Posture Tracking System

Man Sang WONG, Wai Yin WONG
Department of Health Technology and Informatics, The Hong Kong Polytechnic University, Hung Hom, Kowloon, Hong Kong SAR, China

Corresponding Author Email Address:
Man Sang WONG: m.s.wong@polyu.edu.hk
Abstract

Background

Spinal deviations usually refer to abnormal lateral or sagittal curvature that could be the cause or effect of some spinal diseases. The conventional orthotic intervention is to apply passive forces to patient’s body via an orthosis for supporting / controlling the trunk alignments. However, once the orthosis is removed, such functions cannot be maintained. Therefore, an active posture training approach should be postulated in suitable cases as it can keep the trunk in appropriate posture via using the patient’s own back muscles and a long-lasting effect is anticipated.

Method

A portable posture monitoring system has been developed, which consists of 3 inertial sensor modules, a data logging and feedback system, an integrated garment, and software for posture analysis and training. The sensor modules are used for tracking posture change at thoracic and lumber regions in the sagittal and coronal planes relative to a neutral position, in terms of curvature alteration measured between adjacent sensor modules. The system was previously tested on 5 normal subjects. In this study, 2 patients with adolescent idiopathic scoliosis were recruited to compare the posture changes in some specific postures and a preliminary clinical trial of posture monitoring was conducted for 2 weeks.
Results
The results showed that trunk angles of the patients in the specific trunk movements were relatively larger than those of the normal subjects, especially in the coupled movements. It showed that the system could facilitate patients to prevent prolonged poor postures of the spine, especially the posture of the lumbar spine in which at least 40% of the time in poor posture were reduced.

Conclusions
The findings demonstrated the potential of this system in facilitating posture training. It is worthwhile for further developments and the ultimate goals are towards the applications in occupational health promotion as a prophylactic measure for those jobs with high risk of back problems as well as a treatment option for the patients with posture deformities or spinal diseases.

Background
Adolescent idiopathic scoliosis is the most common type and represents about 80% of idiopathic scoliosis. Apart from physical deformity of the spine, postural and proprioceptive dysfunctions are suggested to be the common defect of idiopathic scoliosis [1-4], which may deteriorate the spinal deformities. The multi-disciplinary rehabilitation concept of these spinal disorders include surgical, medical and orthotic interventions, and back muscle strengthening exercises to counteract postural deviations of the patients. For non-surgical and non-medical interventions, conventional orthotic interventions are to apply passive forces to the human body with orthosis for supporting the trunk alignments and controlling the deformities of the
spine. Currently, rigid thoraco-lumbo-sacral orthoses (TLSO) are used for patients with progressive idiopathic scoliosis. However, the use of these external supports is limited by the factors such as poor appearance, bulkiness, physical constraint, cause of muscle atrophy that could lead to low acceptance and compliance [5-7]. Back muscle strengthening exercises are trying to strengthen the back muscle for keeping the trunk in upright posture with active muscular forces. However, the patients’ compliance with the prescribed exercise interventions present a challenge, especially patients who are not self-motivated may not continue with the prescribed exercise programs [8, 9].

Improper posturing for the patients with spinal disorders can further deteriorate their pain and deformities. Thus, the corresponding symptoms may be prevented with the awareness of their posture [10, 11]. Postural training may facilitate the refinement of proprioceptive awareness of upright posture and prevention of deterioration of some spinal deformities such as scoliosis. A “reminder” for a good posture may be an acceptable prophylaxis for those at risk. A posture training device could help to facilitate this therapeutic approach by providing continuous posture monitoring and feedback signals to patients when “poor” posture is detected. In addition, the users of the device may learn good postural habits that might carry over into their whole life.

Based on this therapeutic approach, a posture training system has been developed by Dworkin et al. to handle patients with adolescent idiopathic scoliosis or hyperkyphosis [11]. The system was used to monitor the spinal posture in terms of instantaneous spinal length continuously in real-time and to provide feedback signals to patients in order to correct their posture. However, there are some drawbacks of the
device. It tracks the longitudinal and horizontal torso circumferences only and cannot provide any information directly related to spinal curvatures. The tension of the torso loop can cause discomfort and pressure abrasions at the gluteal cleft and groin area. Therefore, a more user-friendly and innovative portable posture training system, which can measure the parameters related to spinal curvature, should be developed for providing postural information of daily activity and improving the feasibility and effectiveness of posture training.

In the recent decade, many positional sensors have been developed for robotic, industrial and aerospace and biomedical applications. These sensors become smaller in size and better performance by using advanced circuit technology. Accelerometers and gyroscopes are commonly used to provide information on position and orientation in aerospace and robotic industries. For trunk motions analysis, these sensors also can be used to measure the kinematic parameters of body segments [12-20], including inclination relative to the gravity, linear acceleration and angular velocity. Therefore, a portable posture monitoring system can be built with these miniature sensors [21-24].

The aim of this study is to demonstrate the feasibility of the posture tracking system in guiding patients with adolescent idiopathic scoliosis to keep away from poor posture of the spine during daily activities.
Methods

Equipments

A posture tracking system has been developed and it consists of three sensor modules, a digital data acquisition and feedback system, battery pack and a garment. Each sensor module (size: 22x20x12 mm, weight: 6g) has a tri-axial accelerometer (KXM52-Tri-axis, Kionix, USA) and 3 uni-axial gyroscopes (XV-3500CB, Epson, Germany) orthogonally aligned, and assembled in a quasi-rectangular box. These three sensor modules are integrated into the elastic tight-fitting garment and connected to the digital data acquisition and feedback system. The data acquisition and feedback system (size: 21x50x84 mm, weight: 44.5g) include microcontrollers, memory with associated circuit and buzzer, are packaged into a plastic box. The system operates with 4 AAA size rechargeable batteries (Ni-MH type, 1100mAh, 1.2V) which are placed in a battery holder (size: 50×55×12 mm, weight: 82g) and requires recharging after 8 hours operation. The accuracy and feasibility of the system in guiding normal subjects to keep away from poor posture of the spine during daily activities were evaluated in the previous studies [20, 24-26].

Subjects

Five normal subjects participated in the specific trunk movements tracking experiment and two patients with adolescent idiopathic scoliosis (AIS), who were recruited from a scoliosis clinic, participated in both specific trunk movement tracking experiment and preliminary trial of posture monitoring. (Table 1)
Trunk posture tracking in specific trunk movements

All subjects performed a series of 5 specific postures (Table 2) and the posture information was collected for demonstrating the performance of the system in detecting the change of the trunk orientation. The subjects performed each specific posture for 5 seconds after calibration of the posture monitoring system in neutral standing position.

Preliminary clinical trial

The feasibility of the system in tracking the posture change was tested with the two patients for 2 weeks in this pilot clinical trial. Written informed consents were obtained from the two patients and their parents prior to the experiments. The patients wore the posture tracking system for 2 hours continuously a day during their leisure time at home (Figure 1). The system was not worn during sleeping. The sensor modules were attached at the upper trunk (T1/T2), middle trunk (T12) and pelvis (S1). The trunk postural changes in the sagittal and coronal planes were estimated with output signals of the sensor modules in terms of curvature alteration measured between adjacent sensor modules and based on the concept of calculating the change of inclination angles difference between upper trunk and middle trunk for thoracic spine and between middle trunk and pelvis for lumbar spine in different trunk movements [27] (Figure 3). The measurement of the trunk posture using the sensor modules were evaluated and compared with the motion analysis system in previous study and reported in literature [25]. The sign of angle adopted as flexion and lateral bending to right were considered positive, and movement in opposite directions were represented by negative value for all data. It was calibrated in a neutral standing position for 1 minute before starting the posture monitoring. The neutral standing position was defined as standing against the wall and looking forward. In this
position, the shoulder blades and the buttocks of the subject should be flat against the wall and the shoulders and the pelvis should be level, in order to perform the posture with the natural spinal curvature of the subject in standing positions.

The aim of the system for posture training is to keep the tone off as long as the user can, thus the users will learn which postures will keep their back in natural spinal curvature. Eventually, the users can be trained to maintain the natural spinal curvature (good posture) more often as their posture habit. In this study, the mechanism was explained to the subjects in detail, but the exact interventional arrangement was not given to the patients to prevent their perception bias. Feedback was provided in form of tone from a buzzer for 5 times (last for approximately 2 seconds) while the measured changes of trunk posture (trunk angles) at the thoracic and lumbar regions was out of the target range (for controlling flexion only in the sagittal plane, but both sides bending in the coronal plane) and last for longer than the specified tolerance time according to the protocol (Table 3). Two patients with adolescent idiopathic scoliosis were asked to use the system for 2 hours a day continuously in the 2-week trial with two different protocols for the 2 weeks (Table 3) and attend 4 clinical visits for fitting and adjusting the system, downloading data and returning the system. The study period was right after pre-brace measurement and before brace fitting. The protocol of the routine orthotic intervention was not affected. The suggested period of time for the patients to use the posture monitoring system was after school and before going to sleep as an additional posture training session.
Results

Trunk posture tracking in specific trunk movements

Figures 2 and 3 show the mean and standard deviation of trunk angles of the normal subjects and trunk angles of the patients with AIS in these five specific postures in the sagittal and coronal planes, respectively. It was found that trunk angles of the patients in trunk movements were relatively larger than those of the normal subjects, especially in the coupled movements. The possible reason of this observation is the spinal deformities affected some spinal movements of the patients. Therefore, the coupled movements of the spine might be required to compensate the whole spinal movement. The patient group is younger than the normal group, thus their flexibility may be higher. This observation should be further investigated with more scoliotic cases with different curve patterns.

Preliminary clinical trial

For the 2-week clinical trial of the patients with AIS, the total hours of monitoring and averaged trunk angles are shown in Table 4. The posture information of the patients was monitored at least 1.5 hours a day for each patient in this 2-week trial, except the first week of the Patient A. The power supply cable of the system was broken accidentally in the forth day of the first week in the Patient A’s monitoring period. The trunk angle of the lumbar region in the sagittal plane was about 50% smaller with provided feedback in the second week than those without feedback in the first week. Figures 4 and 5 show the trunk posture deviations of the patients. Figure 6 shows the percentage of the monitoring time in which the trunk angles of the patients were in out-of-target postures. Less than 40% of monitoring time of the 2-week trial was
found for the trunk angles in the coronal plane to be in out-of-target postures. For the sagittal plane, there was a trend in reducing the percentage of time of out-of-target postures, especially in the lumbar region with feedback function as those of the normal subjects. The posture of the lumbar was approximately 80% of the time in out-of-target postures in the first week. In the second week, it was reduced about 50% of those in the first week for these two patients with feedback function provided.

**Discussion**

In the 2-week trial of posture monitoring, the patients with AIS also reported that they sat (using computer and doing homework) more often than standing during the monitoring period as normal subjects in the previous study [24]. The trunk posture deviations were also more obvious in the sagittal plane than in the coronal plane, especially on the lumbar region, as those observed in the normal subjects in the previous study [24] and in literatures [21, 28]. In these two cases, one is single curve (right lumbar) and the other is double curve (right thoracic and left lumbar). No typical posture pattern could be observed in the double curve case (Patient B) but the patient with single right lumbar scoliotic curve (Patient A) bent to left side (curvature reduction) more often during the monitoring period (but not significantly) that demonstrated that the system could help to track the deformity. This could be due that the trunk posture is more balanced in double curves pattern than that in single curve pattern. The results demonstrated that the system could provide posture information to the patients with AIS, and they tended to keep the target posture with the feedback function. However, the effectiveness of the posture monitoring system on posture
training of patients with different patterns of scoliotic curves should be evaluated in a long-term clinical trial.

The inherent limitation of the surface methods is that the actual skeletal deformity of the spine cannot be assessed directly. Therefore, the smart garment has been developed for monitoring the posture change of thoracic and lumbar regions relative to those in the neutral standing position as the general posture information in the literatures [11, 23, 29].

The patients had a mild to moderate scoliotic curve (Cobb’s angle: 23°-32°) and a hump at the apex level with 10° to 13° during forward bending test. The preliminary results demonstrated that the system could provide posture information of the patients during daily activities. For further investigation of the posture monitoring system, the evaluation protocol of some intensive exercises and posture trainings for patients with spinal disorders, for example idiopathic scoliosis and low back pain, which reported in literatures could be used as references [10, 11, 30-33]. The posture monitoring system may be applied to the patients for at least 2 hours a day for basic posture training and at least 8 hours per day for intensive posture training. The outcome evaluation of the system in posture training should have at least 1 year follow-up.

The design of the posture monitoring system is a wired system between the sensor modules and the data processing system in this current prototype. The cables may restrict trunk motion and lead to tear and wear for prolonged usage. Therefore, the wireless technology, e.g. Zigbee, is being considered to solve this problem.
This prototype provides a type of feedback signal, warning tone (last for about 2 seconds), which is provided by a buzzer. This type of feedback signal is like a punishment to the user for performing poor postures in a time interval. To reduce the embarrassment caused accordingly, vibration, which can be produced by a miniature vibration motor, have been suggested as another type of feedback signal in the literatures [21, 28, 33]. The vibratory signal could maintain the privacy of the user in using this posture monitoring system but it could be ignored by the user especially the children. For the technical issue of the system design, the power consumption is one of the concerns. The choice of the feedback signal and strategy of providing the signal should strike a balance among the system effectiveness, user’s acceptance, and its relevant technical issues. The most effective type of feedback signal and strategy of posture training should be further investigated for specific target group of users.

Conclusions

The posture tracking system has been developed to be a portable and user-friendly system that could be fixed onto the body for tracking trunk posture change in daily activities, and could be used for collecting the trunk posture information about daily posture habit of the users. The preliminary results demonstrated that the posture of patients with adolescent idiopathic scoliosis could be monitored and trained via this system. The long term effect of this system is still under investigation.

Competing interests

The authors declared that they have no completing interests.
Authors' contributions

MS – study design and coordination, data analysis and report writing.

WY - development of the system, data acquisition, data analysis and report writing.

All authors read and approved the final manuscript.

Acknowledgements

This study was supported by the Research Committee of The Hong Kong Polytechnic University. The authors are grateful to Dr. Alan Lam, Sengital Limited and Miss Theresa Chan, the Institute of Textiles and Clothing, The Hong Kong Polytechnic University for their technical support and advices.

References


Figures

Figure 1 - A subject with the smart garment.

Figure 2 - Trunk angles of the normal subjects and patients in the sagittal plane in the five specific postures.

Figure 3 - Trunk angles of the normal subjects and patients in the coronal plane in the five specific postures.

Figure 4 - Average of the trunk posture deviations from the neutral standing position of the Patient A in 2-week trials. Three line-segments represent the relative tilting of the 3 sensor modules to the neutral position.

Figure 5 - Average of the trunk posture deviations from the neutral standing position of the Patient B in 2-week trials. Three line-segments represent the relative tilting of the 3 sensor modules to the neutral position.

Figure 6 - The percentage of the time of the patients with AIS spent in out-of-target posture (NF: without feedback, F: with feedback).
## Tables

### Table 1 - Demographic details of normal subjects and patients with adolescent idiopathic scoliosis (mean±standard deviation)

<table>
<thead>
<tr>
<th>Dimension</th>
<th>Normal subjects</th>
<th>Patients with adolescent idiopathic scoliosis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sex (male/female)</td>
<td>1 male, 4 female</td>
<td>female</td>
</tr>
<tr>
<td>Age, year</td>
<td>(25.2±4.8)</td>
<td>13</td>
</tr>
<tr>
<td></td>
<td></td>
<td>11</td>
</tr>
<tr>
<td>Height, m</td>
<td>(1.7±0.09)</td>
<td>1.54</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1.46</td>
</tr>
<tr>
<td>Weight, kg</td>
<td>(50.5±7.2)</td>
<td>35.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>33.2</td>
</tr>
<tr>
<td>Body mass index, kgm²</td>
<td>(18.4±1.1)</td>
<td>15.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>15.1</td>
</tr>
<tr>
<td>Risser sign</td>
<td>-</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>Curve pattern</td>
<td>-</td>
<td>Right Lumbar</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Right Thoracic Left Lumbar</td>
</tr>
<tr>
<td>Cobb’s angle, degree</td>
<td>-</td>
<td>28</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Thoracic: 23, Lumbar: 32</td>
</tr>
</tbody>
</table>

### Table 2 - Five specific trunk movements

<table>
<thead>
<tr>
<th>Specific trunk movements</th>
<th>Descriptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Flexion:</td>
<td>The trunk bends forward and the hands touch the knees.</td>
</tr>
<tr>
<td>2. Left side bending:</td>
<td>The trunk bends maximally to left side with the hands at the sides of the trunk.</td>
</tr>
<tr>
<td>3. Right side bending:</td>
<td>The trunk bends maximally to right side with the hands at the sides of the trunk.</td>
</tr>
<tr>
<td>4. Left rotation:</td>
<td>The upper trunk rotates maximally to the left side relative to the pelvic axially.</td>
</tr>
<tr>
<td>5. Right rotation:</td>
<td>The upper trunk rotates maximally to the right side relative to the pelvic axially.</td>
</tr>
</tbody>
</table>
Table 3 - Protocol of trunk posture monitoring for patients with adolescent idiopathic scoliosis

<table>
<thead>
<tr>
<th>Week</th>
<th>Feedback Status</th>
<th>Target range</th>
<th>Tolerance time</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Sagittal plane</td>
<td>Coronal plane</td>
</tr>
<tr>
<td>1</td>
<td>OFF</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>2</td>
<td>ON</td>
<td>&lt;10°</td>
<td>±10°</td>
</tr>
</tbody>
</table>

Table 4 - Monitoring hours and trunk angles (mean ± standard deviation) of the patients with AIS (in degree). (Positive value represents forward flexion or right side bending; value in bracket is negative and represents extension or left side bending)

<table>
<thead>
<tr>
<th>Trials of monitoring</th>
<th>Sagittal Plane</th>
<th>Coronal Plane</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total hours</td>
<td>Thoracic region</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Patient A</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Week 1</td>
<td>5</td>
<td>8.7±10.8</td>
</tr>
<tr>
<td>Week 2</td>
<td>13</td>
<td>6.1±10.0</td>
</tr>
</tbody>
</table>

Patient B

|                      |                |                |               |                |               |
| Week 1               | 15             | 0.0±9.0        | 32.1±11.0     | (1.8)±6.0      | (0.5)±4.0     |
| Week 2               | 14             | (4.7)±8.4      | 10.2±7.3      | (2.7)±4.1      | 5.0±3.1       |
Figure 1 - A subject with the smart garment.

Figure 2 - Trunk angles of the normal subjects and patients in the sagittal plane in the five specific postures.

Figure 3 - Trunk angles of the normal subjects and patients in the coronal plane in the five specific postures.

Figure 4 - Average of the trunk posture deviations from the neutral standing position of the Patient A in 2-week trials. Three line-segments represent the relative tilting of the 3 sensor modules to the neutral position.
Figure 5 - Average of the trunk posture deviations from the neutral standing position of the Patient B in 2-week trials. Three line-segments represent the relative tilting of the 3 sensor modules to the neutral position.

Figure 6 - The percentage of the time of the patients with AIS spent in out-of-target posture (NF: without feedback, F: with feedback).