located at "agree" and "strongly agree " choices (73 %).

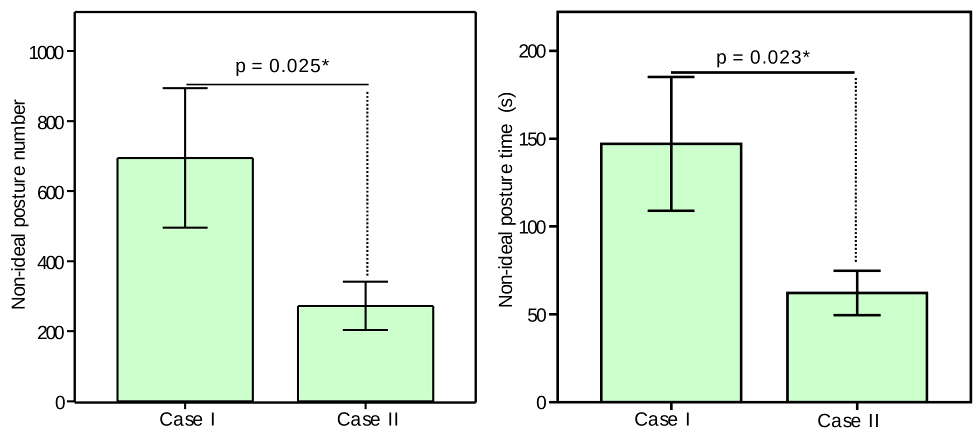

Figure 8. The results of all participants. (a) Non-ideal posture numbers, (b)Non-ideal posture duration (Whiskers represent the standard errors)

Table 3. User satisfaction survey

No	Statement	Score
1	The instructions provided with the vibro-corset are easy to understand and adapting it is not difficult.	4.0
2	The corset is comfortable in terms of moisture transmission and air permeability.	4.2
3	The fabric texture does not hurt my skin.	4.1
4	Satisfied with the electronic components	4.2
5	The corset does not cause sweating.	3.9
6	The corset does not cause pain in my body.	4.1
7	The corset and its electronic components neither restrict my movements nor prevent me from performing my daily life activities.	4.3
8	Satisfied with the vibro actuators of the corset	4.0
9	I think that it aids in improving posture stability.	4.2
10	I want to use it in my daily life.	4.3
Response choices: 1) Strongly disagree, 2) Somewhat disagree, 3) Neither agree nor disagree, 4) Somewhat agree, 5) Strongly agree		

The algorithms used in posture curvature recognition could be classified as model and data-based approaches. The model-based approach is generally implemented by building a geometrical model for determining the spine's posture. Once the geometrical model based on anatomical spine's curvature is established it is updated using measurements from sensors that are attached to humans' skin, garment or corset. Implementing such a model-based approach is simple and does not cause CPU power to consume the battery fast. On the other hand, a data-based approach is performed mostly using pattern recognition and machine learning techniques [36]. It uses direct raw data of measurements, and the algorithm is established using statistical techniques. In primary investigation, we also used this approach to test null hypothesis. The null hypothesis can be considered as; if H_0: $P(\varepsilon_x) = P(\varepsilon_y)$, "ideal posture" against the alternative hypothesis, if H_1: $P(\varepsilon_x) \neq P(\varepsilon_y)$, "non ideal posture". ε_x and ε_y refer to the reference healthy posture and testing posture, respectively. The non-ideal posture could be detected using *F*-statistics for 99 % confidence interval. However, large datasets and higher computational power are required to process them by using a data-based approach that causes higher consumption of a battery. Hence, we preferred to use the model-based approach. However, we expect that the advancements in battery and processor technology will allow us to embed powerful machine learning and pattern recognition approaches in these portable devices to monitor and detect the posture anomalies.

Currently, radiological images that are constructed using X-ray, computer tomography (CT), and magnetic resonance imaging are key standard devices for evaluation of posture curvature [37]. However, expensive lab-based instruments may not effectively monitor the user's posture for daily conditions. Recently, wearable technologies have been proposed and some of them commercially available in the market [29]. These typical devices can monitor one's posture, stimulate him/her in non-ideal posture. However, the algorithms embedded in them are not open to the public due to commercialization. In addition, although many studies reported in history belong to the sitting posture, the ideal sitting posture has not been defined yet [4]. Therefore, the lack of a standardized postural metrics method is challenging. Furthermore, the majority of studies reported in literature have been focused on the postural device placed on the garment, while its ergonomic features have not been investigated [21,28]. In addition, many of commercial postural devices include a single sensor node, and it is not clear whether a single node has a capability to measure relative joint angle. In this study, we characterized the corset's fabric and developed an algorithm that could detect the relative range of motion of a joint, store and transfer the data over a Wi-Fi connection to the server. The microcomputer, sensors and haptic actuator have been enclosed in 3D printed boxes and attached to the corset via velcros. The corset is washable for reuse by detaching the components.

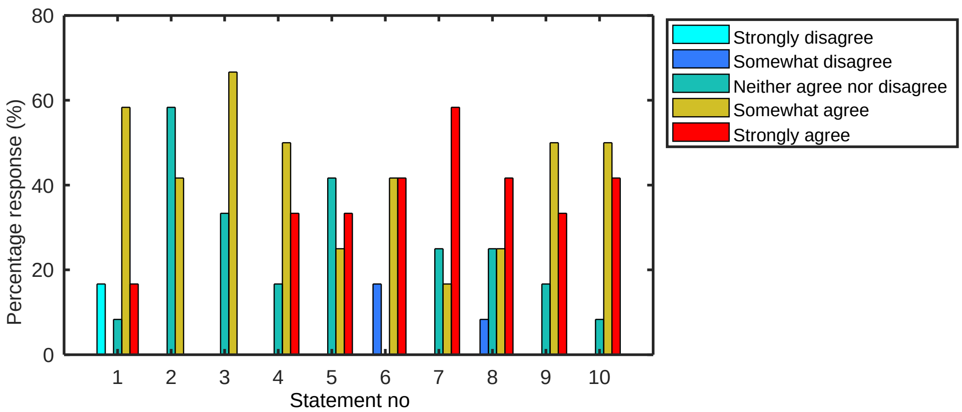

Figure 9. Summary of subjects percentage responses in satisfaction survey

Recently, technological advances have empowered us to design and create powerful wearable tools not just only for patients but also for regular healthy persons. Professional healthcare may be overwhelmed when their patients increase, or such as in a global pandemic, these wearable devices could be brought to the table. It is demonstrated in methodology that the vibro-haptic corset has a capability to transform the user's data to the server. It is expected that a healthcare professional at server side can monitor the user's data and allow preventive care and manage ongoing conditions. It is also expected that the vibro-haptic corset may be used as a supporting tool in the healthcare system and to reduce the overwhelm in clinics.

Although the participants' results indicate that the vibro-haptic corset significantly improves their posture, there are some limitations regarding this study. First, the small population and age demographic are useful for determining its performance. Hence, the population of participants should be increased to figure out how the vibro-haptic stimuli could change the cognitive of participants across age and body index. Second, although the algorithm embedded in corset's device is programmed for sitting posture, it should be expanded to include all daily activities. The current version of the corset monitors a single flexion-extension direction in the sagittal plane. However, it should also include multi axis direction such as left-right lateral bending and twisting along the axis of spine. Future studies should focus on expanding the measurement capabilities.

The overall conclusion is that the vibro-haptic corset effectively provides postural improvements and could be deployed as a promising trainer. To further verify its feasibility, future efforts should be directed to include multi nodes in a network for a large population.

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