Effect of a functional garment on postural control for adolescents with early scoliosis: A six-month wear trial study

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Abstract. Background: Postural alterations that are associated with the orientation of the head, shoulders, scapula, and pelvis in the three basic planes of the human anatomy are commonly found in adolescents with scoliosis. Yet there is a lack of functional garments in the market specifically designed for postural control to address early scoliosis in adolescents.
Objectives: The purpose of this study is to determine the effectiveness of a functional garment for girls aged 10 to 13 who have the early stages of scoliosis. The effects of this functional garment on postural changes are investigated in this study.
Methods: Nine subjects have been recruited to take part in the study. A wear trial has been undertaken for 6 months to evaluate the effectiveness and practical use of the posture correction girdle by 3D motion capturing and 3D body scanning.
Results: After carrying out the 3D motion capturing, significant postural improvements are mainly found in the acromion and pelvis as observed from the frontal plane during standing, the back angle as observed from the sagittal plane during sitting, as well as control of the maximum range of anterior and lateral bending. After implementing the 3D body scanning, it is found that there is no significant change in the rotation angle in the horizontal plane due to a large standard deviation.
Conclusions: The design of the functional garment is found to better control the acromion. The effectiveness of the girdle on postural changes could be affected by compliance, growth and curve type.

Keywords: posture · scoliosis · functional garment

1 Introduction

Posture describes the orientation of any body segment relative to the gravitational vector; that is, as an angular measure from the vertical [1]. Adolescent idiopathic scoliosis (AIS), which affects posture, is characterized by three-dimensional geometric deformations of the spine and rib cage that can lead to changes in the relationship between body segments [2]. Alterations in body posture are commonly found in AIS, including those associated with the orientation of the head, shoulders, scapula and pelvis in all three basic planes of the human anatomy [3]. The severity of postural imbalance and instability might be possible factors that are associated with the progression of spinal curves [4-6]. Hence, postural control, correction or training could be useful in controlling curve progression during the rapid growth period of adolescents with AIS.

In general, AIS patients are recommended to undergo different types of treatments which depend on their spinal situations and stage of scoliosis, e.g. (1) surgery for patients with a spinal curve that is greater than 41 to 50 degrees, (2) bracing for patients with a spinal curve between 21 and 40 degrees, and (3) observation with periodical spinal re-examination for patients with early scoliosis (spinal curve between 6 and 20 degrees). However, researchers believe that other types of treatments or measures can be viable for adolescents with early scoliosis as opposed to only observation. “Posture reminders” from parents or provided through training devices for maintaining good posture are other options that are considered to be acceptable prophylaxis [7-8]. The rationale of postural correction and control is to encourage patients to use their back muscles to keep the spine within its natural curvature. Consequently, the corresponding symptoms of imbalance in posture may be prevented with awareness and the patients may learn good postural habits that can be carried over throughout their entire lives [8-10].

Gur et al. studied the effect of a spinal brace on postural control in patients with AIS in different sensory conditions and found that the brace improves postural stability [11]. However, this kind of brace highly constrains body movement and may not be suitable for adolescents with early scoliosis. Our previous preliminary work shows that the posture of those with AIS could be immediately improved by wearing a tailor-made soft girdle [12-13]. In the present study, a wear trial of 6 months has been undertaken to evaluate the effectiveness and practical use of this posture correction girdle as a form of postural control for AIS. The changes in posture are examined by 3D motion capturing and 3D body scanning.

2 Methods

Subjects. A screening program was carried out in Hong Kong during 2012 to 2014 with 8 schools and the target population was 10-13 year-old females. During the examination process, the subjects were invited to perform Adam's forward bending test and an OSI scoliometer was employed to measure the angle of trunk inclination (ATI) in the spine of the subjects while lying prone, in order to preliminarily assess their spinal conditions [9]. In total, out of the 497 participants who were screened, 109 were found to have an ATI≥ 3 (21.9%). The age and BMI distributions of the screened participants are summarized in **Table 1.** The participants were assigned to the normal subject group (N group) if they have an ATI 0-2° and to the group with the possibility of scoliosis (P group) if they have an ATI ≥3°.

Twelve participants from the P group accepted the invitation to undergo radiography for further evaluation. After the evaluation, a total of 9 participants with a Risser's sign ≤ 2, Cobb's angles of 6 to 20 degrees, and without any previous surgical or orthotic treatment for AIS were recruited for the study. The study was approved by the Human Ethics Committee of the Hong Kong Polytechnic University. All subjects signed an informed consent form and along with their parents, were informed about the purpose of the study.

Wear Trial. A functional garment which consisted of a tight-fitting girdle, shoulder to top-hip in length, was used to help with facilitating support and control of the body from the shoulders to the top of the hips (as shown in **Figure 1**). The application of supportive forces and a point-pressure support system with this girdle were considered to assist with maintaining a more balanced posture and reduce the amount of body bending during daily activities [10].

Each subject who participated in the 6-month wear trial was informed that the recommended girdling time for each day should be 8 hours. They were provided with a 2 week adaptation period prior to the start of the wear trial, i.e. girdling time of 2 hours in the first week and 4 hours in the second week. It was also ensured that all of the subjects were correctly wearing the girdle before the commencement of the wear trial. A temperature logger (Thermocron) was inserted into each girdle for compliance monitoring and set to record data every 5 minutes.

Posture analysis. In order to evaluate the effect of girdling and girdling time on the postural changes in the subjects, testing that comprised 3D body scanning and 3D motion capturing were carried out at the beginning (0 month), after 3 months and at the end (after 6 months) of the wear trial in two conditions, with the girdle and without the girdle, so as to obtain fair comparisons. The subjects were required to wear thin bra tops and tight shorts during the body scanning and motion-capturing processes, in order to obtain more accurate results. Moreover, the subjects were required to perform each task twice with and without wearing the girdle in all of the testing, and only the measurements taken after the task was performed for a second time were analyzed.

Three-dimensional body scanning was performed by using the Anthroscan system (Human Solutions) to evaluate the change in the rotation angle between the shoulders and pelvis in the horizontal plane during standing. During the scanning process, the subject was to stand up straight with the shoulders back and feet apart in accordance with the footprint on the floor and parallel to the eye level with the floor. Markers were placed on both of the left and right sides of the acromion and pelvis, in order to mark the reference points for evaluation. The scanned data were exported after removing the noise and filling in the data gaps. Then, the data were processed by using MatLab 2013a. The data were aligned in accordance with the center of the body of the subjects, i.e. placement of their foot in the x, y and z-axes. The midlines of the body were marked at the shoulder and pelvis levels in the horizontal plane. After projecting the two lines on the same horizontal plane, the intersection angle was measured for comparison.

Three-dimensional motion capturing was performed by using the Vicon system, in order to obtain the data of a series of movements in the dynamic and static phases of postures with and without wearing the functional garment. The system contains a data-station, six wall-mounted video cameras with infrared sources, and a PC workstation. The infrared light-emitting diodes of each camera have a flash of 60 Hz and the system can obtain 3D co-ordinates from each marker through a 3D reconstruction method. Static and dynamic calibrations were implemented before the start of the experiment. As shown in Figure 2, 15 reflective markers are placed onto specific landmarks on the body of the subject after palpation. The motions carried out in different scenarios, including standing, sitting, walking and bending, were captured, and then, 16 posture parameters were determined and analyzed [13].

Table 1. Age and BMI distributions of screened participants

Age	Group	Underweight	Normal weight	Overweight	Total
10	**N**	15 23.4% 93.8%	36 56.3% 80%	13 20.3% 76.5%	64 100% 82%
	P	1 7.1% 6.2%	9 64.3% 20%	4 28.6% 23.5%	14 100% 18%
	Total	16 20.5% 100%	45 57.7% 100%	17 21.8% 100%	78 100% 100%
11	**N**	45 28.7% 69.2%	86 54.8% 78.2%	26 16.5% 76.5%	157 100% 75.1%
	P	20 38.5% 30.8%	24 46.1% 21.8%	8 15.4% 23.5%	52 100% 24.9%
	Total	65 31.1% 100%	110 52.6% 100%	34 16.3% 100%	209 100% 100%
12	**N**	36 24.3% 73.5%	93 62.8% 80.2%	19 12.9% 82.6%	148 100% 78.7%
	P	13 32.5% 26.5%	23 57.5% 19.8%	4 10% 17.4%	40 100% 21.3%
	Total	49 26.1% 100%	116 61.7% 100%	23 12.2% 100%	188 100% 100%
13	**N**	6 31.6% 85.7%	9 47.4% 81.8%	4 21% 100%	19 100% 86.4%
	P	1 33.3% 14.3%	2 66.7% 18.2%	0 0% 0%	3 100% 13.6%
	Total	7 31.8% 100%	11 50% 100%	4 18.2% 100%	22 100% 100%
All ages	**N**	115 29.6% 75.6%	215 55.4% 79.3%	58 15% 78.4%	388 100% 78.1%
	P	34 31.2% 23.4%	59 54.1% 21.7%	16 14.7% 21.6%	109 100% 21.9%
	Total	152 30.6% 100%	271 54.5% 100%	74 14.9% 100%	497 100% 100%

*Remarks:
N = Normal group (Participants with ATI 0-2°);
P = Possibly has scoliosis group (Participants with ATI ≥3°)

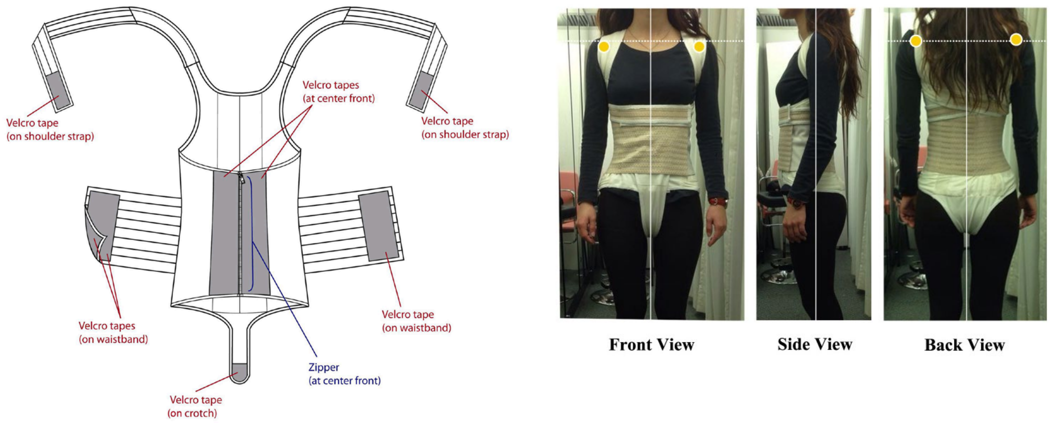


Fig. 1 Posture correction girdle on a subject

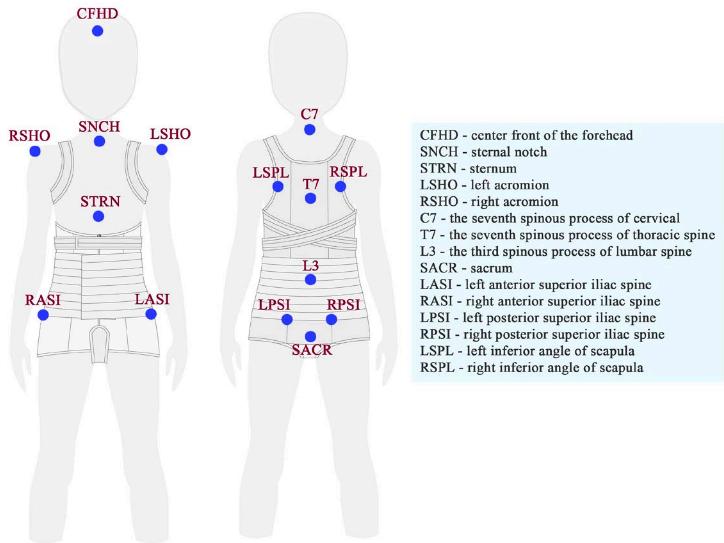


Fig. 2 Location of reflective markers used in 3D motion capturing

Statistical Analysis. In order to examine the possible effect of girdling on the postural changes of the subjects, IBM SPSS Statistic Version 20 was employed to analyze the data with 2-ways repeated measures ANOVA. The independent variables included girdling (with girdle and without girdle) and time (0 month, 3 months and 6 months), while the dependent variables were the measurements obtained from the 3D body scanning and 3D motion capturing. The level of significance was set at p=0.05.

3. Results

Nine female subjects with early scoliosis were recruited, but only 7 subjects (11.14±0.90 years old, 146.86±4.79 cm in height, 39.97±12.03 kg in weight, BMI 18.36±4.19, thoracic Cobb's angle 9.43±6.11°, and lumbar Cobb's angle 10.57±4.79°) completed the entire wear trial (6 months) and performed all of the evaluation tests. The average rate of compliance among the 7 subjects is 85.48%.

3.1 Three-dimension body scanning

Any improvements in the rotation problem at the level between the shoulders and pelvis as observed from the horizontal plane during standing might be indicated by a reduction of the rotation angle. The changes in the rotation angle in the horizontal plane during standing from 0 to 6 months are shown in Figure 3.

According to the results of the 2-ways repeated measures ANOVA, with regard to the main effect, there are no statistically significant differences found in girdling with $F(1,6) = 3.591$, $p = 0.107$ and time with $F(2,5) = 2.963$, $p = 0.142$. With regard to the interaction effects, there is also no statistically significant difference found between girdling and time on postural change with $F(2,5) = 2.022$, $p = 0.227$. In other words, there is no statistically significant improvement of the rotation angle at the level between the shoulders and pelvis as observed from the horizontal plane during standing, which is induced by the effects of girdling and time.

3.2 Motion capture (Vicon) analysis

With regard to the angle measurements of the posture parameters, a more balanced posture in standing and walking, as well as better control of the range of bending, might be indicated by angle reductions, while a straighter back in sitting might be indicated by angle increases.

According to the results of the 2-ways repeated measures ANOVA (as shown in Table 2), there are statistically significant differences in the main effect of girdling on Posture Parameter 1 ($p < 0.05$), 4 ($p < 0.01$), and 9 ($p < 0.01$). The results indicated that girdling might possibly provide immediate improvement, including more even shoulders as observed from the frontal and horizontal planes during standing, as well as straighter upper back as observed from the sagittal plane during sitting. In addition, there are also statistically significant differences in the main effect of time on Posture Parameter 1 ($p < 0.01$), 9 ($p < 0.05$), and 11 ($p < 0.05$). A post-hoc test (Bonferroni) was conducted to examine the pairwise comparison with time. The result showed that there are statistically significant differences between 0 and 6 months ($p < 0.05$) for Posture Parameter 1 as well as 0 and 6 months ($p < 0.05$) for Posture Parameter 11. However, no statistically significant difference was found for Posture Parameter 9. The results indicated that improvements with time might possibly be found with Posture Parameters 1 and 11, i.e. more even shoulders as observed from the frontal plane during standing and walking.

Moreover, according to Table 2, there are statistically significant differences of the interaction effects between girdling and time for Posture Parameter 1 ($p < 0.01$), 2 ($p < 0.05$), 10 ($p < 0.05$), 15 ($p < 0.05$), and 16 ($p = 0.01$). The interaction effects mean that the independent variables, i.e. girdling and time, have a complex influence on the dependent variable, i.e. postural change. The results indicate that the possible postural changes of Posture Parameters 1, 2, 10, 15 and 16, i.e. more evenness in the shoulders and pelvis as observed from the frontal plane during standing, a straighter lower back as observed from the sagittal plane during sitting, as well as acceptable constrained range of anterior and lateral bending, might have possibly been attributed to the effects of girdling and time.

4. Discussion

It has been documented that the ideal alignment in the vertical posture is related to the gravity line, which is a vertical line that passes through the center of gravity of the body [14-15]. It has also been stated that good posture is a state of muscular and skeletal balance, which protects the body structure against injury or progressive deformity independent of whether the structure is working or resting [16].

In regard to the results of 3D motion capturing, significant improvements were mainly found on the acromion, especially in the frontal plane during standing. This result might be related to the design of the posture correction girdle in the present study and the bony structure of humans. In other words, the corrective forces from the adjustable shoulder straps can be directly exerted onto the bony points of the shoulders without the barrier of soft tissues. The postural improvements might also be attributed to posture training with the girdle, as it is believed that the back muscles of the subjects could be trained to keep the spine within a natural curvature, and thus prevent the corresponding imbalanced posture through awareness [8-9, 17]. It has also been considered that children's bodies are "moldable", which means that their body postures could be improved and trained by using different methods [18]. In this study, the posture correction girdle acts as a training device, which reminds the subjects to maintain a better and more balanced posture during the girdling period.

In regard to the results of the 3D body scanning, the postural changes are obvious as seen in Figure 3; however, the results are not statistically significant. The large standard deviation and small sample size might have led to this outcome. A large standard deviation indicates that the subjects have large individual differences. Since this is the case, a preliminary small statistical test was then carried out to determine whether if more homogenous subjects were recruited, the trend of the postural changes would be more obvious. In the preliminary test, 3 subjects with Cobb's angles (both the thoracic and lumbar curves) below 10° were assigned to Group 1, while 2 subjects with Cobb's angles (both thoracic and lumbar curves) more than 10° were assigned to Group 2, after referring to x-rays taken of the baseline. According to the results, the girdle is more likely to have a better effect on postural control for those in

Group 1 (Cobb's angle below 10°), in which a significant across time effect was found p = 0.008. In Group 1, the mean of the measurements was reduced from 2.6733 (0 month) to 2.27 (3 months) and to 0.7867 (6 months) across time when the girdle was not worn, due to the higher homogeneity and smaller standard deviation of the measurements. Therefore, by using the result of this preliminary test as an indicator for subject recruitment, subjects with a smaller Cobb's angle, i.e. 5-10°, should be recruited for similar wear trials in future studies.

Finally, the compliance of the subjects might have affected the success of the girdling for improving posture and reducing the possibility of spinal curve progression, as patient involvement is one of the key factors that affect the success of treatment [19-20]. With regard to the compliance of girdling in this study, Subjects 3 (100%) and 4 (100%) have the highest compliance, while Subjects 1 (62.5%) and 6 (52.25%) show the least compliance. These show that Subjects 3 and 4 wore the girdle for nearly double the time of Subjects 1 and 6. They also show that the subjects who achieve improvement of posture are relatively more compliant in the wear trial of the present study.

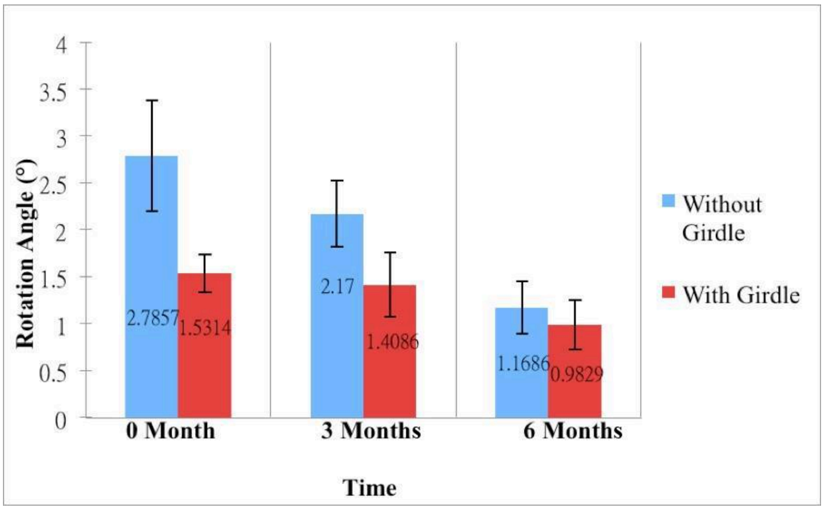


Figure 3 Changes in rotation angle (°) in horizontal plane from 0 to 6 months

5. Limitations and Future Studies

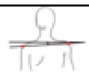
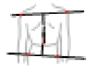
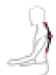
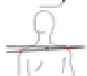
The effect of girdling and time on the changes in posture might be affected by a large standard deviation and small sample size. The standard deviation of the measurements decreases as homogeneity increases; therefore, subjects with a smaller Cobb's angle, i.e. 5-10°, should be recruited for similar wear trials in future studies. Also, some measurements show a trend of improvement, but not all demonstrate that the improvements are statistically significant. The specified length of time for the wear trial and small sample size might be possible factors that have affected the significance of the effects. Therefore, a longer wear trial period and a larger sample size are suggested for future related studies.

Table 2 Descriptive statistics and results of 2-ways repeated measures ANOVA test for motion capturing

Descriptive statistics (n=7)

Posture parameter	0 month (mean ±SD)		3 months (mean ±SD)		6 months (mean ±SD)	
	without girdle	with girdle	without girdle	with girdle	without girdle	with girdle
1)	3.386±1.440	1.706±0.691	2.117±1.007	1.373±0.862	1.564±0.805	1.292±0.872
2)	3.253±1.129	2.027±1.559	2.629±1.433	2.206±1.400	2.503±0.915	2.106±1.066
3)	2.376±1.332	1.477±0.467	2.091±0.061	1.999±0.750	1.978±0.575	1.833±0.581
4)	3.163±3.152	2.890±2.795	2.383±2.084	2.233±2.342	2.207±2.335	2.107±2.328
5)	4.457±3.142	4.487±3.119	4.091±2.433	4.121±3.584	3.617±3.356	3.490±3.710
6)	1.786±1.626	1.644±1.320	1.824±1.641	1.731±0.976	1.583±1.140	1.450±1.006
7)	2.563±2.074	3.209±2.498	2.514±1.704	2.544±1.914	2.536±1.628	2.437±1.817
8)	3.974±2.337	3.914±2.550	3.694±1.830	2.673±1.649	3.051±2.054	2.507±1.744
9)	151.567±6.553	153.117±6.464	153.734±5.986	154.223±5.266	155.818±5.262	156.899±5.671
10)	162.225±12.283	172.020±1.980	167.016±7.375	171.950±3.324	168.136±4.536	172.086±3.832
11)	10.343±1.852	8.863±1.848	9.776±2.504	9.653±3.253	8.746±2.004	7.890±2.564
12)	9.650±1.824	8.409±2.818	9.050±1.834	7.839±1.338	8.347±1.978	7.147±1.105
13)	22.493±7.340	18.774±4.793	19.156±4.589	17.339±5.279	18.381±4.699	17.246±4.102
14)	18.510±4.320	17.571±3.512	17.036±3.170	17.746±4.291	16.161±3.696	16.127±4.535
15)	84.717±28.133	75.057±18.860	80.547±24.846	73.524±21.130	80.589±25.208	74.866±23.430
16)	41.951±6.487	29.716±6.063	42.393±7.210	30.504±4.844	43.403±7.913	32.566±5.588

Results of 2-ways repeated measures ANOVA test

Posture parameter^		Effect	F	Hypothesis df	Error df	Sig.*
1) Standing FP		Time	8.409	2	12	0.005*
- Acromion (°)		Girdling	6.083	1	6	0.049*
Markers: LSHD, RSHD		Time*Girdling	7.856	2	12	0.007 *
2) Standing FP		Time	3.032	2	12	0.086
- Pelvis (°)		Girdling	4.504	1	6	0.078
Markers: LASI, RASI		Time*Girdling	4.096	2	12	0.044*
3) Standing FP		Time	1.636	2	12	0.235
- Acromion/Pelvis (°)		Girdling	13.467	1	6	0.010*
Markers: LSHO, RSHO, LASI, RASI		Time*Girdling	0.220	2	12	0.805
9) Sitting SP		Time	4.270	2	12	0.040*
- Thoracic Angle (°)		Girdling	24.022	1	6	0.003*
Markers: C7, T7, L4, SACR		Time*Girdling	0.021	2	12	0.979
10) Sitting SP		Time	1.856	2	12	0.198
- Lumbar Angle (°)		Girdling	4.186	1	6	0.087
Markers: C7, T7, L4, SACR		Time*Girdling	5.111	2	12	0.025*
11) Walking FP		Time	4.449	2	12	0.036*
- Acromion (°)		Girdling	0.999	1	6	0.356
Markers: LSHD, RSHD		Time*Girdling	1.450	2	12	0.273
15) Bending FP		Time	0.445	2	12	0.651
- Maxi. Anterior Bending		Girdling	2.264	1	6	0.183
Markers: C7, SACR		Time*Girdling	6.021	2	12	0.015*
16) Bending HP		Time	0.456	2	12	0.645
- Maxi. Lateral Bending		Girdling	2.228	1	6	0.186
Markers: LSHO, RSHO, LASI, RASI		Time*Girdling	27.411	2	12	0.000*

Results of post-hoc test for the effect of time

Posture parameter^	Item	Mean difference	Std. Error	Sig. (2-tailed)*
1) Standing FP	**Pair 1: 0 vs. 3 months**	0.744	0.252	0.076
- Acromion (°)	**Pair 2: 3 vs. 6 months**	-0.070	0.187	1.000
Markers: LSHD, RSHD	**Pair 3: 0 vs. 6 months**	0.674	0.149	0.012*
11) Walking FP	**Pair 1: 0 vs. 3 months**	1.194	0.511	0.175
- Acromion (°)	**Pair 2: 3 vs. 6 months**	-0.029	0.542	1.000
Markers: LSHD, RSHD	**Pair 3: 0 vs. 6 months**	1.165	0.266	0.014*

^FP: Frontal plane; HP: Horizontal plane; SP: Sagittal plane

$*p < 0.05$

The data are continuous data, but due to small sample size, may not be representative enough and cannot be normally distributed.

6. Conclusion

In this study, a posture correction girdle is found to contribute to postural changes in the subjects after a 6-month wear trial. Significant improvements are mainly found on the acromion as observed from the frontal and horizontal planes during standing, the back as observed from the sagittal plane during sitting, and there is an acceptable constrained range of anterior and lateral bending. Moreover, there is no statistically significant difference found in the results of the rotation angle in the horizontal plane after analysis is carried out with data from 3D body scanning due to the large standard deviation and small sample size. Compliance, growth and curve type might be factors that affect the effectiveness of this girdle on postural changes.

7. Funding

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