RAE2020

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

Dr. Joanne Yiu-wan Yip

PolyU UoA 38

Contents

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

Descriptor

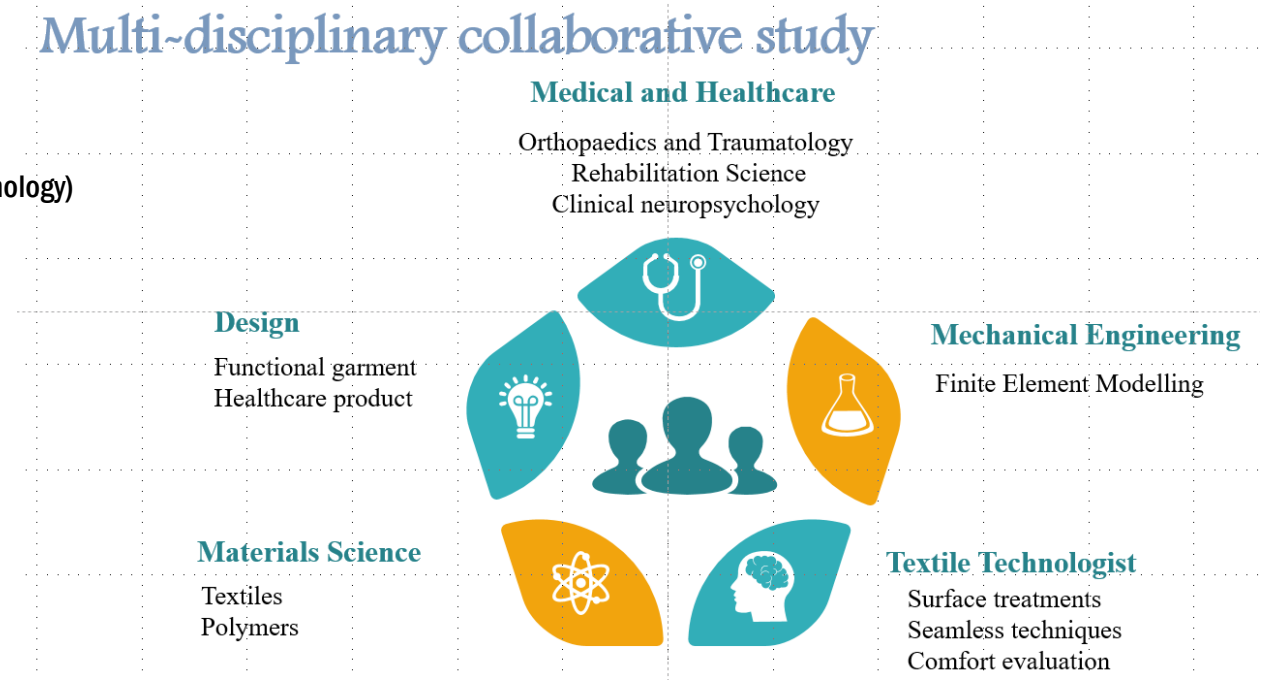
This is a two-year multi-disciplinary collaborative study that involves experts in clinical psychology, computing science, and orthopedics. Conventional orthotic interventions apply passive forces to the human body with orthosis to support the trunk alignment and control the deformities of the spine. 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

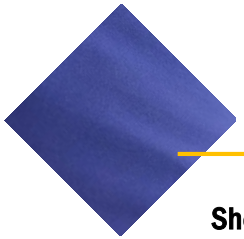
Dr. Yip, Joanne graduated with a BSc (Hons) in Textile Technology (with first class Honors) in 1999 from the Hong Kong Polytechnic University and obtained her PhD at the same university in 2003. Dr. Yip research interests include new materials and technology, surface treatments on textiles, moulding 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)

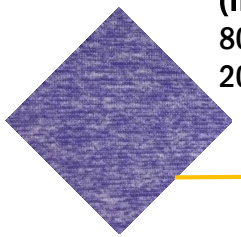


Research Output
Final Design of the Body-Mapping Tank Top with Biofeedback System – First published on 13-July, 2016

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



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



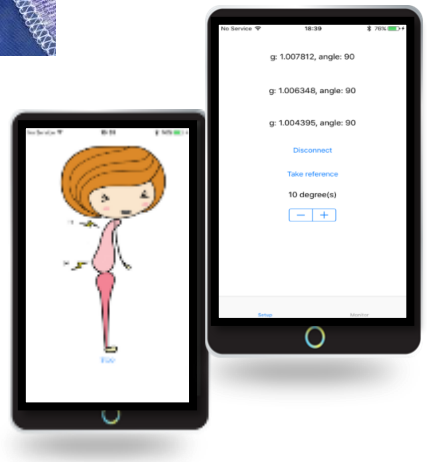
Meta Wear C
Sensor with Bluetooth connection system

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

- **Four-way stretch property**
- **Strectchy, Breathable**
- **Durable, light-weight**

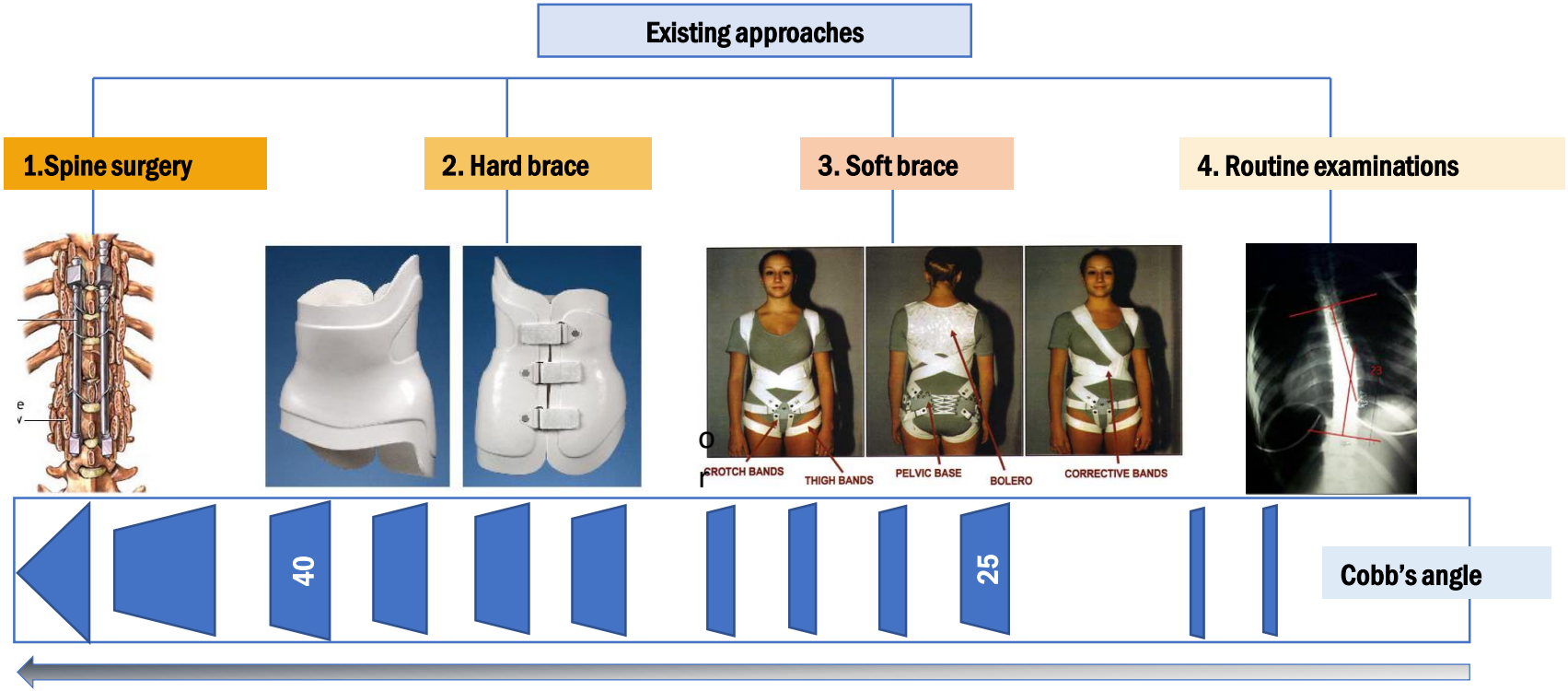
➔ **Provide maximum comfort for the users**

Smartphone App will remind subjects when their bodies begin to slouch



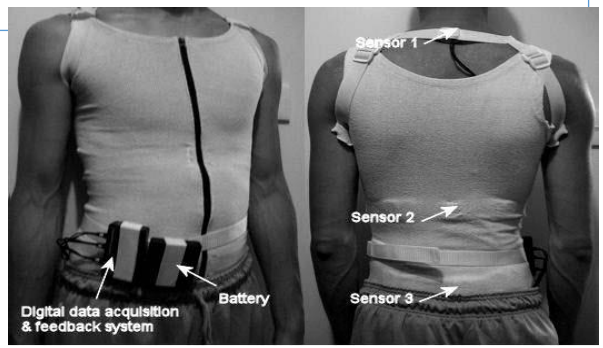
Research Field and Key Works Referenced

- 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

Convectional Treatment	Feedback System
Hard Brace (Boston Brace) • Compliance • Permanent deformation of the ribcage or soft tissues • Affecting hormone regulation • Bulkiness	**"Micro Straight"** (Dworkin B., et al., 1985) • Provides continuous information to patients about their posture through an audio biofeedback system "Smart-garment" (Wong M.S. et. al. 2008) • The curve control rate was 69% • Bulkiness, lacks of interactive display, wireless communication means • Unable to provide online date feedback • Lack of interconnectivity with other medical devices and information systems
Soft Brace (SpineCor) (Coillard C., et. al., 2010) • Difficult to wear/ compliance • Unable to provide thorough biofeedback information	



Research Field and Key Works Referenced

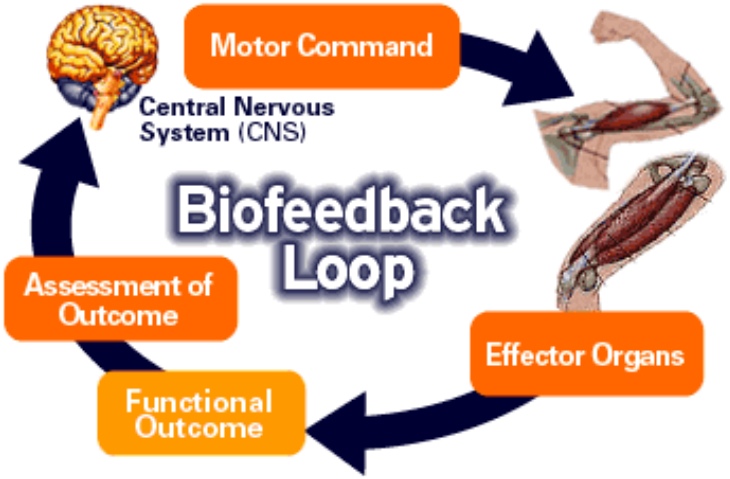
Biofeedback System

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.

Originality

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 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.

12/2014 — **5/2015** — **12/2017**

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 1

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.

Milestone 3

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

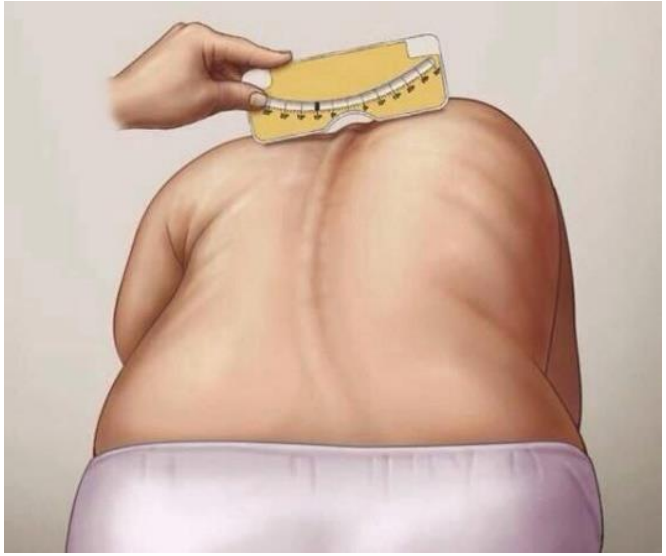
Exclusion Criteria:

- 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, with be invited for further inspection.
- 26 students were found to have an ATI ≥ 3 (14.1%)



Adam's forward bending test

Use of Scolioscan ™

Ultrasound Image of Spine – by Scolioscan™

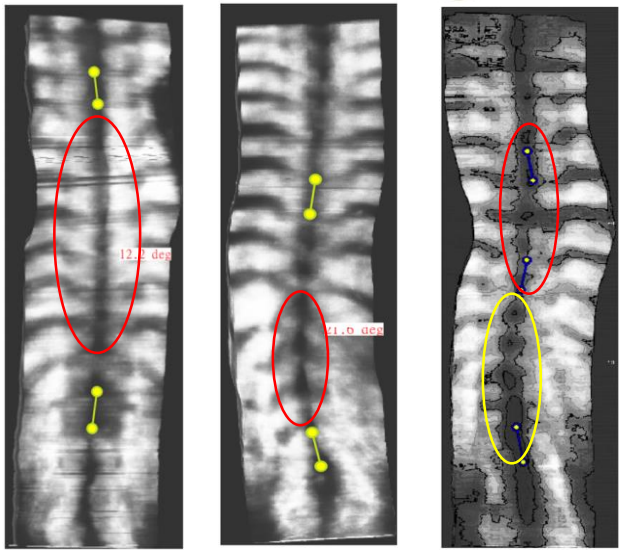
26 subjects (ATI≥ 3) were invited to capture lateral 3D images through Scolioscan™

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.

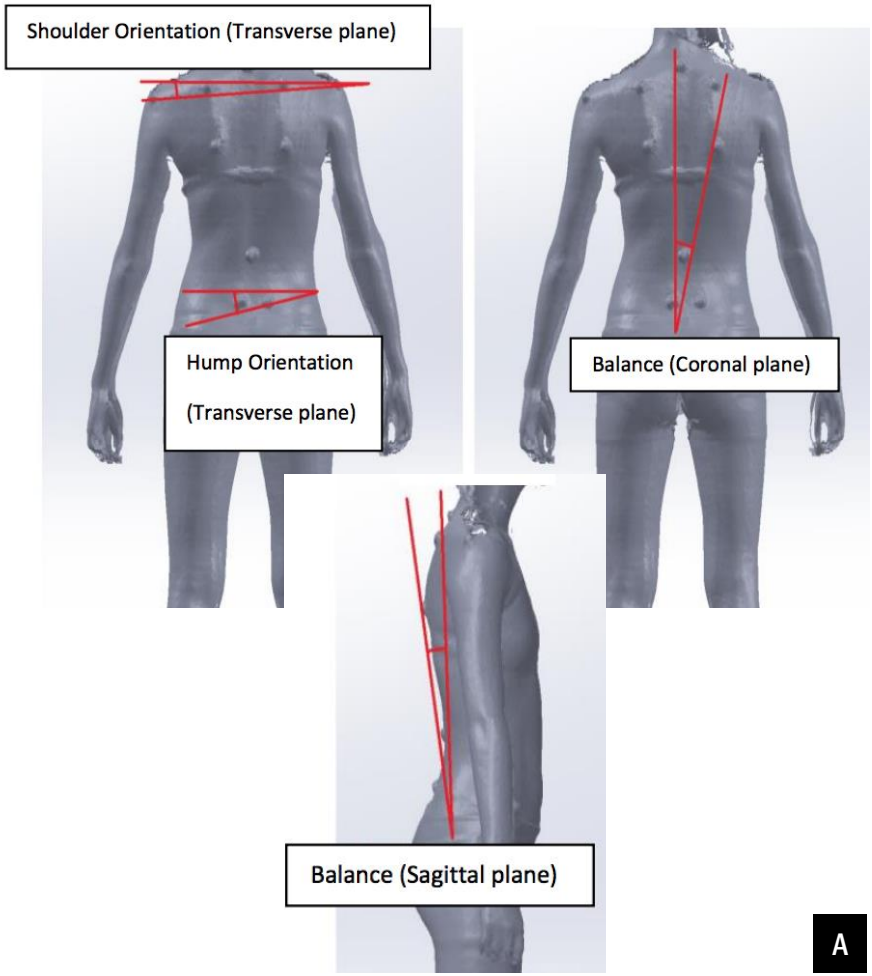
PUMC Classification system (Qiu et al., 2003)

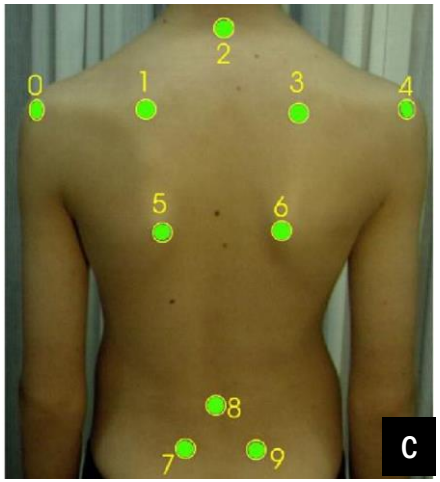
- There are 9 types in PUMC classification system, the most common case would beType I and II
- **PUMC Type Ia:** a single curve where the thoracic apex is between T2 and T11-12 discs.
- **PUMC Type Ic:** a single curve where the lumbar apex is between L1-L5 discs
- **PUMC Type Iic:** both a thoracic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



PUMC Type Ia PUMC Type Ib PUMC Type IIc

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

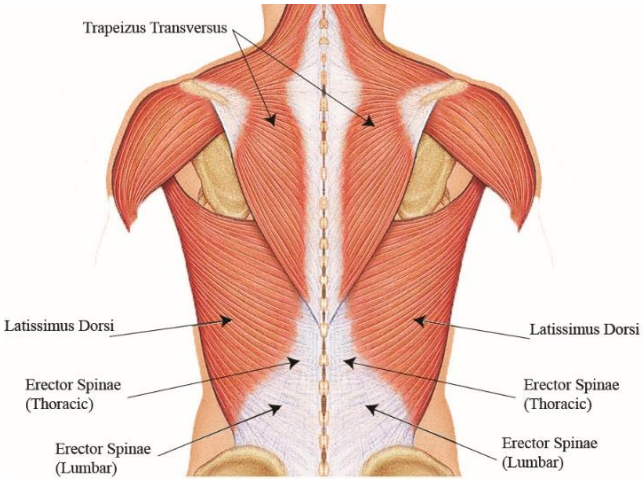
B. 3D Body Scanner developed by Human Solutions

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

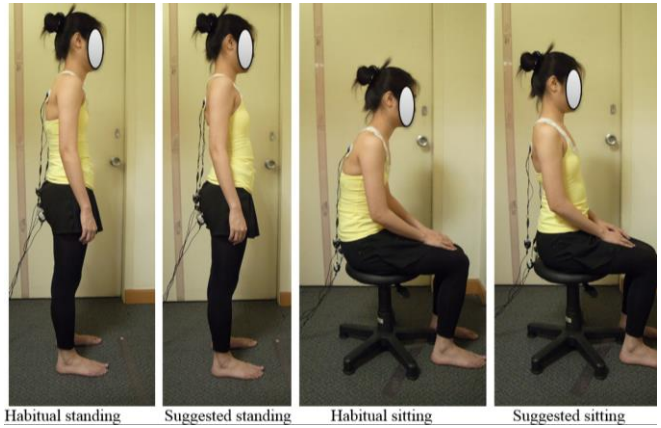
The target muscle regions

- **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)***

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

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

				Mean RMS sEMG Ratio (±s)			
PUMC Type	Concave Side	N	Muscle Region	Habitual Standing	Suggested Standing	Habitual Sitting	Suggested Sitting
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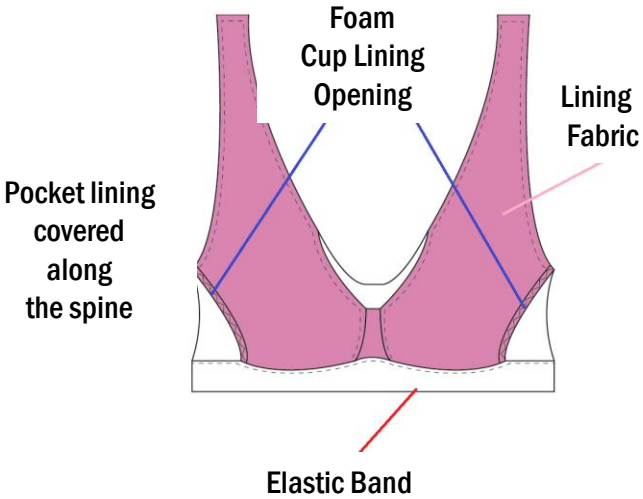
			Erector Spinae Lumbar	1.61 ± 1.83	1.66 ± 1.82	1.14 ± 0.55	2.08 ± 1.59

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 allow 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

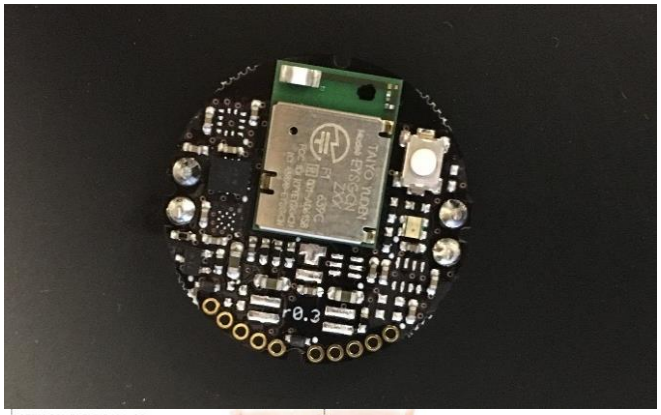
Component	Name	Composition	Structure Type	Stitch Density (Wale X Course)	Weight (gsm)	Thickness (mm)
Lining Fabric	L1	95% Nylon 5% Spandex	Powernet	44X34	80	0.06
	L2	95% Nylon 5% Spandex	Satinnet	47X38	200	0.36
Shell Fabric	S1	65% Nylon 35% Spandex	Tricot	94X70	180	0.28
	S2	80% Nylon 20% Spandex	Tricot	72X70	210	0.62
	S3	65% Nylon 35% Spandex	Simplex	67X70	180	0.32
	S4	90% Nylon 10% Spandex	Tricot	74X90	130	0.2

Specifications of tested fabrics

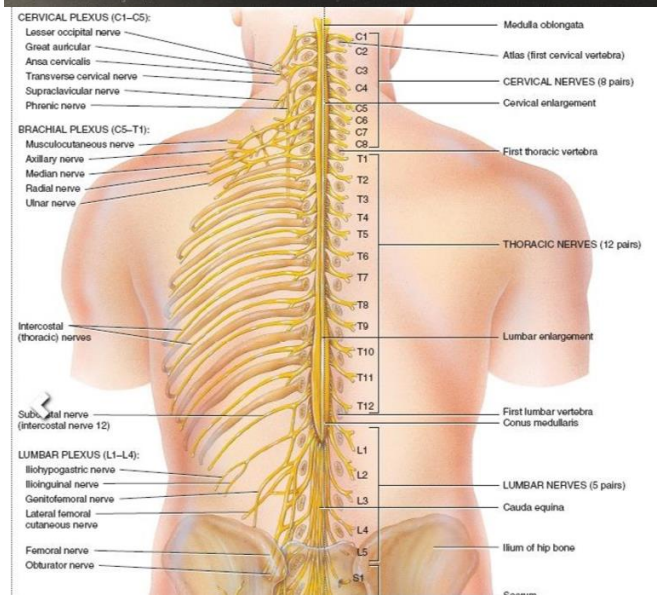
Posture Monitoring Sensor

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

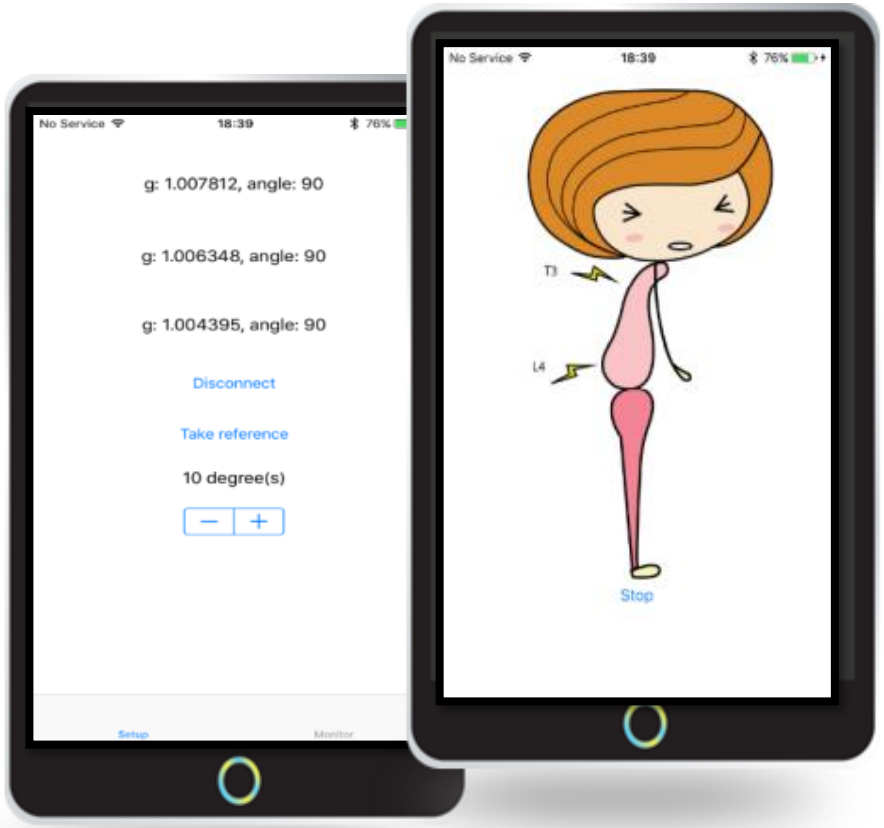


Positions of the posture monitoring sensors	
T3	To monitor the posture of the **thoracic torso** (Wong, 2009)
T12	To monitor the **lumbar spine position**, this position was used to measure the lumbar spine position by 3 orthogonal axes. (McGill & Karpowicz, 2009)
L4 **L5**	A position for calculating the sum of the force of all the muscle fascicles alon g the compressive and shear axes. (McGill et al., 2009)



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

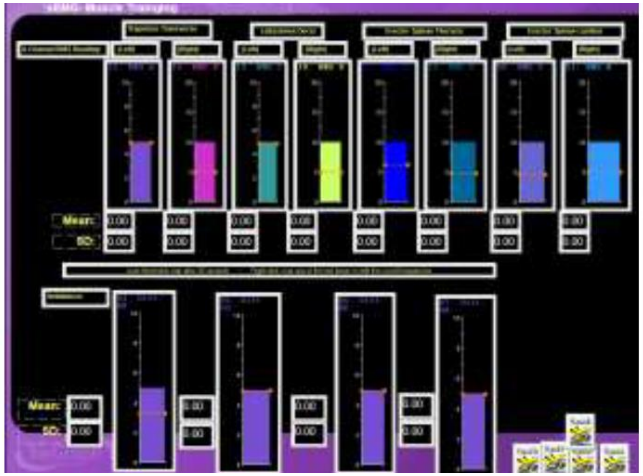
The content of the software are :

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**

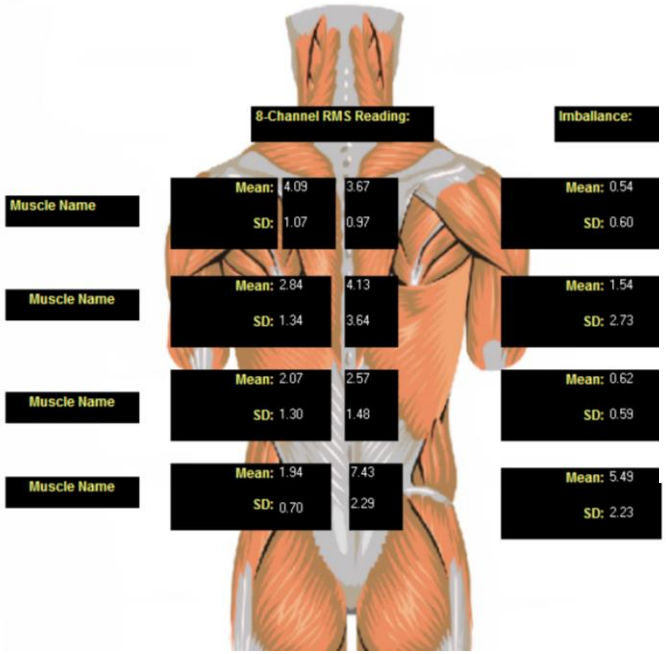
- Subjects were instructed to perform a suggested sitting posture and maintain for 5 minutes
- The animation would be moving if the data fitted the requirements
- The aims of the training were narrow the root mean square (RMS) sEMG difference between left and right side of the same muscle and reduce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

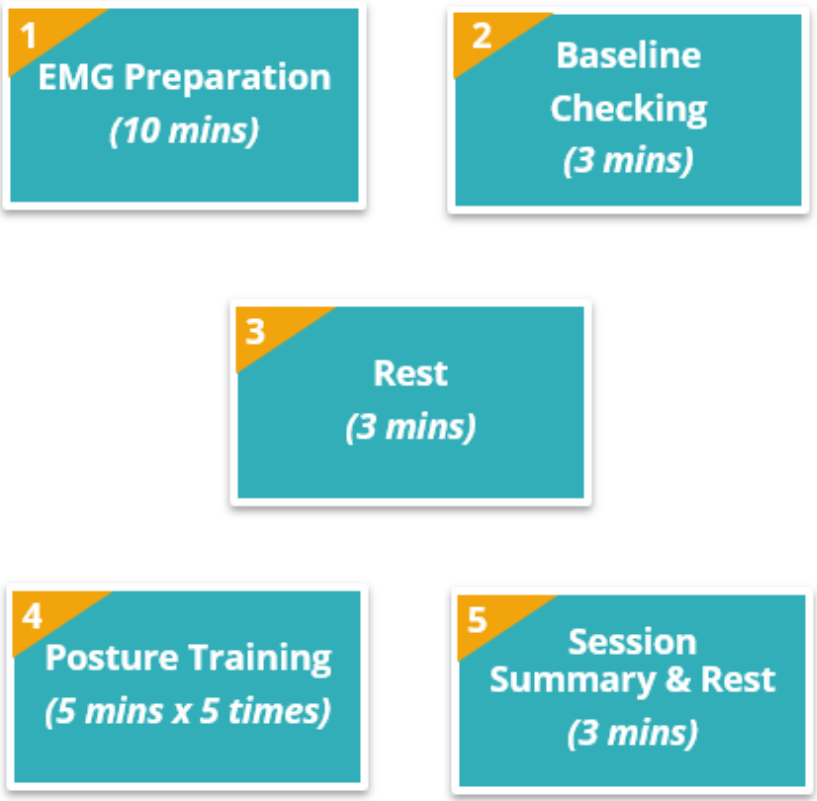


sEMG Biofeedback Training Program

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.

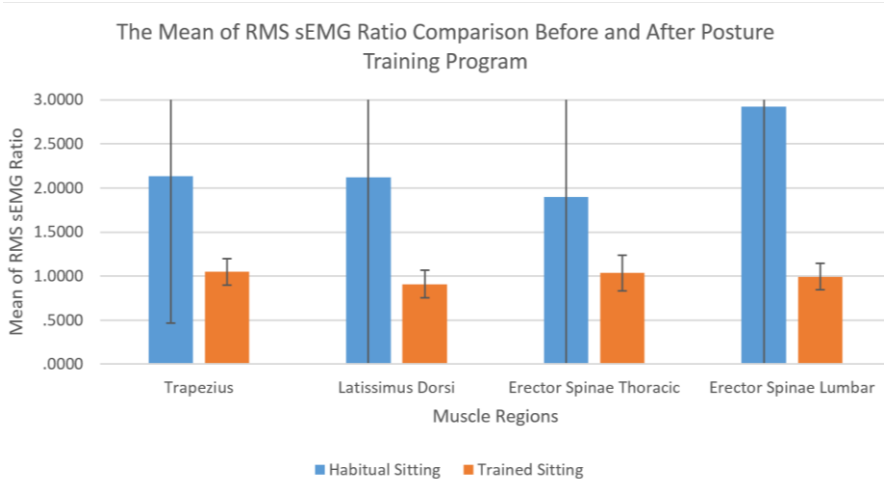




Procedure of the Posture Training Session

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.



			Test Value = 1	
N	Group	Muscle Region	Mean RMS sEMG Ratio	Statistical Significance (p=)
12	Habitual Sitting	Trapezius	2.132 (1.664)	0.038
		Latissimus Dorsi	2.123 (2.975)	0.218
		Erector Spinae Thoracic	1.899 (2.114)	0.169
		Erector Spinae Lumbar	2.923 (7.857)	0.415
	Trained Sitting	Trapezius	1.047 (0.148)	0.298
		Latissimus Dorsi	0.908 (0.157)	0.067
		Erector Spinae Thoracic	1.034 (0.205)	0.578
		Erector Spinae Lumbar	0.993 (0.151)	0.880

The Mean of RMS sEMG Ratio Before and After 30 sessions of Training Program

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 a improved spinal angle after the training**

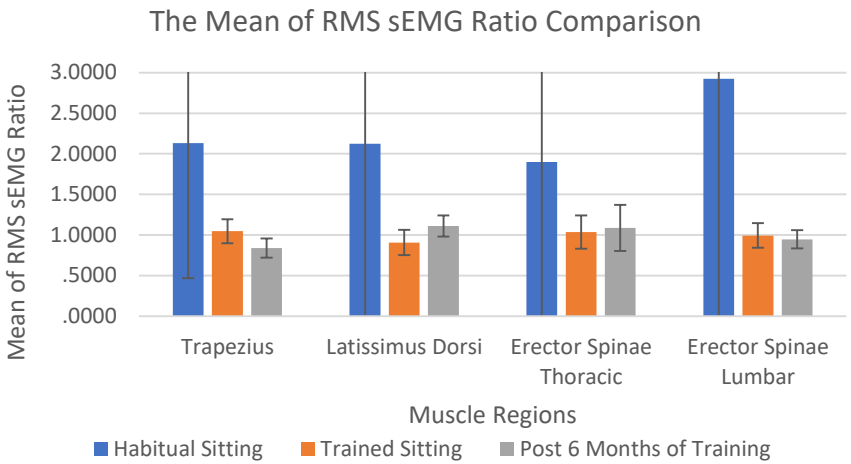
Subject No.	0 Month		6 Month		Difference	
	Thoracic Angle (°)	Lumbar Angle (°)	Thoracic Angle (°)	Lumbar Angle (°)	Thoracic Angle (°)	Lumbar Angle (°)
2	10.6	12.8	12	14.5	+1.4	+1.7
4	3	12.3	7.9	10.9	+4.9	-1.4
11	7.9	12.1	8.2	9.8	+0.3	-2.3
12	8.3	17.4	10.2	15.1	+1.9	-2.3
16	10.2	17.2	9.6	15.8	-0.6	-1.4
17	21.4		25.3		+3.9	
18	9.6		10.3		+0.7	
19	17.6		11.9		-5.7	
22	15.1		16.5		+1.4	
23	17.9		16.2		-1.7	
24	9.9	14.5	16.1	21.3	+6.2	+6.8
27	27.6	15.4	22	15.4	-5.6	0

Changes in Scolioscan angle of subjects from 0 to 6 months

Research Conclusions

Follow-up inspection:

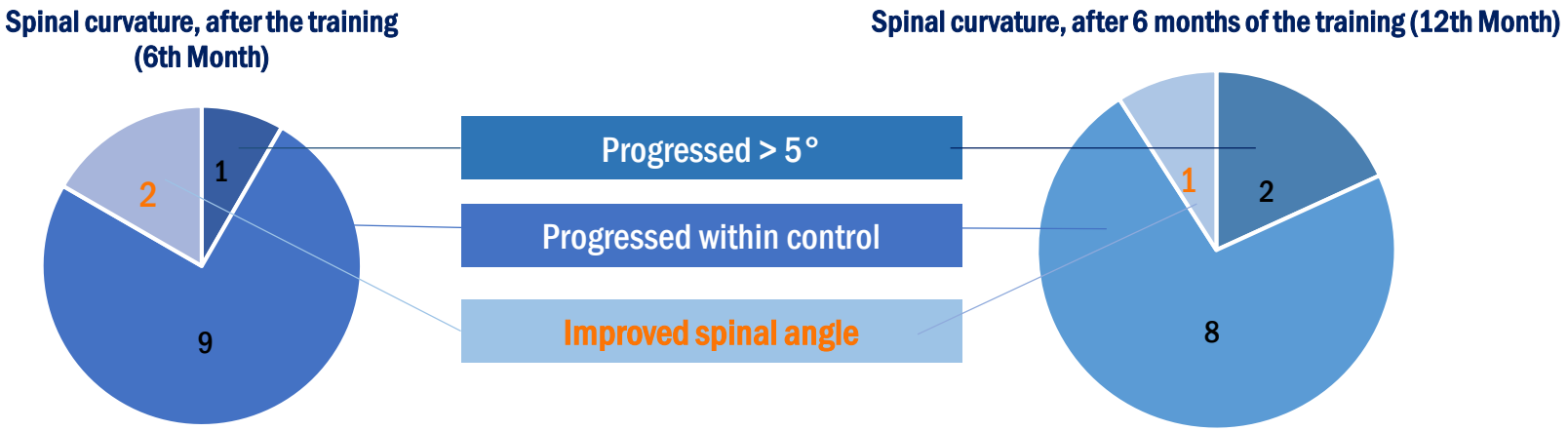
- After 6 months of the posture training , 10 subject participated the Scolioscan inspection
- the subjects were still able to maintain a more balanced muscle signal than their posture before training
- 2 subjects progressed more than 5°; **8** had progression **within control or an improved** spinal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



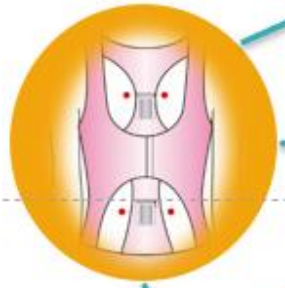
		0 Month		6 Months		12 Months		Difference (0 vs. 6 M)		Difference (0 vs. 12 M)	
Subject code	Attendance (sessions)	Thoracic Angle (°)	Lumbar Angle (°)	Thoracic Angle (°)	Lumbar Angle (°)	Thoracic Angle (°)	Lumbar Angle (°)	Thoracic Angle (°)	Lumbar Angle (°)	Thoracic Angle (°)	Lumbar Angle (°)
002	29	10.6	12.8	12	14.5	14.3	16.5	1.4	1.7	3.7	3.7
004	34	3	12.3	7.9	10.9	5.5	11.9	4.9	-1.4	2.5	-0.4
011	29	7.9	12.1	8.2	9.8	N/A	N/A	0.3	-2.3	N/A	N/A
012	32	8.3	17.4	10.2	15.1	17.3	11.1	1.9	-2.3	9	-6.3
016	38	10.2	17.2	9.6	15.8	12.4	16.1	-0.6	-1.4	2.2	-1.1
017	34	21.4		25.3		N/A		3.9		N/A	
018	27	9.6		10.3		9		0.7		-0.6	
019	34	17.6		11.9		15.2		-5.7		-2.4	
022	31	15.1		16.5		17.6		1.4		2.5	
023	34	17.9		16.2		14.4		-1.7		-3.5	
024	26	9.9	14.5	16.1	21.3	18.3	17.1	6.2	6.8	8.4	2.6
027	32	27.6	15.4	22	15.4	22	16.9	-5.6	0	-5.6	1.5

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.



Future applications



Posture training

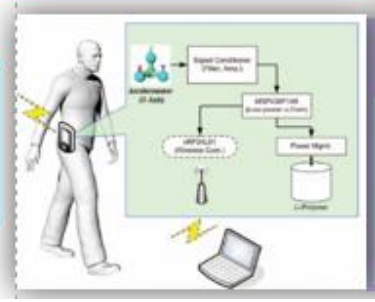
- Tailor-made posture training programme for models, flight attendant, etc.

Sports

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

Elderly

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



Dissemination and distribution of outcomes

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

1. Demonstration Video

https://youtu.be/cRnRsCZrvoU

2. China Patent

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”

(19)中华人民共和国国家知识产权局

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A61B 5/01(2006.01)

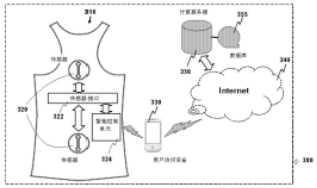
权利要求书2页 说明书9页 附图2页

(54)发明名称

具有用于患脊柱侧凸的患者的生物反馈系统的体感背心

(57)摘要

一种衣物，呈背心形式，用于监测患脊柱侧凸的患者和患者相关信号，从而使得所述患者能够获得个性化生物反馈。所述衣物包括多个传感器、传感器接口和智能控制单元(SCU)，当患者穿戴所述衣物时允许所述传感器非侵入式地测量所述患者相关信号，并同时维持所述患者的舒适性。所述SCU经由所述传感器接口与所述传感器通信，且聚集所述患者相关信号。所述衣物外部的计算服务器经由诸如智能电话的用户访问装置从所述SCU中接收所述聚集的患者相关信号，并处理所述聚集的患者相关信号以产生所述个性化生物反馈，所述个性化生物反馈然后被转发到所述用户访问装置以呈现给所述患者。机器学习算法用于在产生所述生物反馈时处理所述患者相关信号。



CN 105748037 A

3. Journal Papers

1. Kwok G., Yip J., Cheung M.C., Yick K.L. (2015) "Evaluation of Myoelectric Activity of Paraspinal Muscles in Adolescents with Idiopathic Scoliosis during Habitual Standing and Sitting", *BioMed Research International,* 958450.
   doi: 10.1155/2015/958450

Hindawi Publishing Corporation
BioMed Research International
Article ID 958450

Research Article

Evaluation of Myoelectric Activity of Paraspinal Muscles in Adolescents with Idiopathic Scoliosis during Habitual Standing and Sitting

Garcia Kwok,[1] Joanne Yip,[1] Mei-Chun Cheung,[2] and Kit-Lun Yick[1]

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[2]*Department of Social Work, The Chinese University of Hong Kong, Shatin, New Territories, Hong Kong*

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Academic Editor: Massimiliano Pau

There is a number of research work in the literature that have applied sEMG biofeedback as an instrument for muscle rehabilitation. Therefore, sEMG is a good tool for this research work and is used to record the myoelectric activity in the paraspinal muscles of those with AIS during habitual standing and sitting. After the sEMG evaluation, the root-mean-square (RMS) sEMG values of the paraspinal muscles in the habitual postures reflect the spinal curvature situation of the PUMC Type Ia and IIc subjects. Both groups have a stronger average RMS sEMG value on the convex side of the affected muscle regions. Correction to posture as instructed by the physiotherapist has helped the subjects to achieve a more balanced RMS sEMG ratio in the trapezius and latissimus dorsi regions; the erector spinae in the thoracic region and/or erector spinae in the lumbar region. It is, therefore, considered that with regular practice of the suggested positions, those with AIS can use motor learning to achieve a more balanced posture. Consequently, the findings can be used in less intrusive early orthotic intervention and provision of care to those with AIS.

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]. Noninvasive brace therapy is usually recommended for spinal curvatures between 21 and 40 degrees while surgery is suggested for curvatures over 41 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 [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 eliciting growing interest in the medical and psychology fields, and its proven effectiveness for a number of physical, psychological, and psychophysical problems [9–11], it is possible that biofeedback can be one of the new techniques that will provide an alternative type of noninvasive 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-ability to control specific psychophysiological processes [12]. The literature has consistently indicated that surface electromyography (sEMG) biofeedback is effective for muscle rehabilitation. A review

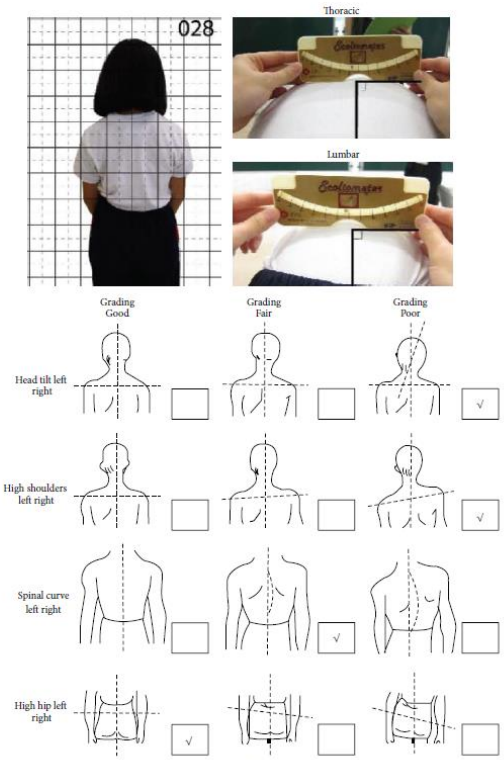

Figure 1: Adam's forward bending test and posture record form.

Figure 3: Habitual standing postures of participants.

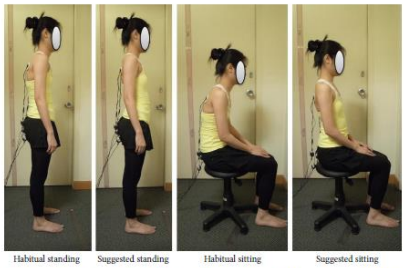

Figure 4: Subject whose posture has been "corrected" per instructions from a physiotherapist.

duration of 1 minute and repeated twice. A band pass filter that ranged from 10 to 500 Hz was applied to eliminate undesired artifacts, such as sudden movement, and a 60 Hz notch filter was used to eliminate noise. The sEMG 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 RMS sEMG ratio of the subjects was calculated based on the following equation [29]:

$$\text{RMS sEMG Ratio} = \frac{\text{RMS sEMG (convex)}}{\text{RMS sEMG (concave)}}. \quad (1)$$

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 sEMG 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 are effective if the ratio is 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 convex and concave sides during habitual standing and sitting was compared by t-testing with the significance level at $p < 0.05$. Besides, the difference between habitual and the suggested standing and sitting sEMG ratios was compared through the significance of a one-sample t-test with a test value of 1. The level of significance is $p < 0.05$.

4. Journal Papers

2. Kwok G., Yip J., Yick K.L., Cheung M.C., Tse C.Y., Ng S.P., Luximon A. (2017) "Posture screening for adolescent idiopathic scoliosis with infrared thermography", *Scientific Reports*, 7(1) p. 14431. https://www.nature.com/articles/s41598-017-14556-w

SCIENTIFIC REPORTS

OPEN

Postural Screening for Adolescent Idiopathic Scoliosis with Infrared Thermography

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Accepted: 12 October 2017
Published online: 31 October 2017

Garcia Kwok[1], Joanne Yip[1], Kit-Lun Yick[1], Mei-Chun Cheung[2], Chi-Yung Tse[3], Sun-Pui Ng[4] & Ameersing Luximon[1]

Adolescent idiopathic scoliosis (AIS) is a multifactorial, three-dimensional deformity of the spine and trunk. School scoliosis screening (SSS) is recommended by researchers as a means of 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 inexpensive. 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 also consider a larger sample of both non-scoliotic and scoliotic subjects to further validate the findings.

Adolescent idiopathic scoliosis (AIS) is a multifactorial, three-dimensional (3D) deformity of the spine and trunk. AIS can appear and sometimes progress during any of the rapid periods of growth in children[1]. Since the 1960s, research has shown that the early detection of scoliosis is effective in preventing its progression[2]; therefore, school scoliosis screening is recommended by researchers[3,4]. Early detection reduces the number of cases that require surgery through non-surgical interventions[5]. Despite criticisms of the effectiveness of school screening, primarily regarding unnecessary referrals and the high cost[6], there are studies that justify the cost and effectiveness of school screening. For example, Lee *et al.*[7] conducted a study on the cost of scoliosis screening in schools and concluded that the savings achieved by avoiding surgery compensate for the cost. Most of the cost lies in human resources and follow-up. Therefore, school scoliosis screening (SSS) should be conducted for the purpose of early detection. Fong *et al.*[8] statistically examined the effectiveness of SSS by reviewing 36 studies. After conducting a meta-analysis, they could not provide a definite conclusion regarding the effectiveness of screening due to variations in screening methods and sample size. However, they found that the forward bending test (FBT) has a higher referral rate and less precision when it is the only means of assessment compared with that of other screening methods that use more than one form of screening. Based on this result, they suggested that SSS programmes that use the FBT as the only assessment tool are subjective and insufficient for providing a reliable and precise diagnosis; therefore, an additional test aside from the FBT is recommended.

Adams[9], the leading expert on spinal deformity during his time, described the FBT as a screening technique to assess the likelihood of scoliosis during a series of twelve lectures that were presented from 1860 to 1861[10]. The FBT is still widely used today because it is the most conventional means of screening for AIS, and the technique is simple, non-invasive and inexpensive. Despite these advantages, there have been numerous criticisms against the FBT, and many researchers have reached similar conclusions to that reported by Luk *et al.*[3], namely, the technique results in high false-positive and false-negative rates[5], resulting in misdiagnoses and unnecessary referrals. Alternatives to the FBT include optical methods, such as Moiré topography, which has been used to

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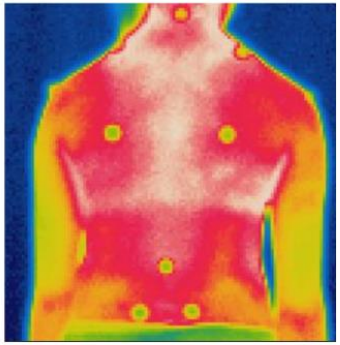


Figure 1. IR image of a non-scoliotic subject - symmetrical temperature distribution along the paraspinal muscles

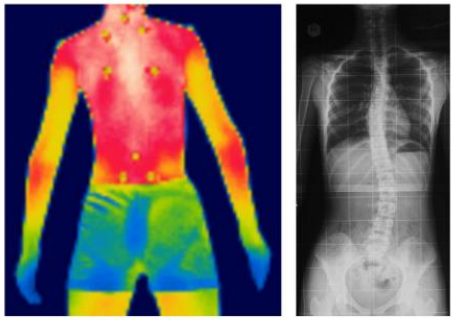


Figure 2. Comparison of IR images of a scoliotic subject with X-rays - S-curve of 23.6 degrees at L3 and 25.5 degrees at T9.

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 also be easily transported and saves on 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 analyse the collected IR data, which could minimize intra-observer error[20,29] 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.

However, this study has some limitations, including the small number of subjects recruited, rendering the study findings non-generalizable. It is recommended that the number of both non-scoliotic and scoliotic subjects be increased. In this way, the false-negative and false-positive rates with the use of this technique can be examined through a 'blind' interpretation of the IR images. A larger sample can also help to define the indices that would

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.

1. Kwok G., **Yip J.,** Cheung M. C., Yick K. L., (2017) Development of Posture Correction Tank-Top Synchronized with Biofeedback Muscle Training for Adolescents with Early Scoliosis. *12th SOSORT International Conference on Scoliosis*, Lyon France, 4-6 May 2017, p.63-64. http://www.sosort-lyon.net/P/index.php/en/

2. Kwok G., **Yip J.**, Cheung M. C., Yick K. L., Tse C. Y., Ng S. P., (2016) Posture Training Tank-Top For Adolescent Patients with Mild Idiopathic Scoliosis Synchronized with Electromyographic Signal, *Textile Summit,* 28-30 June 2016, Hong Kong

3. Kwok G., **Yip J.,** Cheung M.C., Yick K.L., Tse C.Y., Ng S.P. (2016) Behavioral Training of Paraspinal Muscles in Sitting Position with Biofeedback for Adolescent Patients with Mild Idiopathic Scoliosis. *CPCE Health Conference: Aging, Health and Long Term Care – Integrity, Innovation and Sustainability*, 11 Jan 2016, Hung Hom, Kowloon, Hong Kong, p.40. http://healthconf2016.cpce-polyu.edu.hk/session/parallel-sessions

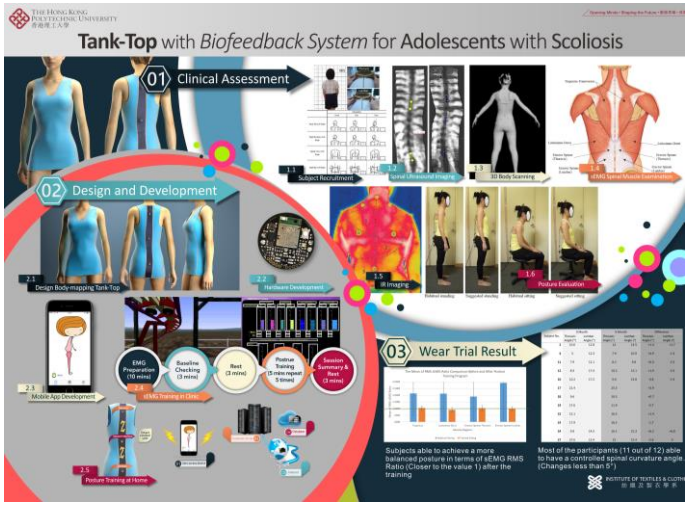
4. Kwok G., **Yip J.,** Cheung M. C., Yick K. L., (2014) Posture Training for Mild Adolescent Idiopathic Scoliosis by Electromyography Assessment. *BME2014 Biomedical Engineering International Conference,* 4-6 December 2014, Hong Kong https://scholars.uow.edu.au/display/n46699

6. International Exhibition and Competition

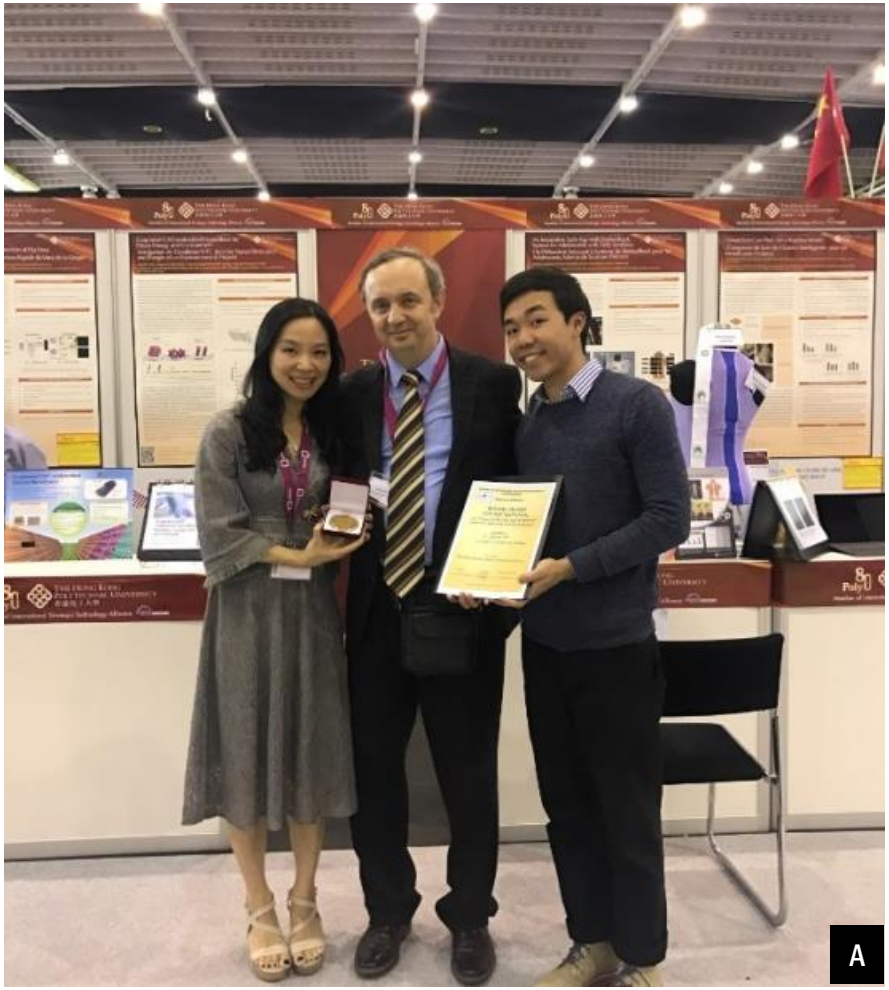
The body-mapping tank top was selected by University to be exhibited in The 45th International Exhibition of Inventions Geneva, Switzerland, 29 March to 2 April 2017.

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.

Visitors were trying our tank top for sitting posture training



7. Awards



A

DIPLÔME

Inventions Geneva

SALON INTERNATIONAL DES INVENTIONS GENÈVE

Après examen, le Jury International a décidé

de remettre à: Dr Yiu Wan Joanne YIP, Dr Mei Chun CHEUNG, Mr Garcia Hin Chun KWOK, Dr Alvin Toong Shoon CHAN, Dr Kit Lun YICK, Mr Chi Yung TSE, Dr Sun Pui NG, Mr Ming Fai CHAN

pour l'invention: Débardeur à Système de Biofeedback pour les Adolescents Atteints de Scoliose

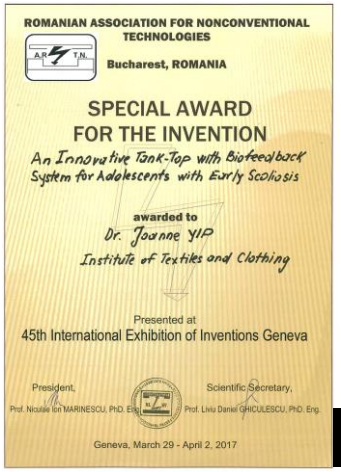
MÉDAILLE D'OR GOLD MEDAL GOLDMEDAILLE

Avec les félicitations du jury
With the congratulations of the jury
Mit besten Empfehlungen der Prospective

Le Président du jury: David Tay

Le Président du Salon: Jean-luc Vincent

B



ROMANIAN ASSOCIATION FOR NONCONVENTIONAL TECHNOLOGIES

A.R.T.N.

Bucharest, ROMANIA

SPECIAL AWARD FOR THE INVENTION

An Innovative Tank-Top with Biofeedback System for Adolescents with Early Scoliosis

awarded to

Dr. Joanne YIP

Institute of Textiles and Clothing

Presented at

45th International Exhibition of Inventions Geneva

President, Prof. Nicolae Ion MARINESCU, PhD. Eng.

Scientific Secretary, Prof. Liviu Daniel GHICULESCU, PhD. Eng.

Geneva, March 29 - April 2, 2017

C

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

科普講座

挺腰做人　昂首背心

2017-09-28

青少年原發性脊椎側彎，是最常見的三維脊柱變形疾病。是次講座介紹的生物反饋智能背心，配備多個傳感器，為早期患者提供背部肌肉及個人化姿勢訓練。

此外，專門為智能背心而設計的手機應用程式，可實時監察使用者姿勢，並於姿勢

A. **Biofeedback Tank top**

挺腰做人 昂首背心

Inno Tech Expo 創科博覽

2017-09-28

A

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，並積極參與各項研究工作，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。

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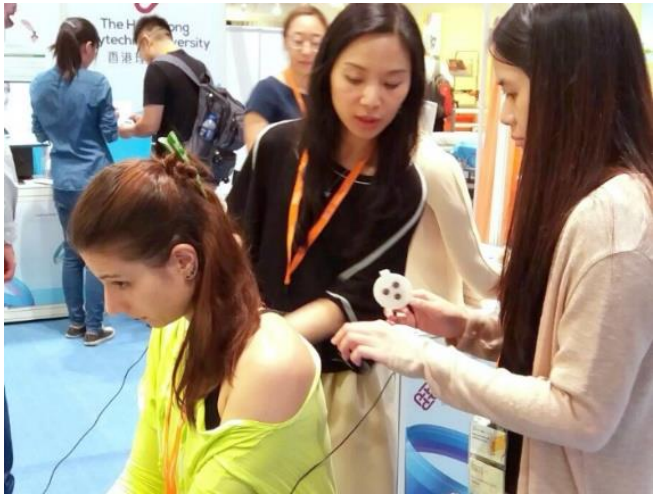
9. Ex-Chief Executive of Hong Kong – Award ceremony for 45th International Exhibitions of Geneva

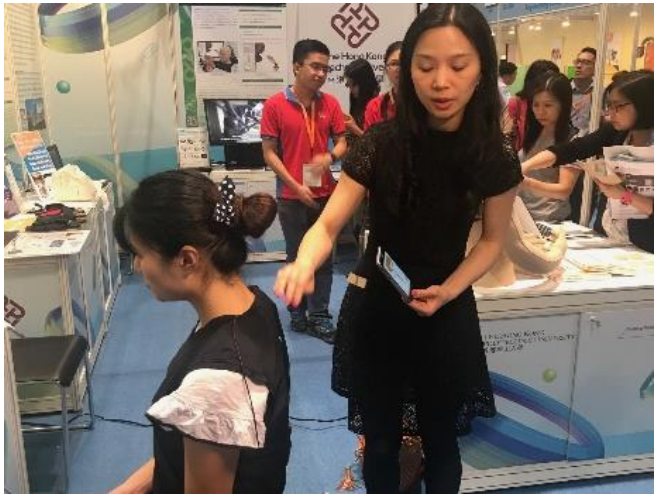
Speech by ex-CE Mr C Y Leung at reception for awardees of 45th International Exhibition of Inventions of Geneva

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.

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.

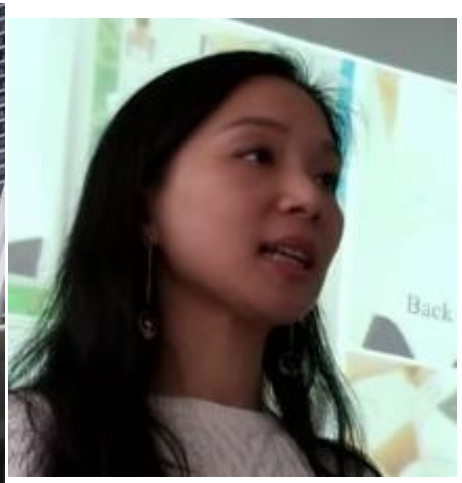
Isha – Specialism Mixed Media

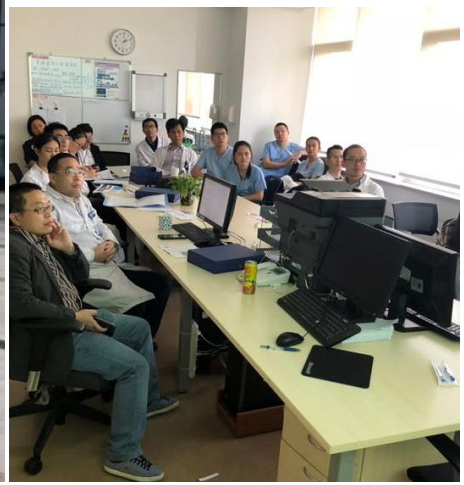
Isha has been exploring interactive objects for a positive play experience. Nice to link to play and people saying more when they are engaged in an activity. This could potentially be linked to therapy or different environments where this would have a positive of assistive impact?

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

PolyU Technology and Consultancy Company Limited 理大科技及顧問有限公司

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 Incu-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.

Kelvin Wong
General Manager

KW/EL

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

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