Biofeedback Posture Training for Adolescents with Mild Scoliosis

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Research Article

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Abstract

Asymmetry in paraspinal myoelectric activities is a prominent risk factor for curve progression in adolescent idiopathic scoliosis. This study aimed to evaluate the effectiveness of a surface electromyography (sEMG) biofeedback posture training program for adolescents with mild scoliosis (Cobb’s angle < 30°), with the ultimate goal of controlling the curve progression. Seven female adolescents (age, 12–14 years) with mild scoliosis (Cobb’s angle < 30°) were recruited. The participants received 30 tailor-made sessions of sEMG biofeedback posture training at a rate of one to two sessions per week for approximately 6 months. The activities of the paraspinal muscles (the trapezius, latissimi dorsi, thoracic erector spinae, and lumbar erector spinae), as measured by sEMG during habitual sitting postures, and spinal deformity, as evaluated by ultrasound imaging, were compared before and after training to evaluate its effectiveness. The mean values of the root-mean-square sEMG ratio, an index of symmetry in paraspinal muscle activity between the concave and convex of the spinal curve, revealed significant asymmetry over the trapezius and lumbar erector spinae before the training. After the training, all seven adolescents achieved significantly more symmetrical muscle activity over these two muscle pairs. In two adolescents, the spinal curvature decreased by more than 5°, whereas the remaining adolescents showed a minimal curve progression with changes in the spinal curvature controlled under 5°. sEMG biofeedback posture training is effective in adolescents with mild scoliosis, and can be implemented as an early intervention to improve their posture and mitigate curve progression.

Introduction

Posture is defined as the orientation or alignment of body segments while maintaining an upright position. Poor posture is characterized by any prolonged deviation from a “neutral spine”. Juskeliene et al. reported that 46.9% of the 791 children included in their study had trunk asymmetry caused by poor posture. Adolescent idiopathic scoliosis (AIS), the most common type of poor posture, is characterized by uneven shoulders, spinal curvature, and uneven hips. Asymmetry in paraspinal myoelectric activities is common in AIS. A previous study that compared paraspinal myoelectric activities between female adolescents with and without mild scoliosis (i.e., spinal curve angle less than 20°) by surface electromyography (sEMG) during habitual standing and sitting postures found that those with thoracic- or thoraco-lumbar-type scoliosis had higher average root-mean-square (RMS) sEMG values on the convex side of the affected muscle regions. In addition, adolescents with mild scoliosis showed evident asymmetry in muscle activities between the left and right upper trapezius and latissimi dorsi in the habitual sitting posture, whereas those without AIS demonstrated a smaller difference in the RMS sEMG values between the left and right sides of the same muscle pairs. While most investigators concede that abnormalities in paraspinal myoelectric activities are likely to be secondary to spinal deformity in AIS, some studies show that asymmetry in paraspinal myoelectric activities is a prominent risk factor for curve progression. Therefore, posture training to improve the symmetry of paraspinal muscle activities in AIS can reduce the risk of curve progression.

The earliest postural training device for AIS was developed by Dworkin. It was a small microprocessor-based postural training device that provided continuous information to patients about their posture through an audio feedback mechanism. Wong et al. studied the effectiveness of this device for posture training in a sample of adolescents in Hong Kong with spinal Cobb angles between 25° and 35°. The device achieved a curve-control success rate of 69% in this population. However, one disadvantage of this device is that patients may not hear the auditory feedback if the level of ambient noise is high. Furthermore, although the device is portable, it needs to be worn for 23 hours a day for a minimum of 18 months, which causes discomfort and thus results in poor compliance. Later, to monitor the trunk posture, Wong introduced a smart garment with integrated accelerometers and gyroscopes, which can detect postural changes in terms of the curvature variation of the spine in the sagittal and coronal planes. However, this garment does not measure specific and quantifiable bodily signals, such as muscle activity.

At present, adolescents with early scoliosis do not receive any intervention. Some of them are generally followed up through clinical monitoring and re-examination of the degree of spinal curvature every 8–12 months. However, during the period from 10 to 16 years of age, they have a high growth potential and a high risk of curve progression. Therefore, early intervention during this stage is crucial, given that it can reduce curve progression and the likelihood of requiring orthotic spinal brace and surgical treatment in the long run. Biofeedback is a non-invasive means of intervention in which individuals are trained to improve their health and/or performance by monitoring physiological signals from their own bodies, such as their heart rate and muscle activities. It is a means of gaining control over physiological signals to relax and relieve pain and stress. Biofeedback training has been successfully used to treat various disorders, such as headaches and pain, and improve neuromuscular function and gait symmetry. Hence, this study aimed to evaluate the effectiveness of a 30-session sEMG biofeedback posture training program for female adolescents with early scoliosis, given that scoliosis in girls tends to progress more rapidly than in boys. We hypothesized that adolescents would achieve relatively symmetric paraspinal muscle activity after 30 sessions of biofeedback training (i.e., the RMS sEMG ratio would approach 1), compared with the activity recorded during the baseline measurement, and would exhibit beneficial changes in the curve progression over time.

Results

Symmetry in the sEMG activities over the trapezius, latissimi dorsi, thoracic erector spinae, and lumbar erector spinae muscle pairs were compared before and after the biofeedback posture training. The corresponding RMS sEMG ratios are provided in Figure 1. Spinal deformity was evaluated using Scolioscan™, and the curve angles over the thoracic and lumbar regions before and after the training are presented in Table 1.
The RMS sEMG ratios were used as an index of symmetry in the paraspinal muscle activity, and the values corresponding to the four paraspinal muscle pairs were subjected to one-sample t-tests to identify any asymmetry in the sEMG activities at baseline. The results showed significant asymmetry in all seven participants over the trapezius \( [M = 2.837, t(6) = 2.800, p < 0.05] \) and lumbar erector spinae \( [M = 0.629, t(6) = -3.894, p < 0.01] \). After the biofeedback training, a Time (Pre and Post) × Muscle (trapezius, latissimi dorsi, thoracic erector spinae, and lumbar erector spinae) repeated measures ANOVA was conducted to compare the symmetry in sEMG activities over the four paraspinal muscle pairs before and after the biofeedback training. The multivariate results showed that there was no significant difference in the main effects of Time \([F(1, 6) = 1.898, p > 0.05]\) and Muscle \([F(3, 4) = 5.467, p > 0.05]\), whereas the Time × Muscle interaction had significant effects \([F(3, 4) = 6.784, p < 0.05, \eta^2 = 0.836]\). A post-hoc pairwise comparison revealed that the post-training RMS sEMG ratio of the trapezius was significantly lower \([M = 1.049, t(6) = 2.739, p < 0.05]\) than that at baseline \((M = 2.837)\). Similarly, a significant difference was observed in the RMS sEMG ratio of the lumbar erector spinae from before \((M = 0.629)\) to after \((M = 1.033)\) the biofeedback training \([t(6) = -3.581, p < 0.05]\). A one-sample t-test was then performed to determine whether there was symmetry in sEMG activities over these two muscle pairs after the biofeedback training. The results showed symmetry in the paraspinal muscle activities over both the trapezius pair \([t(6) = 0.953, p > 0.05]\) and the lumbar erector spinae pair \([t(6) = 0.682, p > 0.05]\) after the biofeedback training, i.e., their RMS sEMG ratios were closer to 1.

Next, spinal deformity was measured in terms of the spinal curve angle to further demonstrate the effectiveness of the training. After the biofeedback training, two participants showed a reduced curvature, with a reduction in the spinal curve angle of more than 5°. Though the remaining five participants exhibited a minimal curve progression over the thoracic and/or lumbar regions, the spinal angle change was controlled under 5° (Table 1).

**Discussion**

The RMS sEMG ratios of the participants shown in Fig. 1 demonstrate that the seven female adolescents exhibited asymmetry in the paraspinal muscle activity before training. Specifically, the average RMS sEMG ratios of the trapezius and lumbar erector spinae muscle pairs were significantly greater or less than 1, suggesting asymmetry in these two paraspinal muscle activities before training. While the trapezius tended to show a stronger muscle activity on the convex side than on the concave side, the lumbar erector spinae exhibited a stronger muscle activity on the concave side than on the convex side. The myoelectric asymmetry in the trapezius was consistent with the findings of previous research on AIS patients, which revealed a higher average RMS sEMG value on the convex side of the trapezius because of lower bioelectricity activity on the concave side\(^{10,12}\). However, a contradictory finding was reported in the lumbar erector spinae, with a higher average RMS sEMG value on the concave side than on the convex side. This difference may be attributable to the fact that our sample was quite heterogeneous in terms of the curve type (four participants had an S curve and three had a C curve), and to the potential influence of the degree of spinal curvature on the sEMG values\(^{10}\). For a more conclusive implication, a larger sample that is homogeneous in terms of the curve type should be evaluated in the future to further confirm the association between spinal curvature and asymmetry in the muscle activity in terms of the RMS sEMG ratio.

After 30 sessions of biofeedback posture training, the RMS sEMG ratios of all of the tested muscle regions approached 1, indicating more symmetric muscle pair activities relative to those measured before training. The most significant improvement in muscle activity symmetry after training was observed over the trapezius and lumbar erector spinae \((p < 0.05)\). Given that the biofeedback posture training also relied on the sEMG signals as feedback for monitoring the posture, it is reasonable to speculate that the training would have significant effects on the participants’ sEMG signals after training. Given that asymmetry in paraspinal myoelectric activity is considered as a prominent risk factor for curve progression\(^{14–17}\), another more objective outcome measure, i.e., spinal deformity, was measured before and after the training to determine the effectiveness of the biofeedback posture training. We speculated that reduction in the asymmetry of paraspinal muscle activities would have beneficial effects on the curve progression over time. Consistent with our hypothesis, after 6 months of training, two adolescents (28.57%) showed an improved curve with a spinal curvature reduction by more than 5° in the thoracic region, whereas the remaining adolescents (71.43%) showed a minimal curve progression with changes in the spinal curve angle controlled under 5°. Due to our small sample size, the spinal curve angles did not exhibit a significant difference from before to after the training. However, the results are promising enough to provide initial evidence to support the effectiveness of biofeedback posture training for adolescents with mild scoliosis.

Mild scoliosis adversely affects the quality of life of adolescents in terms of lower self-image, increased back pain, and unhappiness with their lives\(^{23,24}\). At present, no intervention is provided for adolescents with mild scoliosis, and they are only followed up every 6 to 12 months. Although the majority of cases (approximately 80–90%) are non-progressive, the remaining adolescents are at risk of curve progression during puberty (age 10–16 years) if they are skeletally immature. Therefore, the adverse effects of poor posture and/or spinal deformity on adolescents’ health and well-being can be prominent and enduring. The results of our study are consistent with those of previous studies regarding the use of exercise for AIS, which found that the active participation of AIS adolescents in an individualized selection of exercises could be regarded as a preventive measure to improve their paraspinal muscle activity\(^{25}\), slow the curve progression\(^{26}\), or enhance their balance, strength, and mobility\(^{27,28}\). Biofeedback is a non-invasive means of intervention in which individuals are trained to improve their health and/or performance by monitoring physiological signals from their own bodies, such as their heart rate and muscle activities. It is a means to gain control over physiological signals to relax and relieve pain and stress. Biofeedback training has been successfully used to treat various disorders, such as headaches and pain, and improve neuromuscular function and gait symmetry\(^{21}\). The findings of our study further substantiate that evidence-based sEMG biofeedback posture training is an effective intervention for AIS, especially among adolescents with mild scoliosis who are at a high risk of curve progression.
This study is the first to explore the possibility of implementing sEMG in non-invasive posture training for adolescents with mild scoliosis who have not given much attention to their spinal deformity. The significance of this study should be considered in light of the following limitations. First, because the sample size was limited, the difference in the spinal curve angle before and after training did not reach significance, and its association with the change in RMS sEMG ratios could not be evaluated. Second, this study recruited adolescents with different types (S and C curves) and severities of spinal curvatures, with Cobb angles ranging from 7.9° to 27.6°. This heterogeneity allowed us to analyze the extent of applicability of the proposed training program to different types of scoliosis. However, the effectiveness of the biofeedback posture training program on AIS patients with a particular curve type could not be evaluated. Hence, further studies with a larger sample size that is homogeneous in term of the range of Cobb angle and curve type are recommended. Given that curve progression occurs over time, it would be conceivable to conduct a randomized controlled trial to further explore and confirm the effectiveness of such biofeedback posture training on AIS patients and its sustainability over time.

Methods

Participants

Seven female adolescents aged between 12 and 14 years were recruited through a school screening program during which the angle of trunk rotation (ATR) in the thoracic and lumbar regions was assessed using the Adam's forward bending test. For adolescents who showed possible signs of scoliosis (an ATR ≥ 3), during school screening, their spinal condition was further evaluated by ultrasound imaging using Scolioscan™ to measure the spinal deformity, which was evaluated again after completing the biofeedback posture training. Female adolescents were excluded from the study if they had a history of surgical or orthotic treatment for AIS. The curve type was based on the Lenke classification system. The demographic data of the seven recruited female adolescents are provided in Table 1. The study followed the tenets of the Declaration of Helsinki as developed by the World Medical Association, and the research protocol was approved by the Human Subjects Ethics Sub-committee of the Hong Kong Polytechnic University. All adolescents participated voluntarily, and informed assent from the adolescents and written informed consent for participation from their parents were solicited before beginning the study, as per institutional guidelines.

sEMG measurement before and after training

The parameters of the sEMG values were formulated based on the standards for the Surface EMG for Noninvasive Assessment of Muscles (SENIAM) and the myoelectrical activities of the paraspinal muscles of the adolescents were measured in terms of sEMG activities using a preamplified sensor, MyoScan (model T9503M), and a data acquisition system, Flexcomp (model T7555M; both acquired from Thought Technology, Montreal, Canada), within 1 week before starting the posture training and after completing the training. Briefly, the sEMG electrodes were placed onto the paraspinal muscles, namely the trapezius, latissimi dorsi, thoracic erector spinae, and lumbar erector spinae, in pairs to determine the muscle activities along the spine in habitual sitting postures. The sEMG signals were sampled at a rate of 10 kHz with a 10–500-Hz band pass filter and a 60-Hz notch filter to eliminate artefacts and noise. The measurements were taken three times for 3 minutes each time. The RMS sEMG values for each trial were calculated using BioGraph Infiniti software, and the scores for three trials were averaged. The RMS sEMG ratio for each tested muscle pair of each participant was then calculated using the following equation:

\[ \text{RMS sEMG Ratio} = \frac{\text{RMS sEMG (convex)}}{\text{RMS sEMG (concave)}} \]

This ratio is an index of symmetry in the myoelectric activities of the tested paraspinal muscle pairs in habitual sitting postures. A ratio of 1 indicates that the tested muscle pair has symmetric sEMG activity between the concave and convex sides.

Biofeedback posture training

An sEMG biofeedback posture training protocol was delivered using Thought Technology BioGraph Infiniti software (Montreal, Canada). Each adolescent received 30 sessions of training delivered in one to two sessions per week for approximately 6 months. During each training session, the adolescents underwent a 10-minute EMG setup procedure with an impedance check, which was followed by the baseline measurement. During the baseline measurement, the participants were required to sit for 3 minutes in a relaxed state to measure their muscle activities in terms of sEMG signals. During posture training, they were instructed to sit in an ideal recommended posture and maintain this posture for 5 minutes. Animated indicators on the biofeedback screen appeared whenever the posture fell below the threshold of specific individualized requirements. These indicators were aimed at reducing the RMS sEMG ratio between the left and right sides of the four pairs of muscles—the trapezius, latissimi dorsi, thoracic erector spinae, and lumbar erector spinae—toward 1 and the individual sEMG values of each of those muscles to less than 5 µV. As 12 indexes (4 ratios and 8 individual values) were required to be measured to activate the animated indicators, the exact threshold was individually tailored for an overall success rate of approximately 80%, which also motivated the adolescents to engage in the training. This posture training routine was administered five times in each session, with a 2-minute resting period between each time. Each training session lasted approximately 60 minutes.

Statistics

All statistical analyses were performed using the SPSS Statistic Version 25 program for Windows (Armonk, NY: IBM Corp). The RMS sEMG ratios were subjected to one-sample t-tests to identify any asymmetry (deviation from the test value of 1) in sEMG activities over the trapezius, latissimi dorsi, thoracic erector spinae, and lumbar erector spinae before and after the biofeedback training. A repeated measures analysis of variance (ANOVA) was
performed to compare the symmetry in the sEMG activities of the four paraspinal muscle pairs before and after the biofeedback training, followed by a post-hoc pairwise comparison if the multivariate results were significant. The level of significance was set at $p < 0.05$. The difference in the degree of the spinal curve angle from baseline to post-training was measured using Scolioscan™ (Telefield Medical Imaging Limited, Hong Kong).

**Declarations**

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**Author Contributions**

All authors have contributed significantly to the manuscript, including conceptualization, design, or analysis and interpretation of data. They have read, approved the submitted version of the paper, and given consent to their names on the manuscript.

**Competing Interests**

The authors declare no competing interests.

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Demographic Information of the Participants and their Spinal Deformity Angles before and after the Biofeedback Posture Training

| Subject No. | Age (years) | Lenke's Classification | Convex Side | Height (cm) | Weight (kg) | BMI | Thoracic Angle (°) | Lumbar Angle (°) | Thoracic Angle (°) | Lumbar Angle (°) | Thoracic Angle (°) | Lumbar Angle (°) | Difference |
|-------------|-------------|------------------------|-------------|-------------|-------------|-----|-------------------|-----------------|-------------------|-----------------|-------------------|-----------------|------------|
| A           | 14          | Type 6                 | Right (Thoracic) Left (Lumbar) | 156         | 44.6        | 18.3 | 10.6              | 12.8            | 12                | 14.5            | 1.4               | 1.7             |            |
| B           | 14          | Type 6                 | Right (Thoracic) Left (Lumbar) | 142         | 39          | 19.3 | 7.9               | 12.1            | 8.2               | 9.8             | 0.3               | -2.3            |            |
| C           | 14          | Type 6                 | Right (Thoracic) Left (Lumbar) | 152         | 38.5        | 16.7 | 8.3               | 17.4            | 10.2              | 15.1            | 1.9               | -2.3            |            |
| D           | 13          | Type 1                 | Right (Thoracic) Left (Lumbar) | 163         | 45.1        | 17   | 21.4              | N/A             | 25.3              | N/A             | 3.9               | N/A             |            |
| E           | 13          | Type 5                 | Left (Lumbar) | 154         | 46.3        | 19.5 | N/A               | 9.6             | N/A               | 10.3            | N/A               | 0.7            |            |
| F           | 13          | Type 5                 | Left (Thoracic) | 151         | 53.6        | 23.5 | 17.6              | N/A             | 11.9              | N/A             | -5.7a           | N/A             |            |
| G           | 12          | Type 6                 | Right (Thoracic) Left (Lumbar) | 155         | 40          | 16.5 | 27.6              | 15.4            | 22                | 15.4            | -5.6a           | 0              |            |

*More than 5° reduction in spinal deformity

BMI, body mass index; N/A, not applicable