Effect of Biomechanical Feedback Device Utilizing Tilt and Tension Sensors on Young Adults Balance Control Ability, Proprioception and Craniovertebral Angle (CVA)

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Abstract

Introduction: Due to the continuous development of technology, smartphones have become an essential part of our daily lives. These devices offer us convenient access to information and communication, but they also contribute to poor posture, characterized by bending the neck and shoulders forward. This poor posture can lead to reduced physical activity and muscle imbalances, ultimately resulting in kyphosis of the back.

Objectives: The purpose of this study is to investigate the effect of a biofeedback device using a tilt sensor and a tension sensor on balance control ability, proprioception, and craniovertebral angle(CVA) in young adults.

Methods: The 10 subjects participated 3 times. Before the start of the experiment, the height, sitting height, weight, CVA, balance control ability, proprioception of the subjects were measured. The tilt sensor, tension sensor, and tilt + tension sensor interventions were conducted for 30 minutes each. Experiments were conducted at intervals of one day.

Results: As a result of measuring balance control ability according to tilt, tension, and tilt + tension, there was no significant improvement in all three groups. Repositioning errors were significantly improved after intervention in the tension group and the tilt + tension group in extension cervical joint position error(JPE)($p<0.05$). In right rotation, only the tension group showed significant improvement ($p<0.05$). The CVA improved significantly in all three groups after intervention ($p<0.05$).

Conclusions: In conclusion, both biofeedback devices prevent thoracic kyphosis, positively affecting the CVA. Among them, biofeedback using tension can have a positive effect on the proprioception of the neck.

Keywords: Tilt Sensor, Tension Sensor, Balance Control Ability, Proprioception, Craniovertebral Angle(CVA)

1. Introduction

Due to the continuous development of technology smartphones have now become an indispensable element in our daily lives [1]. Smartphones are tools that provide us with convenient access to information, communication and bending the back and neck, and tilting or bending the shoulder forward [2]. Poor posture can lead to reduced activity and muscle imbalance, resulting in a thoracic kyphosis [3]. A thoracic kyphosis is a posture in which the waist and back are excessively bent forward, which puts a strain on the spine and muscles, and can reduce postural stability and proprioception.

Studies have shown that a thoracic kyphosis is closely related to proprioception [3, 4, 5]. Proprioception is the ability to recognize and control the balance of our body. In a study of thoracic kyphosis, the ability to perceive body posture and control movements has decreased due to reduced proprioceptive sensitivity [5]. In addition a thoracic kyphosis can make movement control and regulation difficult due to postural changes. Therefore enhancing proprioceptive sensitivity is crucial for alleviating a thoracic kyphosis [5].

According to recent studies, biofeedback training is being used to improve proprioception [6, 7]. Biofeedback is a term used in biology and refers to the ability to maintain a certain degree of result at all times by allowing a result to control the strength of a cause [8]. However, new technologies such as smart bio artificial intelligence

(AI), big data, Internet of Things, cloud, and nano are converged. With a new concept, individuals can easily receive health care anytime, anywhere, going further than the existing healthcare area. This is a field that is getting a lot of attention [9, 10, 11].

Biofeedback is used as a way to relieve a thoracic kyphosis [11]. It is mainly a visual feedback method that improves posture and has various effects [12]. However, this has the downside of having to set aside time to exercise. In order to solve this drawback, biofeedback devices have been developed, and biofeedback devices using tilt are representative [13]. The tilt sensor is used to measure the inclination angle or inclination of an object, and collects data by detecting changes in posture or motion [13].

However, it is difficult to accurately determine individual factors such as people's various heights and weights with only the tilt sensor. Therefore, this study plans to conduct an experiment by comparing the tilt sensor and the tension sensor. In the case of the tension sensor, it provides information related to muscle tension or tension of other muscles, making up for the difficulty of understanding only the tilt sensor [14]. Therefore, it is expected that a comprehensive biofeedback system using this will be able to solve posture problems more accurately and in a personalized manner.

Although there are many studies using biofeedback for thoracic kyphosis, there are not so many studies that have verified the effect using biofeedback equipment. Therefore, we want to verify the effectiveness of biofeedback equipment through experiments. Therefore, the purpose of this study is to investigate the effect of a biofeedback device using a tilt sensor and a tension sensor on balance control ability, proprioception, and craniovertebral angle(CVA) in young adults.

2. Materials and Methods

2.1 Participants

This study conducted an experiment with 10 men and women in their 20s and 30s residing in Asan, Korea. Ten subjects completed the final study without dropouts.

The selection criteria for study subjects were as follows: Subjects with no history of neck and shoulder surgery within 3 months, no cervical disc diagnosis, and no pathological conditions in cardiopulmonary function were included. Before the experiment, the purpose and procedures of the study were explained to all subjects, and they voluntarily signed a consent form.

Table 1. General subject characteristics(N=10).

Variable	Mean± SD
Age(year)	24.40±3.17
Height(cm)	170.90±8.80
Weight(kg)	68.99±16.55
Sex(M/F)	7/3

Data are expressed as means ± standard deviations. SD standard deviation.

2.2 Experimental Procedure

In all trials, the subjects were guided to practice before the experiment so that they could get used to the experiment and participate comfortably. The 10 subjects participated 3 times. The tilt biofeedback, tension biofeedback, and tilt + tension biofeedback interventions were conducted for 30 minutes each. Before the start of the experiment, the height, sitting height, and weight of the subjects were measured, and the effects before and after the intervention were compared by evaluating the forward head posture, balance control ability, and neck and head proprioceptive ability. In order to reduce the influence and bias between interventions, the next experiment was conducted at intervals of one day, and the order of intervention was randomly determined for each subject.

2.3 Tilt Sensor

The tilt biofeedback device consisted of a wireless tilt sensor and an Arduino microcontroller (Arduino, Arduino.cc, Italy), and was manufactured in a size of 8x16cm². It is designed to measure the inclination of the wearer's neck and back so that when they bend forward, they can immediately sit with your back straight through a sound. The device is attached to the T2 and T3 vertebrae and is set to sound when the neck and back are tilted more than 18°. The tilt was set to 0° relative to the line of gravity. The subject wore the biofeedback device for 30 minutes and performed typing tasks while gazing at the monitor [Figure 1].

Figure 1

Fig. 1. Tension Sensor. The tension that is pulled in the vertical direction when the subject's neck and back angle are bent forward

2.4 Tension Sensor

As for tension (TAS501, HT Sensor Technology Co Ltd, USA), participants were induced to assume an upright sitting posture through sound by measuring the tension that is pulled in the vertical direction when the subject's neck and back angle are bent forward. The device is placed between T2-T5 vertebrae and is set to sound when it senses a tension of 1.5 kg or more. The subjects were instructed on how to use the tension device and then performed computer tasks for 30 minutes [Figure 2].

Figure 2

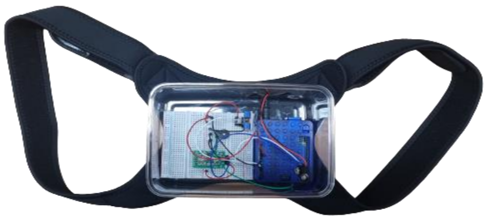

Fig. 2. Tilt Sensor. The tilt biofeedback device consisted of a wireless tilt sensor and an Arduino microcontroller

2.5 Forward Head Posture

CVA was assessed using lateral photographs of subjects standing. To minimize picture distortion, a default camera application (Samsung, Korea) on a smartphone (Galaxy S23 Ultra, Samsung, Korea) was used with vertical and horizontal guidelines set, and images were taken at 1x magnification. A sticker was attached to the 7th cervical vertebra (C7) of subjects, who were then instructed to perform three repetitions of neck flexion and extension and then return to neutral posture [15]. While taking photographs, the subjects kept a distance of 1 meter from the smartphone. CVA was measured using Image J (National Institutes of Health, USA). CVA was defined as the angle formed by the line connecting the tragus of the ear to the C7 vertebra and the horizontal line passing through the C7 vertebra [15,16].

2.6 Balance Control Ability

A Tetrax(Sunlight Medical Ltd., Israel) was used to measure balance control ability. This instrument evaluates fall risk and has four force plates that measures vertical pressure changes at the toes and heels and vibrations transmitted to the feet. The subjects were instructed to stand barefoot on the instrument, maintain an eyes-open posture (normal eyes open, NO), and concentrate on a sticker positioned in front of the Tetrax. They were then asked to repeat the procedure with their eyes closed (normal eyes closed, NC). Pressure changes were measured for 32 seconds under each condition, and stability index (SI, a measure of degree of postural sway on the four force plates) and weight distribution index (WDI, a measure of weight distribution on the four force plates) were provided by the instrument smaller SI and WDI values indicate a more stable state [17,18].

2.7 Joint Position Error Test

The Cervical Joint Position Error (JPE) test was conducted to evaluate the proprioceptive ability of the neck and head. The subject sat on a chair with a backrest 90 cm away from the target and wore a helmet with a laser attached to the head. After aligning the laser at the center of the target with the head straight, they were instructed to close their eyes and bend their necks as much as possible away from the target to accurately return to the zero position [19]. The subject had time to practice only once, and the measurement was conducted 5 times, and the average value obtained through the calculation formula was used [Figure 3]. After the bending posture, maximum neck extension, left rotation, and right rotation were performed. An error of less than 4.5 degrees or less than 7 cm is considered normal, and a joint position error of more than 4.5 degrees is considered abnormal [20,21].

Figure3

$$\text{Angle} = \tan -1\ [\text{error distance}/90\ \text{cm}]$$

Fig. 3. Fourmla. cervical JPE was calculated using the formula

2.8 Statistical Analysis

SPSS for Windows (version 29.0) was used for data analysis in this study. The Kruskall Wallis test was used for comparison between the three groups, and the Mann Whitney U-test was used for post hoc. The Wilcoxon signed rank test was used for the before-and-after comparison within the group. The statistical significance level was set at α = .05.

Figure4

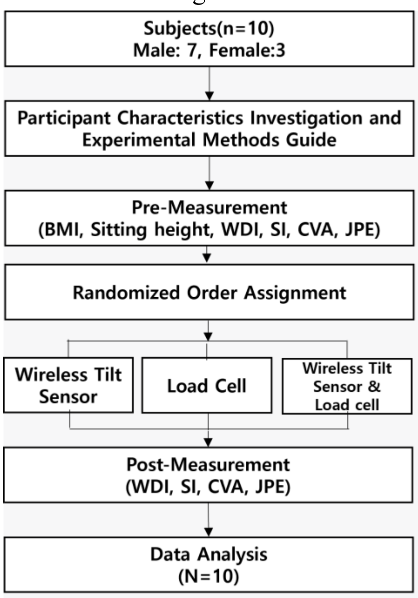

Fig. 4. Flow Chart. Flow of research method

3. Results

As a result of measuring balance control ability according to tilt, tension, and tilt + tension, there was no significant improvement in all three groups.

Table 2. Comparison of balance control abilities.

		Tilt	Tension	Tilt+Tension	χ2	p
NO WDI	Pre	5.97±3.48	6.22±3.36	6.15±3.17	0.126	0.939
	Post	5.11±2.43	5.86±3.51	6.11±3.49	0.204	0.903
	Z	-1.376	-0.051	-0.255		
	P	0.169	0.959	0.799		
NC WDI	Pre	5.18±3.60	5.45±3.24	5.63±3.62	0.217	0.897
	Post	4.54±2.73	5.64±3.51	5.59±3.26	0.699	0.705
	Z	-0.866	-0.866	-0.051		
	P	0.386	0.386	0.959		
NO SI	Pre	14.88±7.35	15.05±7.29	15.31±6.61	0.065	0.968
	Post	14.84±7.82	16.34±6.88	16.28±7.73	0.699	0.705
	Z	-0.663	-0.663	-1.070		
	P	0.508	0.508	0.285		
NC SI	Pre	17.64±6.04	17.76±7.31	18.08±6.29	0.049	0.976
	Post	19.01±6.16	19.48±6.43	17.43±6.46	0.637	0.727
	Z	-1.682	-0.866	-0.459		
	P	0.093	0.386	0.646		

*p<0.05; (Mean±SD)
*NO, normal eyes open; NC, normal eyes closed; WDI, weight distribution index; SI, stability index.

JPE values were significantly improved after intervention in the tension group and the tilt + tension group in extension cervical JPE ($p<0.05$). In right rotation, only the tension group showed significant improvement ($p<0.05$).

Table 3. Comparison of proprioception in neck movements.

		Tilt	Tension	Tilt+Tension	χ2	p
Flexion JPE	Pre	3.81±1.72	3.76±1.56	2.98±1.45	1.628	0.443
	Post	3.60±1.86	2.84±1.40	3.61±1.80	1.373	0.503
	Z	-1.000	-1.274	-1.481		

	P	0.317	0.203	0.139		
Extension JPE	Pre	4.12±0.98	3.65±1.74	3.89±1.28	0.808	0.668
	Post	3.72±1.51	2.54±1.45	2.91±0.82	9.530	0.009*
	Z	-1.000	-2.701	-2.293	post hoc	Tilt>Tension =Tilt+Tension
	P	0.317	0.007*	0.022*		
Right rotation JPE	Pre	3.46±1.28	3.19±1.27	2.89±1.26	0.581	0.748
	Post	3.29±1.07	2.54±1.45	3.03±1.21	2.000	0.368
	Z	-1.000	-1.988	-0.153		
	P	0.317	0.047*	0.878		
Left rotation JPE	Pre	3.36±1.51	2.95±1.17	3.39±1.63	0.867	0.648
	Post	3.97±1.46	2.95±1.36	3.46±1.14	0.816	0.665
	Z	-1.000	-0.357	-0.866		
	P	0.317	0.721	0.386		

*p<0.05; (Mean±SD); cervical JPE, cervical joint position error.

The CVA improved significantly in all three groups after intervention (p<0.05).

Table 4. Comparison of CVA.

		Tilt	Tension	Tilt+Tension	χ2	p
CVA	Pre	52.14±4.70	52.80±5.29	52.56±4.25	0.348	0.840
	Post	53.40±5.08	54.40±5.52	53.50±4.49	0.010	0.995
	Z	-2.456	-2.039	-3.299		
	P	0.014*	0.041*	0.001*		

**p<0.05; (Mean±SD); CVA, craniovertebral angle.

4. Discussion

In this study, the effects of a biofeedback device using a tilt sensor and a tension sensor on the balance control ability, proprioception, and CVA of normal adults were investigated. Since balance control ability and CVA are closely related to thoracic kyphosis, the effect was verified using a biofeedback device. Accordingly, it is intended to provide the effect of a biofeedback device using a tilt sensor and a tension sensor on balance control ability, proprioception, and CVA in young adults.

There was no significant improvement in balance control ability in all three groups. Balance control ability refers to the ability to control body sway within a certain range [22]. Sway directly affects the ability to control balance. When sway occurs, the stability of the body decreases due to irregular muscle movements, which can make it difficult to maintain balance. Therefore, sway and balance control ability are two important functions that interact, and the harmonious action between them is important. To this end, sway is controlled through continuous movement, which is controlled through proprioception and active muscle movement [21].

Since biofeedback device sends signals only within a certain range, it is smaller than the range of angles in which proprioception works, and the frequency of activation is naturally low [23]. The action of this biofeedback can play a role in preventing errors from occurring, ensuring that proprioceptive ability stays within a certain level or range. However, it should be noted that it cannot function to the extent of completely replacing proprioceptive ability. For this reason, it is thought that the balance control ability after training was not improved through the biofeedback device, which is the result of our study.

In this study, proprioception was evaluated using a cervical JPE. Regarding cervical JPE, better proprioception is indicated by a smaller error between the initial posture and the repositioning [24]. As a result of this experiment, cervical JPE values were significantly improved in the tension group and the tension + tilt group. According to Lee et al., higher errors appeared in the group with forward head posture compared to the group without forward head posture. Cervical JPE tests in all motions (flexion, extension and rotation) showed significant differences between the two groups. This means that forward head posture adversely affects joint position sense [25]. Lee et al. reported that the more severe the forward head posture, the worse the sense of joint position [27]. De Vries et al. conducted a systematic review including 14 studies, and cervical JPE was significantly higher in the neck pain group than in the healthy group [26]. According to the study by Yong et al., the CVA and cervical JPE was investigated to identify the correlation between head posture and proprioceptive function [28]. As a result, a negative correlation was observed between CVA and cervical JPE. This means that forward head posture is related to proprioception [27].

Xu et al., wearable biofeedback was used for 6 healthy elderly people, and it was found that the proprioception was improved through the biofeedback system. The results of this study suggest that the biofeedback device has a positive effect on proprioception, which can be presented as evidence to support the claim of our thesis [29].

In this study, proprioception was improved only in the tension group, which means that in the case of the tilt sensor, an alarm sounds when it exceeds a certain range, but it does not directly limit movement beyond the range. However, in the case of the tension group, it is judged that this part made a difference from the tilt group because there are some parts that are physically limited by the tension sensor.

The CVA was significantly improved in all three groups after intervention. In Stuart et al.'s study, body alignment was measured in 25 patients with Parkinson's disease using a biofeedback device similar to that used in this study. It has been reported that tilt sensor biofeedback tends to reduce neck tilt and correct head posture [30]. According to Fernandez et al., subjects with a small CVA value were found to exhibit more severe forward head posture and were more likely to suffer from chronic tension-type headaches [31].

According to Elliott's study, the participants' CVA improved after using the biofeedback device [32]. Also, according to the study by Paul et al., 6 people were divided into a 5-hour biofeedback group and a group that did not use biofeedback, and the experiment was conducted. As a result, the CVA increased more in the group that received biofeedback than in the group that did not receive biofeedback [33]. In the case of Paul et al. and Elliott's study, not only the CVA was selected as a subject of less than 50 degrees, but also the application of the intervention was similar to this experiment, supporting our study results. This means that when a thoracic kyphosis exceeds a certain range, the biofeedback device gives a warning and corrects the posture as much as possible, which has a good effect on the CVA.

The results of this study will be helpful as basic data for treating musculoskeletal disorders related to abnormal neck position using a biofeedback device. In addition, the limitation of this study is that the number of subjects is restricted and the intervention period is short, and future studies should be conducted to verify long-term effects by increasing the number of subjects and the intervention period.

5. Conclusion

In conclusion, both biofeedback devices prevent thoracic kyphosis, positively affecting the CVA. Among them, biofeedback using tension can have a positive effect on the proprioception of the neck.

Ethical Considerations

The study was conducted according to the guidelines of the Declaration of Helsinki, and ap-prroved by the Institutional Review Borad of Sunmoon University (No. SM-202303-007-3). Ethical issues regarding plagiarism informed consent, misconduct, data fabrication and/or flasi-fication, double publication and/or submission, and redundancy have been completely observed by the authors.

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