Journal of Magnetics 30(4), 645-650 (2025)
ISSN (Print) 1226-1750
ISSN (Online) 2233-6656
https://doi.org/10.4283/JMAG.2025.30.4.645

Effects of Tilt Sensor-Based Biofeedback Training and Repetitive Peripheral Magnetic Stimulation on Cervical Joint Position Sense and Craniovertebral Angle in Young Adults

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(Received 13 November 2025, Received in final form 4 December 2025, Accepted 5 December 2025)

The aim of this study was to investigate the short-term effects of repetitive peripheral magnetic stimulation (rPMS) and tilt-sensor biofeedback training on cervical proprioception and craniovertebral angle (CVA) in young adults. Fifteen healthy participants (13 male and 2 female) from K University were randomly assigned to either the rPMS or the biofeedback group. The rPMS intervention was applied to the upper trapezius using a magnetic stimulation device (G-500, Stratek, Korea) for 20 minutes at 1 Hz, with stimulation delivered for 10 seconds followed by 5 seconds of rest. The biofeedback group performed 30 minutes of posture training using a tilt-sensor device that emitted an auditory cue when the head deviated from neutral alignment. Cervical proprioception was evaluated using joint position error (JPE) during flexion, extension, and left–right rotation tasks, and CVA was measured using ImageJ analysis from lateral-view photographs. No significant pre–post changes in CVA were observed in either group ($p > 0.05$). In contrast, the rPMS group demonstrated a significant reduction in flexion JPE ($p < 0.05$), indicating improved proprioceptive accuracy following the intervention. The biofeedback group showed a significant improvement in left-rotation JPE ($p < 0.05$), whereas the other directions demonstrated non-significant trends toward improvement. These findings suggest that rPMS enhances proprioception by increasing afferent sensory input and neuromuscular activation, while tilt sensor biofeedback promotes postural awareness and motor learning. Overall, both interventions showed selective benefits for cervical proprioception. However, changes in global postural alignment were not evident after a single session. rPMS and biofeedback training may serve as valuable early rehabilitation strategies for addressing proprioceptive deficits in individuals exhibiting early signs of forward head posture (FHP).

Keywords : biofeedback training, craniovertebral angle (CVA), forward head posture (FHP), joint position error (JPE), proprioception, repetitive peripheral magnetic stimulation (rPMS)

1. Introduction

The prevalence of forward head posture (FHP) has increased markedly with the widespread use of smartphones and computers. FHP causes anterior displacement of the head's center of gravity, resulting in cervical and scapular muscle imbalance, spinal misalignment, and impaired respiratory function [1, 2]. Prolonged smartphone use has been reported to decrease the craniovertebral angle (CVA), which leads to greater cervical lordosis and postural instability [1]. In addition, FHP is closely associated with neck and shoulder muscle fatigue, reduced cervical muscle endurance, and weakened postural control ability [3, 4]. Therefore, FHP is not merely a postural deviation but a clinically important condition that can cause musculoskeletal dysfunction and impaired sensory integration [4].

The anterior shift of body mass in FHP induces biomechanical changes such as increased trunk flexion during gait and compensatory movements in the lower extremity joints [4, 5]. Consequently, the cervical extensors remain in a state of overactivation, whereas the deep neck flexors become weakened, creating a muscular imbalance [2, 3]. These changes ultimately cause muscle fatigue and reduced postural stability, and prolonged imbalance can lead to deterioration of proprioception [4]. In other words,

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FHP involves not only structural musculoskeletal imbalance but also functional disturbance of the sensorimotor feedback system.

Proprioception plays a key role in sensing body position and movement, which are essential for postural control and balance [6]. The cervical region serves as a central hub for postural regulation, where afferent signals from muscle spindles and joint receptors integrate with visual and vestibular inputs to maintain static and dynamic equilibria [7]. In FHP, the efficiency of these sensory pathways decreases, reducing the accuracy of cervical joint position sense (JPS) and consequently diminishing postural and balance control [3, 8]. Patients with FHP also demonstrate slower and less accurate postural-correction responses than healthy individuals [7]. Hence, restoring cervical proprioception has been emphasized as a key component of FHP rehabilitation [6].

Recently, repetitive peripheral magnetic stimulation (rPMS) has gained attention as an intervention for enhancing cervical proprioception. rPMS is a non-invasive technique that stimulates muscle spindles and motor nerves through electromagnetic induction, thereby reducing muscle tension and increasing afferent sensory input [9]. This stimulation modulates cortical excitability, promotes neuroplasticity, and strengthens sensorimotor integration [10]. Clinically, rPMS has shown positive effects on pain relief, functional recovery, and balance control in patients with myofascial neck and lower back pain [10]. Thus, rPMS is considered a promising intervention for correcting muscle imbalances and proprioceptive deficits associated with FHP.

Biofeedback training, on the other hand, provides real-time sensory feedback that allows individuals to recognize and voluntarily control their posture or muscle activity [11]. Tilt-sensor-based biofeedback devices detect head or trunk inclinations and deliver visual or auditory cues, enabling immediate awareness and correction of improper posture. These devices have been reported to improve postural awareness, reduce muscle tension, enhance CVA, and alleviate pain [12]. However, previous studies have mainly focused on the independent effects of each device, and few have directly compared or combined rPMS and biofeedback interventions [6].

Therefore, the aim of this study was to compare the short-term effects of rPMS and tilt-sensor-based biofeedback training on cervical joint position error (JPE) and CVA in young adults. By analyzing the differences between these two interventions, this study sought to provide foundational evidence for developing effective rehabilitation programs that target cervical proprioception and postural correction.

2. Materials and Methods

2.1. Study Participants

Fifteen healthy young adults (13 male and 2 female) in their twenties who were enrolled at K University in Chungcheongbuk-do, South Korea, were recruited.

All participants were free from physical or psychological disorders and had no history of neck pain or orthopedic treatment within the previous six months.

The purpose and procedures of the study were fully explained to all participants before participation, and written informed consent was obtained.

The participants' mean age was 22.1 ± 2.0 years, mean height 172.4 ± 5.3 cm, mean body weight 72.1 ± 12.3 kg, and mean body mass index (BMI) 24.3 ± 3.2 kg/m².

All procedures were approved by the Institutional Review Board (IRB) of Sunmoon University (approval number: SM-202303-007-3).

2.2. Experimental Design

A pre–post comparative design was used. The participants were randomly assigned to either the biofeedback group (n = 9) or the magnetic stimulation group (n = 8). Both groups underwent identical pre- and post-intervention assessments conducted by the same examiner, including measurements of the CVA and JPE.

2.3. Measurement Tools and Evaluation Methods

2.3.1. Craniovertebral Angle (CVA)

The CVA was assessed to quantify the degree of FHP. Each participant was instructed to stand in a relaxed, natural position, and a lateral-view photograph of the right side was taken. The images were analyzed using ImageJ software (National Institutes of Health, USA). The angle between the line connecting the tragus of the ear and the spinous process of the seventh cervical vertebra (C7) and a horizontal reference line was measured. A smaller angle indicated a more pronounced FHP.

2.3.2. Joint Position Error (JPE)

Cervical proprioceptive accuracy was evaluated by measuring the JPE. The participants wore a laser pointer attached to their head, which projected onto a target positioned 90 cm in front of them. They performed flexion, extension, and left/right rotation movements from a neutral position and then returned to the neutral position. The deviation distance (cm) between the laser point and the target was recorded and converted into an angular error (°) using the following formula:

Fig. 1. (Color online) Magnetic field therapy device (G-500, Stratek, Korea), used to apply rPMS to the upper trapezius at 1 Hz (10-s stimulation, 5-s rest cycles).

$$\mathrm{JPE}(^{\circ}) = \tan^{-1}\left(\frac{\text{error distance (cm)}}{90}\right) \quad (1)$$

A smaller error value indicated greater proprioceptive accuracy.

2.3.3. Magnetic Stimulation Intervention

rPMS was applied to the upper trapezius muscle using a magnetic therapy device (G-500; Stratek, Korea). Stimulation was delivered at 1 Hz, with 10 seconds of stimulation followed by 5 seconds of rest, repeated for 20 minutes. The stimulation intensity was set to approximately 70–80 % of the maximum output, which was sufficient to elicit visible muscle contraction. The detailed configuration of the magnetic stimulation device is shown in Fig. 1.

2.3.4. Biofeedback Intervention

A tilt-sensor-based postural biofeedback device was used for the biofeedback intervention. The sensor module was attached to the participant's forehead, and neutral alignment was defined as positioning the head in a comfortable upright posture with the external auditory meatus vertically aligned with the acromion. The device was programmed to emit an auditory signal when the head deviated more than 18° anteriorly from the neutral position, prompting immediate postural correction. The participants wore the device for 30 minutes and underwent postural awareness and correction training aimed at maintaining proper cervical alignment. A photograph of the biofeedback device used is shown in Fig. 2.

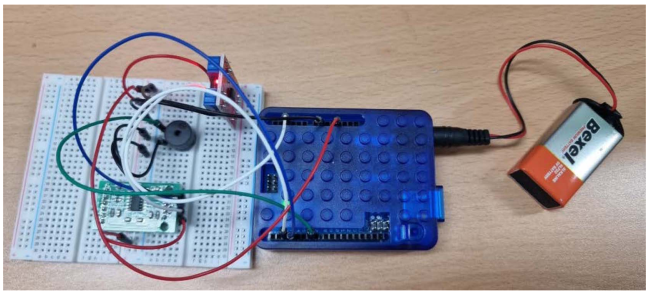

Fig. 2. (Color online) Tilt-sensor–based biofeedback device used for posture training.

2.4. Statistical Analysis

All data were analyzed using SPSS Statistics 26.0 (IBM Corp., USA). The normality of the data distribution was assessed using the Shapiro–Wilk test. Within-group pre- and post-intervention comparisons were performed using a paired t-test, and between-group differences were analyzed using an independent t-test. The statistical significance level for all tests was set at $\alpha = 0.05$.

3. Results

A total of fifteen participants completed the study, and no dropouts or adverse events occurred during the intervention period.

No statistically significant changes were found in the CVA in either group ($p > 0.05$, Table 1).

Table 1. Changes in Craniovertebral Angle (CVA) before and after intervention.

Group	Pre (°, Mean ± SD)	Post (°, Mean ± SD)	ΔChange	p-value (within group)
Biofeedback (n=9)	54.23 ± 3.21	54.45 ± 3.12	+0.22 ± 0.18	0.212
Magnetic (n=8)	55.12 ± 2.98	55.37 ± 2.76	+0.25 ± 0.22	0.188

Values are presented as mean ± standard deviation (°). ΔChange indicates the mean difference between pre- and post-intervention values. No significant differences were observed within groups ($p > 0.05$). CVA, craniovertebral angle.

Table 2. Changes in Joint Position Error (JPE) before and after intervention.

Motion	Group	Pre (°, Mean ± SD)	Post (°, Mean ± SD)	ΔChange	p-value (within group)
Flexion	Biofeedback	5.12 ± 1.31	4.86 ± 1.29	−0.26 ± 0.22	0.082
	Magnetic	5.47 ± 1.42	4.53 ± 1.15	−0.94 ± 0.37	0.021*
Extension	Biofeedback	5.78 ± 1.28	5.60 ± 1.20	−0.18 ± 0.15	0.313
	Magnetic	5.85 ± 1.35	5.31 ± 1.27	−0.54 ± 0.28	0.067
Left Rotation	Biofeedback	5.44 ± 1.19	4.73 ± 1.10	−0.71 ± 0.25	0.038*
	Magnetic	5.29 ± 1.24	4.85 ± 1.13	−0.44 ± 0.18	0.094
Right Rotation	Biofeedback	5.32 ± 1.26	5.04 ± 1.19	−0.28 ± 0.21	0.163
	Magnetic	5.44 ± 1.30	5.07 ± 1.17	−0.37 ± 0.22	0.074

Values are presented as mean ± standard deviation (°); *p < 0.05 indicates a significant difference between pre- and post-intervention within the group.

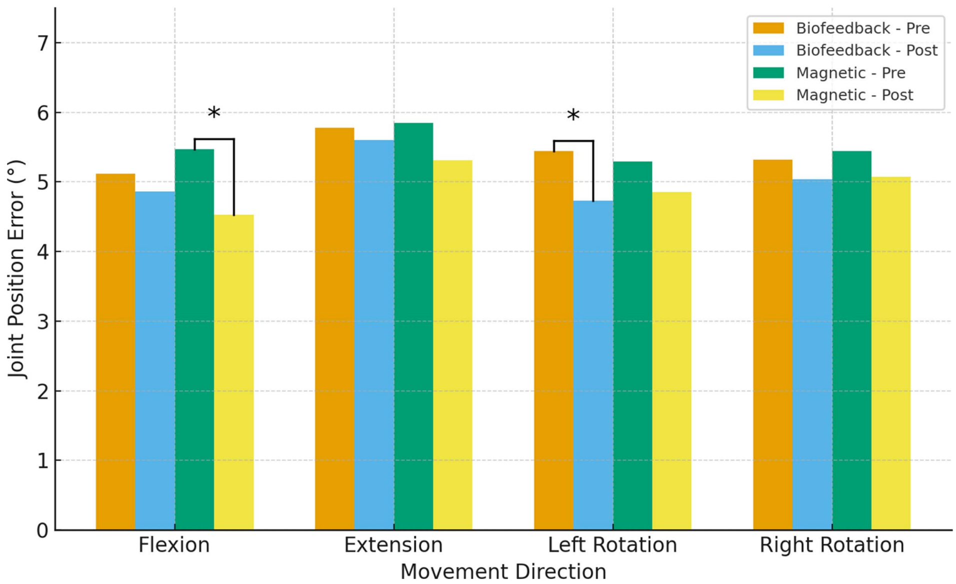

Fig. 3. (Color online) Comparison of joint position error (JPE) before and after intervention in the Biofeedback and Magnetic groups.

As shown in Table 2 and illustrated in Fig. 3, the magnetic stimulation group demonstrated a significant reduction in JPE during flexion after the intervention ($p < 0.05$). In the biofeedback group, a significant improvement in JPE was observed during left rotation ($p < 0.05$), as also confirmed in Table 2 and Fig. 3.

4. Discussion

In this study, the short-term effects of tilt-sensor-based biofeedback training and rPMS on cervical JPE and CVA in young adults were compared. The magnetic group showed a significant reduction in JPE during flexion, indicating improved cervical proprioception, while the biofeedback group exhibited partial improvement only in left rotation. Neither group showed significant changes in CVA. These findings suggest that rPMS may directly influence sensory input and neuromuscular regulation over a short period, whereas biofeedback training facilitates gradual improvement in postural awareness through repeated learning processes.

rPMS depolarizes motor nerves and muscle spindles via electromagnetic induction, increasing afferent sensory input from peripheral receptors and activating sensory integration within the central nervous system [10]. This enhanced sensory input regulates cortical excitability and sensorimotor integration, thereby improving proprioceptive accuracy [10, 13, 14]. Because rPMS was applied to the upper trapezius, one of the primary stabilizers engaged during cervical flexion, the intervention may have preferentially enhanced proprioceptive sensitivity in this direction. Flexion tasks generally show higher spindle sensitivity, which may explain why improvements were more prominent in this movement [15]. These muscles are involved in postural stability and movement precision, and rPMS increases the sensitivity of muscle spindles, thereby strengthening proprioceptive feedback. Previous studies have similarly reported that magnetic stimulation enhances muscle spindle sensitivity and proprioceptive afferent pathways, thereby improving body position awareness and postural control in both cervical and limb regions [10, 14, 15]. Therefore, the improvement in proprioception observed in this study may be attributed to rPMS-induced neuroplastic enhancement of the sensory–motor circuit.

Biofeedback training is a non-invasive intervention that enhances intrinsic sensory perception and promotes sensorimotor learning by allowing individuals to recognize postural deviations in real time [11, 16]. Although such devices provide immediate postural information and increase postural awareness, a single 30-minute session may be insufficient to produce significant improvements in proprioceptive function. Lee *et al*. (2023) applied a tilt-sensor-based biofeedback device for FHP correction and reported significant increases in CVA and decreases in JPE after more than two weeks of continuous training [12]. Similarly, Ashfaq and Riaz (2021) demonstrated that four weeks of pressure biofeedback training improved deep cervical flexor endurance and muscle activation [17]. These findings indicate that proprioceptive learning occurs gradually through repetitive sensory feedback and cumulative neural adaptation. Hence, the absence of significant short-term effects in this study may reflect the time-dependent nature of proprioceptive reeducation. Future studies should, therefore, incorporate long-term, task-specific sensorimotor integration programs to better evaluate the sustained effects of biofeedback [18].

Participants in this study were young adults with mean CVA values ranging from 52° to 57°, which falls within the normal range. Previous studies classified CVA values greater than 50° as normal, 45°–50° as mild FHP, and less than 45° as moderate to severe FHP [19–23]. Titcomb *et al.* (2024) reported that normal posture groups typically show a mean CVA of about 53°, with minimal changes (0.8° ± 1.2°) after intervention [22]. Similarly, Shin *et al.* (2017) observed minimal CVA changes in individuals with mild FHP [24], while Kim and Kim (2019) found that the closer the baseline posture was to the normal range, the smaller the corrective effect [25]. These findings support the notion that postural correction interventions yield greater improvements in individuals with abnormal postures. Given that this study involved participants with normal alignment, the limited CVA changes are likely attributable to a ceiling effect [21, 26]. Thus, in such populations, improvements may first manifest in functional variables such as muscle tone and proprioception rather than in angular postural parameters.

The present study results suggest that rPMS can effectively improve cervical proprioception within a short period. As a non-invasive modality, rPMS reduces muscle fatigue and tension, enhances sensory feedback, and improves neuromuscular function [27–29]. It has also been recognized for normalizing muscle tone, reducing pain, and serving as a safe and efficient intervention during early rehabilitation [30, 31]. Biofeedback training, in contrast, is more suitable for long-term programs focusing on postural awareness and motor control, and its combination with rPMS may simultaneously promote neuromuscular activation and postural learning [15, 27, 32]. Indeed, combined applications of magnetic stimulation and biofeedback have been reported to produce superior outcomes in muscle strength, tone normalization, and functional recovery compared with either intervention alone [11, 33].

This study has two notable limitations. First, the intervention consisted of a single session, which limits the ability to draw conclusions regarding long-term adaptations or motor learning. Second, the participants were healthy young adults with near-normal CVA values, which restricts the generalizability of the findings to clinical populations with moderate or severe FHP. Accordingly, an integrated rehabilitation protocol combining rPMS-based sensory stimulation and biofeedback-mediated postural training may serve as a promising clinical strategy for improving proprioception, muscle tone, and postural awareness in individuals with FHP.

5. Conclusion

In this study, the effects of biofeedback training and rPMS on cervical proprioception and the CVA in young adults were compared. The magnetic stimulation group showed a significant reduction in JPE during flexion, while the biofeedback group demonstrated significant improvement during left rotation. These findings indicate that both interventions can enhance cervical postural awareness and sensory feedback through distinct physiological mechanisms. Therefore, both rPMS and biofeedback training may serve as effective therapeutic approaches for early correction of FHP and improvement of cervical proprioceptive function.

Acknowledgements

This research was supported by the Regional Innovation System & Education (RISE) program through the Chungbuk Regional Innovation System & Education Center, funded by the Ministry of Education (MOE) and Chungcheongbuk-do, Republic of Korea (2025-RISE-11-004-02).

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