Body-Mapping Tank Top Equipped with Biofeedback System for Adolescents with Early Scoliosis

Dr. Joanne Yiu-wan Yip
PolyU UoA 38
## Contents

<table>
<thead>
<tr>
<th>Section</th>
<th>Topic</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Descriptor</td>
<td>03</td>
</tr>
<tr>
<td>2</td>
<td>Biography of Principle Investigator</td>
<td>04</td>
</tr>
<tr>
<td>3</td>
<td>Research Output</td>
<td>05</td>
</tr>
<tr>
<td>4</td>
<td>Research Field and Key Works Referenced</td>
<td>08</td>
</tr>
<tr>
<td>5</td>
<td>Research Questions</td>
<td>09</td>
</tr>
<tr>
<td>6</td>
<td>Originality</td>
<td>10</td>
</tr>
<tr>
<td>7</td>
<td>Research Process</td>
<td>11</td>
</tr>
<tr>
<td>8</td>
<td>Research Conclusions</td>
<td>25</td>
</tr>
<tr>
<td>9</td>
<td>Future applications</td>
<td>29</td>
</tr>
<tr>
<td>10</td>
<td>Dissemination and distribution of outcomes</td>
<td>30</td>
</tr>
<tr>
<td>11</td>
<td>References</td>
<td>47</td>
</tr>
</tbody>
</table>
Body-Mapping Tank Top Equipped with Biofeedback System for Adolescents with Early Scoliosis

Descriptor

This is a two-year multi-disciplinary collaborative study that involves experts in clinical psychology, computing science, and orthopedics. Conventional orthotic interventions apply passive forces to the human body with orthosis to support the trunk alignment and control the deformities of the spine. However, the use of these external supports is limited by factors such as poor appearance and physical constraint. Back muscle strengthening exercises attempt to strengthen the back muscles to maintain the trunk in an upright position with active muscular forces. Moreover, patient compliance with the prescribed intervention exercises presents a challenge. Given these issues, the research team designed and developed a body-mapping tank top equipped with a biofeedback system. The tank top can be used to progressively provide muscle training to patients with spinal deformities so as to restore a balance in muscle activity and a reduction in the displacement of both sides of the spine. The sensor-based biofeedback tank top can motivate patients to play active roles, thus improving movement control and coordination, as well as daily posture. The results have been communicated in journals and conference papers, and have been exhibited at the 45th International Exhibition of Inventions of Geneva and at the Hong Kong International Medical Devices and Supplies Fair. The research methodology was introduced in RCA, UK and HKUSZ hospital. The major findings of this study are that after about 30 sessions of posture training, the majority of the participants were able to train their sitting postures so that they were relatively more balanced and involved lower degrees of muscle activities in terms of sEMG signals compared to their circumstances prior to the training. Despite the limited sample size of participants in this study, these are encouraging results which warrant further study of posture training of mild scoliotic patients.
Principal investigator - Dr. Joanne Yip

Associate Professor, ITC,
The Hong Kong Polytechnic University

Dr. Yip, Joanne graduated with a BSc (Hons) in Textile Technology (with first class Honors) in 1999 from the Hong Kong Polytechnic University and obtained her PhD at the same university in 2003. Dr. Yip research interests include new materials and technology, surface treatments on textiles, moulding or seamless techniques used in Intimate Apparel. Recently, her research focus is related to posture correction and control of spinal deformity using a newly developed functional garments. Dr. Yip has published more than 100 referee and conference papers in Textile and Material Science Journals.

Co-I:
- Dr. Mei-Chun Cheung (CUHK)
- Dr. Kit Lun Yick (ITC, PolyU)
- Dr. Sun Pui Ng (HKCC, PolyU)
- Dr. Alvin Chan (Singapore Institute of Technology)
- Mr. Chi Yung Tse (P&O, Non-PolyU)
Research Output

Lining Fabric (Powernet):
95% Nylon & 5% Spandex

Shell Fabric (Tricot):
80% Nylon & 20% Spandex

- Four-way stretch property
- Stretchy, Breathable
- Durable, light-weight

⇒ Provide maximum comfort for the users

Meta Wear C Sensor with Bluetooth connection system

Sensor will be inserted in this small pocket to monitor subjects’ compliance and posture

Smartphone App will remind subjects when their bodies begin to slouch
Research Field and Key Works Referenced

- AIS is prevalent among 2% to 3% of children between the ages 10 and 16 (i.e. during skeletal maturity)
- 10% of AIS that may require medical intervention.
- more than 90% only require observation with repeat examinations during the growing years.
## Research Field and Key Works Referenced

<table>
<thead>
<tr>
<th>Conventional Treatment</th>
<th>Feedback System</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Hard Brace (Boston Brace)</strong></td>
<td><strong>“Micro Straight”</strong> (Dworkin B., et al., 1985)</td>
</tr>
<tr>
<td>• Compliance</td>
<td>• Provides continuous information to patients about their posture through an audio biofeedback system “Smart-garment” (Wong M.S. et al. 2008)</td>
</tr>
<tr>
<td>• Permanent deformation</td>
<td>• The curve control rate was 69%</td>
</tr>
<tr>
<td>of the ribcage or soft tissues</td>
<td>• Bulkiness, lacks of interactive display, wireless communication means</td>
</tr>
<tr>
<td>• Affecting hormone regulation</td>
<td>• Unable to provide online date feedback</td>
</tr>
<tr>
<td>• Bulkiness</td>
<td>• Lack of interconnectivity with other medical devices and information systems</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Soft Brace (SpineCor) (Coillard C., et. al., 2010)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>• Difficult to wear/ compliance</td>
<td></td>
</tr>
<tr>
<td>• Unable to provide thorough</td>
<td></td>
</tr>
<tr>
<td>biofeedback information</td>
<td></td>
</tr>
</tbody>
</table>

---

Image: Body-Mapping Tank Top Equipped with Biofeedback System for Adolescents with Early Scoliosis
Biofeedback System

Biofeedback is an area of growing interest in medicine and psychology, and has proven efficient for a number of physical, psychological and psychophysical problems (Lehrer et al., 2000; Nestoriue et al., 2008; Ahmed et al., 2011).

It is a non-invasive treatment technique, in which people are trained to improve health and performance by monitoring physiological signals from their own bodies, such as heart rate, muscle activity etc.

During training, the signal are conveyed to the patient in real-time process

→ The basic aim of biofeedback training is to facilitate patients increase self-awareness, gain relaxation, relieve pain and stress
Research Questions

1. Formulate and develop a database of myoelectric activities from surface electromyography (sEMG)-based biofeedback training for adolescents with early scoliosis.

2. Develop a sensor-based biofeedback system where sensors are embedded into a body mapping tank top that can control and record postures and spinal curvature, and monitor the myoelectric activities of adolescents with early scoliosis via a handheld device.

3. Optimise the design of a body mapping tank top and formulated sEMG biofeedback training for adolescents with early scoliosis.
Given these issues, this project aims to develop a body-mapping tank top equipped with a biofeedback system for adolescents with early scoliosis. The aim is to progressively provide muscle training to patients with scoliosis so as to restore a balance in muscle activity and reduction in the displacement of both sides of the spine.

It is believed that the sensor-based biofeedback device can motivate patients to play an active role, thus improving their control and coordination of movement and daily posture more efficiently.
Research Process

**Milestone 1**
Formulate and develop on the basis of clinical assessment, neuropsychology and computer science, a database of myoelectric activities from surface electromyography (sEMG)-based biofeedback training for adolescents with early scoliosis.

**Milestone 2**
Develop a sensor-based biofeedback system where sensors are embedded into a body mapping tank top that can control and record postures and spinal curvature and monitor the myoelectric activities of adolescents with Early scoliosis via a handheld device.

**Milestone 3**
Optimize the design of a body-mapping tank top equipped with sensor-based biofeedback system and formulate sEMG biofeedback training for adolescents with early scoliosis.
Subject recruitment

Inclusion Criteria:

- Females ages of 10-13 with early stages of AIS
- Cobb angle is between 10° to 20
- Physically and mentally able to adhere to the posture training protocols
- Literate and speak English or Chinese for effective communication purposes
- Consented to participate in the study on a voluntary basis.
- Agreed that their personal data could be used for data analysis and research purposes

Exclusion Criteria:

- With history of previous surgical or orthotic treatment for AIS
- Contraindications to x-ray exposure or pulmonary tests, recent trauma, mental disorder, skin allergy
- Fail to comply with sEMG testing and wearing the posture training device protocol
Subject recruitment

School screening programme

- 185 participants from TWO secondary schools were screened.
- The angle of trunk inclination (ATI) was measured with Adam’s forward bending test by Scoliometer.
- Participants with ATI ≥ 3, will be invited for further inspection.
- 26 students were found to have an ATI ≥ 3 (14.1%)
Use of Scolioscan™

Ultrasound Image of Spine – by Scolioscan™

26 subjects (ATI≥ 3) were invited to capture lateral 3D images through Scolioscan™

17 participants were found with spine curve angle of 10 to 20 ° and were recruited for the study

The concave and convex sides of the paraspinal muscle region were identified based on the scan.

PUMC Classification system (Qiu et al., 2003)

• There are 9 types in PUMC classification system, the most common case would be Type I and II
  • **PUMC Type Ia:** a single curve where the thoracic apex is between T2 and T11-12 discs.
  • **PUMC Type Ic:** a single curve where the lumbar apex is between L1-L5 discs
  • **PUMC Type Iic:** both a thoracic curve and a thoracolumbar/ lumbar curve, where the curve difference is less than 10 °
3D Body Scanning

A. Measurement of posture indices with anatomic landmarks → Measured on the 3D body scanned images with the aid of anatomic landmarks for the back surface as recommended by SOSORT

B. 3D Body Scanner developed by Human Solutions

C. 10 body markers were placed on the subjects' body suggested by International Society on Scoliosis Orthopedic and Rehabilitation Treatment (SOSORT) → To acquire subjects' body measurement for manufacture the tank tops
sEMG Paraspinal Muscle Signal Examination

The target muscle regions

- **4 pairs** of muscle were tested, the trapezius, latissimi dorsi, erector spinae at the thoracic region and erector spinae at the lumbar region.
- A professional physiotherapist was invited to help for positioning the mentioned regions.
- sEMG electrodes were placed and recorded the data

sEMG examination contents

- Both standing and sitting in habitual and suggested posture were recorded
- Habitual postures were performed by the subject without any instructions
- The suggested posture were corrected by the physiotherapist

Postural difference **with** and **without** the posture training instruments
sEMG Paraspinal Muscle Signal Examination

sEMG Results:

- The RMS mean μV (S.D.) of different tested postures were shown in the table.

- Scoliotic subjects showed stronger sEMG signal at their concave side due to muscle impairment. (Highlight in yellow)

<table>
<thead>
<tr>
<th>PUMC Type</th>
<th>Concave Side</th>
<th>N</th>
<th>Muscle Region</th>
<th>Habitual Standing</th>
<th>Suggested Standing</th>
<th>Habitual Sitting</th>
<th>Suggested Sitting</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ia</td>
<td>Right (Thoracic)</td>
<td>5</td>
<td>Trapezius</td>
<td>0.64 ± 0.34</td>
<td>1.03 ± 0.96</td>
<td>0.69 ± 0.47</td>
<td>0.82 ± 0.77</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Latissimus Dorsi</td>
<td>1.37 ± 1.70</td>
<td>0.87 ± 0.69</td>
<td>1.49 ± 1.95</td>
<td>1.05 ± 0.84</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Erector Spinae Thoracic</td>
<td>2.57 ± 3.98</td>
<td>2.47 ± 4.04</td>
<td>3.13 ± 5.16</td>
<td>1.66 ± 2.11</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Erector Spinae Lumbar</td>
<td>0.86 ± 0.70</td>
<td>0.58 ± 0.34</td>
<td>1.52 ± 1.52</td>
<td>1.07 ± 0.94</td>
</tr>
<tr>
<td>Ic</td>
<td>Left (Lumbar)</td>
<td>2</td>
<td>Trapezius</td>
<td>1.39 ± 1.13</td>
<td>3.93 ± 4.19</td>
<td>1.56 ± 1.01</td>
<td>1.06 ± 0.66</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Latissimus Dorsi</td>
<td>0.90 ± 0.17</td>
<td>1.19 ± 0.32</td>
<td>0.97 ± 0.08</td>
<td>1.53 ± 0.67</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Erector Spinae Thoracic</td>
<td>0.92 ±0.53</td>
<td>1.51 ± 0.61</td>
<td>0.50 ± 0.22</td>
<td>1.06 ± 0.14</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Erector Spinae Lumbar</td>
<td>5.29 ± 6.30</td>
<td>1.41 ± 0.35</td>
<td>2.56 ± 2.65</td>
<td>1.86 ± 1.47</td>
</tr>
<tr>
<td>IIc</td>
<td>Right (Thoracic)</td>
<td>10</td>
<td>Trapezius</td>
<td>0.69 ± 0.58</td>
<td>0.72 ± 0.65</td>
<td>0.88 ± 0.69</td>
<td>0.77 ± 0.52</td>
</tr>
<tr>
<td></td>
<td>Left (Lumbar)</td>
<td></td>
<td>Latissimus Dorsi</td>
<td>1.52 ± 1.23</td>
<td>1.38 ± 0.95</td>
<td>1.49 ± 1.30</td>
<td>1.27 ± 1.15</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Erector Spinae Thoracic</td>
<td>2.51 ± 3.48</td>
<td>1.91 ± 2.40</td>
<td>3.02 ± 5.61</td>
<td>2.16 ± 3.26</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Erector Spinae Lumbar</td>
<td>1.61 ± 1.83</td>
<td>1.66 ± 1.82</td>
<td>1.14 ± 0.55</td>
<td>2.08 ± 1.59</td>
</tr>
</tbody>
</table>
**sEMG Paraspinal Muscle Signal Examination**

Comparison between habitual and suggested posture

- The mean RMS EMG ratio (± s) where shown in the table.
- When the ratio = 1, the concave and convex muscle signals were the same
- If the ratio < 1, the concave side of a muscle has a stronger sEMG signal than the convex side and vice versa

<table>
<thead>
<tr>
<th>PUMC Type</th>
<th>Concave Side</th>
<th>N</th>
<th>Muscle Region</th>
<th>Habitual Standing</th>
<th>Suggested Standing</th>
<th>Habitual Sitting</th>
<th>Suggested Sitting</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ia</td>
<td>Right (Thoracic)</td>
<td>5</td>
<td>Trapezius</td>
<td>0.64 ± 0.34</td>
<td>1.03 ± 0.96</td>
<td>0.69 ± 0.47</td>
<td>0.82 ± 0.77</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Latissimus Dorsi</td>
<td>1.37 ± 1.70</td>
<td>0.87 ± 0.69</td>
<td>1.49 ± 1.95</td>
<td>1.05 ± 0.84</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Erector Spinae Thoracic</td>
<td>2.57 ± 3.98</td>
<td>2.47 ± 4.04</td>
<td>3.13 ± 5.16</td>
<td>1.66 ± 2.11</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Erector Spinae Lumbar</td>
<td>0.86 ± 0.70</td>
<td>0.58 ± 0.34</td>
<td>1.52 ± 1.52</td>
<td>1.07 ± 0.94</td>
</tr>
<tr>
<td>Ic</td>
<td>Left (Lumbar)</td>
<td>2</td>
<td>Trapezius</td>
<td>1.39 ± 1.13</td>
<td>3.93 ± 4.19</td>
<td>1.56 ± 1.01</td>
<td>1.06 ± 0.66</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Latissimus Dorsi</td>
<td>0.90 ± 0.17</td>
<td>1.19 ± 0.32</td>
<td>0.97 ± 0.08</td>
<td>1.53 ± 0.67</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Erector Spinae Thoracic</td>
<td>0.92 ±0.53</td>
<td>1.51 ± 0.61</td>
<td>0.50 ± 0.22</td>
<td>1.06 ± 0.14</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Erector Spinae Lumbar</td>
<td>5.29 ± 6.30</td>
<td>1.41 ± 0.35</td>
<td>2.56 ± 2.65</td>
<td>1.86 ± 1.47</td>
</tr>
<tr>
<td>IIc</td>
<td>Right (Thoracic)</td>
<td>10</td>
<td>Trapezius</td>
<td>0.69 ± 0.58</td>
<td>0.72 ± 0.65</td>
<td>0.88 ± 0.69</td>
<td>0.77 ± 0.52</td>
</tr>
<tr>
<td></td>
<td>Left (Lumbar)</td>
<td></td>
<td>Latissimus Dorsi</td>
<td>1.52 ± 1.23</td>
<td>1.38 ± 0.95</td>
<td>1.49 ± 1.30</td>
<td>1.27 ± 1.15</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Erector Spinae Thoracic</td>
<td>2.51 ± 3.48</td>
<td>1.91 ± 2.40</td>
<td>3.02 ± 5.61</td>
<td>2.16 ± 3.26</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Erector Spinae Lumbar</td>
<td>1.61 ± 1.83</td>
<td>1.66 ± 1.82</td>
<td>1.14 ± 0.55</td>
<td>2.08 ± 1.59</td>
</tr>
</tbody>
</table>

The subjects, especially the single curve subject, were able to achieve a more balanced sEMG signal under suggested sitting posture.
Product Development

- **U shape shoulder straps:**
  - Exerting the pulling force to secure the tank-top
  - Maximize the cooling effect by reducing fabrics coverage on the back
  - Allowing the insertion of biofeedback sensors into the extended piece

- **Foam cup lining:** allowed the wearers to insert foam paddings for increase support of the breasts

- **The elasticity of the fabric for the foam cup lining should be adequate enough to accommodate**
  different foam thickness and size.
Material Selection

Selection Criteria: Comfort, Fit, Durable

**Four-way stretch property:** Fabric L1 allows adequate elasticity in all directions to accommodate the different sizes of the foam cups.

Fabric S2 has the **best performance among all:**

- Better elongation,
- Air permeability,
- Pilling resistance
- Dimensional stability

<table>
<thead>
<tr>
<th>Component</th>
<th>Name</th>
<th>Composition</th>
<th>Structure Type</th>
<th>Stitch Density (Wale X Course)</th>
<th>Weight (gsm)</th>
<th>Thickness (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lining Fabric</td>
<td>L1</td>
<td>95% Nylon 5% Spandex</td>
<td>Powernet</td>
<td>44X34</td>
<td>80</td>
<td>0.06</td>
</tr>
<tr>
<td></td>
<td>L2</td>
<td>95% Nylon 5% Spandex</td>
<td>Satinnet</td>
<td>47X38</td>
<td>200</td>
<td>0.36</td>
</tr>
<tr>
<td>Shell Fabric</td>
<td>S1</td>
<td>65% Nylon 35% Spandex</td>
<td>Tricot</td>
<td>94X70</td>
<td>180</td>
<td>0.28</td>
</tr>
<tr>
<td></td>
<td>S2</td>
<td>65% Nylon 35% Spandex</td>
<td>Tricot</td>
<td>72X70</td>
<td>210</td>
<td>0.62</td>
</tr>
<tr>
<td></td>
<td>S3</td>
<td>65% Nylon 35% Spandex</td>
<td>Simplex</td>
<td>67X70</td>
<td>180</td>
<td>0.32</td>
</tr>
<tr>
<td></td>
<td>S4</td>
<td>90% Nylon 10% Spandex</td>
<td>Tricot</td>
<td>74X90</td>
<td>130</td>
<td>0.2</td>
</tr>
</tbody>
</table>

Specifications of tested fabrics
# Posture Monitoring Sensor

## Hardware Development

- Micro controller unit (MCU) equipped with 3-axis accelerometer, gyroscope, body angle detector was selected.
- MCU had a Bluetooth connection system allow the connection with any devices with Bluetooth function.
- It is circular shape with 3 cm diameter.
- 3v battery was inserted to the back of the MCU

<table>
<thead>
<tr>
<th>Positions of the posture monitoring sensors</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>T3</strong></td>
</tr>
<tr>
<td><strong>T12</strong></td>
</tr>
<tr>
<td><strong>L4 L5</strong></td>
</tr>
</tbody>
</table>
Smart devices application development
pMon Version 0.4

- Based on #mbientlab C sensors
- A complete new app for IOS is developed
- The app can adjust the sensitivity level
- Three separated alerts positions
- Enable LED alert lights

Get real time information

Increase self-awareness

Easy to access
sEMG Biofeedback Training Program

sEMG Posture Training Software:

- Thought Technology BioGraph Infiniti ver 5.3

The content of the software are:

A. Baseline checking
   - Assessment for the paraspinal muscle of the subjects
   - Check the muscle condition in terms of sEMG
   - The subjects were told to sit 3 minutes in a relax state

B. Posture training
   - Subjects were instructed to perform a suggested sitting posture and maintain for 5 minutes
   - The animation would be moving if the data fitted the requirements
   - The aims of the training were narrow the root mean square (RMS) sEMG difference between left and right side of the same muscle and reduce the sEMG value
sEMG Biofeedback Training Program

C. Training session summary

- A summary of the training session was generated for record.
- The RMS EMG value, standard deviation of RMS sEMG and absolute RMS sEMG difference of the session were shown here.
Research Conclusions

- After around 30 sessions of posture training, subjects successfully yielded a more balanced sEMG ratio. (closer to 1)

- All the tested muscle regions of all three groups of PUMC curve types subjects resulted a closer to 1 sEMG ratio after 30 sessions of training*

- Before the training, there is a significant difference with the test value of 1 at the trapezius region (p=0.038), after the training similar trend was not found.
Research Conclusions

- 1 Subject (No. 24) had increased angle at both thoracic and lumbar (> 5°)

- 9 subjects had progressed spinal curvature angle but within control (< 5°)

- 2 subjects had improved spinal angle after the training

<table>
<thead>
<tr>
<th>Subject No.</th>
<th>0 Month</th>
<th>6 Month</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Thoracic Angle (°)</td>
<td>Lumbar Angle (°)</td>
<td>Thoracic Angle (°)</td>
</tr>
<tr>
<td>2</td>
<td>10.6</td>
<td>12.8</td>
<td>12</td>
</tr>
<tr>
<td>4</td>
<td>3</td>
<td>12.3</td>
<td>7.9</td>
</tr>
<tr>
<td>11</td>
<td>7.9</td>
<td>12.1</td>
<td>8.2</td>
</tr>
<tr>
<td>12</td>
<td>8.3</td>
<td>17.4</td>
<td>10.2</td>
</tr>
<tr>
<td>16</td>
<td>10.2</td>
<td>17.2</td>
<td>9.6</td>
</tr>
<tr>
<td>17</td>
<td>21.4</td>
<td></td>
<td>25.3</td>
</tr>
<tr>
<td>18</td>
<td>9.6</td>
<td></td>
<td>10.3</td>
</tr>
<tr>
<td>19</td>
<td>17.6</td>
<td></td>
<td>11.9</td>
</tr>
<tr>
<td>22</td>
<td>15.1</td>
<td></td>
<td>16.5</td>
</tr>
<tr>
<td>23</td>
<td>17.9</td>
<td></td>
<td>16.2</td>
</tr>
<tr>
<td>24</td>
<td>9.9</td>
<td>14.5</td>
<td>16.1</td>
</tr>
<tr>
<td>27</td>
<td>27.6</td>
<td>15.4</td>
<td>22</td>
</tr>
</tbody>
</table>

Changes in Scolioscan angle of subjects from 0 to 6 months
Research Conclusions

Follow-up inspection:

- After 6 months of the posture training, 10 subjects participated the Scolioscan inspection.
- The subjects were still able to maintain a more balanced muscle signal than their posture before training.
- 2 subjects progressed more than 5°; 8 had progression within control or an improved spinal angle after 6 months of the posture training.

<table>
<thead>
<tr>
<th>Subject code</th>
<th>Attendance (sessions)</th>
<th>Thoracic Angle (°)</th>
<th>Lumbar Angle (°)</th>
<th>Thoracic Angle (°)</th>
<th>Lumbar Angle (°)</th>
<th>Thoracic Angle (°)</th>
<th>Lumbar Angle (°)</th>
</tr>
</thead>
<tbody>
<tr>
<td>002</td>
<td>29</td>
<td>10.6</td>
<td>12.8</td>
<td>12</td>
<td>14.5</td>
<td>14.3</td>
<td>16.5</td>
</tr>
<tr>
<td>004</td>
<td>34</td>
<td>3</td>
<td>12.3</td>
<td>7.9</td>
<td>10.9</td>
<td>5.5</td>
<td>11.9</td>
</tr>
<tr>
<td>011</td>
<td>29</td>
<td>7.9</td>
<td>12.1</td>
<td>8.2</td>
<td>9.8</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>012</td>
<td>32</td>
<td>8.3</td>
<td>17.4</td>
<td>10.2</td>
<td>15.1</td>
<td>17.3</td>
<td>11.1</td>
</tr>
<tr>
<td>016</td>
<td>38</td>
<td>10.2</td>
<td>17.2</td>
<td>9.6</td>
<td>15.8</td>
<td>12.4</td>
<td>16.1</td>
</tr>
<tr>
<td>017</td>
<td>34</td>
<td>21.4</td>
<td>17.2</td>
<td>25.3</td>
<td>N/A</td>
<td>3.9</td>
<td>N/A</td>
</tr>
<tr>
<td>018</td>
<td>27</td>
<td>9.6</td>
<td>10.3</td>
<td>15.2</td>
<td>11.9</td>
<td>10.7</td>
<td>-0.6</td>
</tr>
<tr>
<td>019</td>
<td>34</td>
<td>17.6</td>
<td>11.9</td>
<td>15.1</td>
<td>17.6</td>
<td>2.5</td>
<td>-2.4</td>
</tr>
<tr>
<td>022</td>
<td>31</td>
<td>15.1</td>
<td>16.5</td>
<td>16.5</td>
<td>14.4</td>
<td>3.5</td>
<td>-3.5</td>
</tr>
<tr>
<td>023</td>
<td>34</td>
<td>17.9</td>
<td>16.2</td>
<td>14.4</td>
<td>16.1</td>
<td>1.4</td>
<td>-2.3</td>
</tr>
<tr>
<td>024</td>
<td>26</td>
<td>9.9</td>
<td>14.5</td>
<td>16.1</td>
<td>21.3</td>
<td>6.2</td>
<td>6.8</td>
</tr>
<tr>
<td>027</td>
<td>32</td>
<td>27.6</td>
<td>15.4</td>
<td>22</td>
<td>15.4</td>
<td>-5.6</td>
<td>-5.6</td>
</tr>
</tbody>
</table>
Summary

- After the Biofeedback training (6th month), the participants were able to train up a stable and more balanced muscle profile in terms of sEMG signal.

- The follow-up inspection after 6 months of the training (12th month) indicated that the effect of the training can carry over after the training. The more balanced muscle profile can maintain even without training.

- After about 30 sessions of posture training, the majority of the participants are able to train their sitting posture so that it is relatively more balanced and involves a lower degree of muscle activity in terms of sEMG signals compared to their circumstances prior to the training.

- Despite the size of participants in this study has a limited representative, this is still an encouraging result which warrants further study for the posture training of mild scoliotic patients.

![Pie charts showing spinal curvature changes](chart.png)
Future applications

- Tailor-made posture training programme for models, flight attendant, etc.

- Improve athletes’ postures, reduce muscles under stress, reduce injury.
  - Good posture will make athletes more effective, efficient and injury free.

- Real-time elderly activity monitoring system
  - Detect emergency state such as fall

Posture training

Sports

Elderly
Dissemination and distribution of outcomes

<table>
<thead>
<tr>
<th>Deliverables</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>01</td>
<td>Demonstration Video</td>
</tr>
<tr>
<td>02</td>
<td>One China Patent</td>
</tr>
<tr>
<td>03</td>
<td>Two Journal Papers</td>
</tr>
<tr>
<td>04</td>
<td>Four Conference Papers</td>
</tr>
<tr>
<td>05</td>
<td>Intervention Exhibition and Competition</td>
</tr>
<tr>
<td>06</td>
<td>Two Awards</td>
</tr>
<tr>
<td>07</td>
<td>Media and Newspaper Reports</td>
</tr>
<tr>
<td>08</td>
<td>Chief Executive of Hong Kong – Award ceremony for 45th International Exhibitions of Geneva</td>
</tr>
<tr>
<td>09</td>
<td>Press conference and Exhibition in Medical Device and Supplies</td>
</tr>
<tr>
<td>10</td>
<td>Presentation to MPhil / PhD students Royal College of Art, London, UK</td>
</tr>
<tr>
<td>11</td>
<td>Presentation to Clinicians / Doctors in HKU Shenzhen Hospital (Shenzhen, China)</td>
</tr>
<tr>
<td>12</td>
<td>Licensing agreement with Active Biotechnology (Hong Kong) Limited</td>
</tr>
</tbody>
</table>
1. Demonstration Video

https://youtu.be/cRnRsCZrvoU

Step 03

Synchronize EMG signal with the posture sensors under an ideal posture.
A China patent has been granted for this design
(China Patent no. CN105748037) Date of Patent: July 13, 2016 “具有用于患脊柱侧凸的患者的生物反馈系统的体感背心”
3. Journal Papers


1. Introduction

Adolescent idiopathic scoliosis (AIS) is a multifactorial, three-dimensional deformity of the spine and trunk. It can appear and sometimes progress during any of the rapid periods of growth in children [1]. Non-invasive brace therapy is usually recommended for spinal curvatures between 25 and 40 degrees while surgery is suggested for curvatures over 45 degrees [2, 3]. Conventional orthoses are used to apply passive forces onto the human body to support the trunk alignment and control the deformity of the spine. However, the use of an external support is affected by factors such as poor appearance, bulkiness, and physical constraint that could lead to low acceptance and compliance [4, 5]. Regardless of current clinical practices, treatment is nothing more than just observation (if the curve is less than 20 degrees, even if the child is at high risk of progressive spinal deformity during puberty, which is between the ages of 10-16 years) [6, 7]. The reason is that the prediction of curve progression is not available for untreated AIS patients (a Risser stage less than 1 is 22% and larger than 1 is only 2.4%) [8] and alternative treatment options are very limited. However, with biofeedback as an area that is attracting growing interest in the medical and psychological fields, its proven effectiveness for a number of physical, psychological, and psychosocial problems [9-11], it is possible that biofeedback can be one of the new techniques that will provide an alternative type of non-invasive treatment for AIS patients.

Biofeedback is a nonmedical process that involves the measuring of specific and quantifiable bodily functions of a subject, such as the brain wave activity, blood pressure, heart rate, skin temperature, sweat gland activity, and muscle tension, thus conveying the information to the patient in real-time. The basic aim of biofeedback therapy is to support a patient in realizing his/her self-control ability to control specific psychophysiological processes [12]. The literature has consistently indicated that surface electromyography (sEMG) biofeedback is effective for muscle rehabilitation. A review duration of 1 minute and repeated twice. A hand pass filter that ranged from 30 to 60 Hz was applied to eliminate unwanted artifacts, such as sudden movement, and a 60 Hz notch filter was used to eliminate noise. The EMG signals were sampled at a rate of 2048 Hz. The EMG raw data were averaged by using root mean square (RMS) to obtain the average amplitude of the EMG signal. The EMG RMS ratio of the subjects was calculated based on the following equation [19]:

\[ \text{EMS sEMG Ratio} = \frac{\text{EMS sEMG (correct)}}{\text{EMS sEMG (incorrect)}} \]

The ratio is an index of the symmetric sEMG activity of the tested muscles in which when the ratio is 1, the tested pairs of muscles have identical (EMS) activity from the concave and convex sides of the tested muscle. If the ratio is less than 1, the concave side of the muscle has stronger sEMG activity than the convex side. If the ratio is larger than 1, the concave side of the muscle has weaker sEMG activity than the convex side. The equation was applied to assess the effectiveness of the suggested positions for the scoliosis subjects. The suggested positions were effective if the ratio was closer to 1 compared to the ratio recorded for the habitual postures.

3. Statistics

Statistical analyses were conducted by using the SPSS 19 program for Windows. The difference between the concave and convex sides during habitual sitting and sitting was computed by t testing with the significance level p < 0.05. Besides, the difference between habitual and the suggested standing and sitting sEMG ratios was compared through the significance of a one-tailed t-test with a test value of 1. The level of significance is p < 0.05.
4. Journal Papers


**Postural Screening for Adolescent Idiopathic Scoliosis with Infrared Thermography**

Garcia Kwok, Joanne Yip, Kit-Lun Yick, Mei-Chun Cheung, Chi-Ying Tse, Sun-Pui Ng & Anoop Singh Luximon

Adolescent idiopathic scoliosis (AIS) is a multifactorial, three-dimensional deformity of the spine and trunk. School scoliosis screening (SSS) is recommended by researchers as an early detection of AIS to prevent its progression in school-aged children. The traditional screening technique for AIS is the forward bending test because it is simple, non-invasive and inexhaustible. Other tests, such as the use of Moiré topography, have reduced the high false referral rates. The use of infrared (IR) thermography for screening purposes based on the findings of previous studies on the asymmetrical paraspinal muscle activity of scoliotic patients compared with non-scoliotic subjects was explored in this study. IR thermography is performed with an IR camera to determine the temperature differences in paraspinal muscle activity. A statistical analysis showed that scoliotic subjects demonstrate a statistically significant difference between the left and right sides of the regions of interest. This difference could be due to the higher IR emission of the convex side of the observed area, thereby creating a higher temperature distribution. The findings of this study suggest the feasibility of incorporating IR thermography as part of SSS. However, future studies could consider larger sample of both non-scoliotic and scoliotic subjects to further validate the findings.

The emissivity level of the IR camera can also be adjusted, which will ensure better accuracy of the measurements at different locations. The IR camera can be easily transported and saves the cost of hiring a professional clinician to perform the screening, as personnel with the ability and skills to operate the IR camera can perform the screening. In addition, there are examples of using automated algorithms to analyze the collected IR data, which could minimize intra-observer errors and demonstrate the potential of using IR in clinical assessments. All of these factors contribute to the feasibility of using this technique in an SSS programme.

**Figure 1.** IR image of a non-scoliotic subject - symmetrical temperature distribution along the paraspinal muscles

**Figure 2.** Comparison of IR images of a scoliotic subject with X-rays - S-curve of 23.6 degrees at 1.3 and 23.5 degrees at TV.
5. Conference Papers

The design and development process, posture evaluation, wear trial results of tank top were presented in different international conferences held in France, and Hong Kong.


6. International Exhibition and Competition

The body-mapping tank top was selected by University to be exhibited in The 45th International Exhibition of Inventions Geneva, Switzerland, 29 March to 2 April 2017.

The project team showcased the prototype during the exhibition. The visitors could try the biofeedback training session for 5 minutes. They could understand the concept of “biofeedback” training and were able to adjust their sitting posture in a better way. They also tried the mobile application and understood why the instant feedback signals from the sensors important to improve the sitting posture.
7. Awards

A. Award Presentation to Project Team
(Dr. Joanne Yip and Mr. Garcia Kwok)
From Prof. Liviu Daniel, Scientific Secretary, Romanian Association for Nonconventional Technologies

B. Gold Medal - The 45th International Exhibition of Inventions Geneva, Switzerland

C. Special Award for the Invention, Romanian Association for Nonconventional Technologies
8. Media and Newspaper Reports

A. Biofeedback Tank top
   挺腰做人 昂首背心
   Inno Tech Expo 創科博覽
   2017-09-28
8. Media and Newspaper Reports

A. Invited Talk in 2017 InnoTech Expo
創科博覽2017-科普講座
【有助控制青少年脊椎側彎惡化的生物反饋智能背心 - 葉曉雲博士】

有助控制青少年脊椎側彎惡化的生物反饋智能背心
日期：9月28日(星期四)
時間：11:00-11:40
語言：粵語
地點：香港會議展覽中心展覽廳3/F・G演講廳

講者：葉曉雲博士
現於香港理工大學紡織及製衣學系任教，並積極參與多項研究工作，包括將姿勢矯正束身衣，新物料研發及新科技應用，無縫技術等應用於內衣行業。

https://qr.go.page.link/mC6J1
9. Ex-Chief Executive of Hong Kong – Award ceremony for 45th International Exhibitions of Geneva

Speech by ex-CE Mr C Y Leung at reception for awardees of 45th International Exhibition of Inventions of Geneva
10. Press conference and Exhibition in Medical Device and Supplies

9th Hong Kong International Medical Devices and Supplies Fair, 16th to 18th May 2017. The eighth HKTDC Hong Kong International Medical Devices and Supplies Fair concluded its three-day run today. Organised by the Hong Kong Trade Development Council (HKTDC) and co-organised by the Hong Kong Medical and Healthcare Device Industries Association (HKMHDIA), the fair welcomed more than 10,700 buyers from 62 countries and regions, up 7 per cent over the previous year.

Major exhibiting categories include electromedical equipment, medical technology, laboratory equipment, diagnostics, physiotherapy and orthopaedic technology, commodities and consumer goods for surgery and hospitals, information and communication technology, facility management, medical textiles and fabrics, Chinese medical devices, medical device components, premises and building technology as well as medical services and publications.
11. 3-day workshop for MPhil / PhD students at Royal College of Art, London, UK

A. Visit RCA, London, UK To give a talk about “An Innovative Body-Mapping Tank Top Equipped with Biofeedback System for Adolescents with Early Scoliosis”

B. RCA students were thinking how to use IMU sensors in their own projects.

C. A group of MPhil / PhD students and their lecturer
11. 3-day workshop for MPhil / PhD students at Royal College of Art, London, UK

Rebekka – Specialism Weave

Rebekka has been working towards a posture related end use of the IMU sensor for a particular sport and been researching various sports and speaking with physio therapists to refine her ideas. She has combined her research with her personal interest in creating innovative weave structures (offering something different to knit or mimicking knit) and yarn combinations, and yarn properties to place the IMU close to the body.

Isha – Specialism Mixed Media

Isha has been exploring interactive objects for a positive play experience. Nice to link to play and people saying more when they are engaged in an activity. This could potentially be linked to therapy or different environments where this would have a positive of assistive impact?

Ciaran – Specialism Print

Ciaran has been exploring how he can use the IMU sensor to capture data of movement or drawing in space for a virtual environment. His work deals with digital visualization of pattern and colour using different software.

The advice after the IMU workshop is to now:
- Refine objects, think about scale and variety;
- Control the experiments and gain insight from conversation/interview on emotions/feelings;
- Validate hypothesis of insight already collected from interviews, people stop playing when they have built something they feel looks good or are satisfied with or that they feel more comforted when they have the object wrapped around their arm etc;
- Use video as well as the data from IMU;
12. Presentation to Clinicians / Doctors in HKU Shenzhen Hospital (Shenzhen, China) 02-Jan-2019

Visit HKU SZ Hospital Shenzhen Orthopaedic department

To give a talk about “An Innovative Body-Mapping Tank Top Equipped with Biofeedback System for Adolescents with Early Scoliosis”
13. Licensing agreement with Active Biotechnology (Hong Kong) Limited

5 July 2019

To Whom It May Concern

Licensing status for the technologies related to body-sensing tank top with biofeedback system

PolyU Technology and Consultancy Company Limited ("PTeC"), the wholly owned subsidiary of The Hong Kong Polytechnic University ("PolyU") is pleased to learn that Active Biotechnology (Hong Kong) Company Limited ("ABC"), a startup company formed by PolyU’s faculty members and alumni, is applying for the Inno-Bio programme (the “Application”).

This letter serves as our support to the Application and PTeC, on behalf of the PolyU, is going to grant a license the technology to ABC and make its business free to operate for related to body-sensing tank top with biofeedback system for patients with scoliosis.

Most licensing terms have been negotiated by both parties already. Currently, we have been working on due diligence check according to governance processes, it may take one to two months, PTeC will enter into the license agreement with ABC right after the clearance of processes.

If you have any questions on the licensing status, please feel free to contact my colleague Mr. Edmond Lam at 3400 1803.

Yours faithfully,

For and on behalf of
PolyU Technology and Consultancy Co. Ltd.

[Signature]

General Manager

Licensing agreement between
PolyU and Active Biotechnology
(Hong Kong) Limited
References


Unless the sources are specified in this Body of Work, the copyright of the materials presented (excerpts, photos, videos, figures, drawings, diagrams and media) is owned by the author.