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Original Article

Effects of a Posture Correction Feedback System on Upper Body Posture, Muscle Activity, and Fatigue During Computer Typing

Subin Kim[1], PT, BPT, Chunghwi Yi[2], PT, PhD, Seohyun Kim[1], PT, BPT, Gyuhyun Han[1], PT, BPT, Onebin Lim[3], PT, PhD

[1]Department of Physical Therapy, The Graduate School, Yonsei University, [2]Department of Physical Therapy, College of Software and Digital Healthcare Convergence, Yonsei University, Wonju, [3]Department of Physical Therapy, Mokpo Science University, Mokpo, Korea

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Corresponding Author
Chunghwi Yi
E-mail: pteagle@yonsei.ac.kr
https://orcid.org/0000-0003-2554-8083

Key Words
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Background: In modern society, the use of computers accounts for a large proportion of our daily lives. Although substantial research is being actively conducted on musculoskeletal diseases resulting from computer use, there has been a recent surge in interest in improving the working environment for prevention.

Objects: This study aimed to examine the effects of posture correction feedback (PCF) on changes in neck posture and muscle activation during computer typing.

Methods: The participants performed a computer typing task in two sessions, each lasting 16 minutes. The participant's dominant side was photographed and analyzed using ImageJ software to verify neck posture. Surface electromyography (EMG) was used to confirm the participant's cervical erector spinae (CES) and upper trapezius muscle activities. The EMG signal was analyzed using the percentage of reference voluntary contraction and amplitude probability distribution function (APDF). In the second session, visual and auditory feedback for posture correction was provided if the neck was flexed by more than 15° in the initial position during computer typing. A 20-minute rest period was provided between the two sessions.

Results: The neck angle ($p = 0.014$), CES muscle activity ($p = 0.008$), and APDF ($p = 0.015$) showed significant differences depending on the presence of the PCF. Furthermore, significant differences were observed regarding the CES muscle activity ($p = 0.001$) and APDF ($p = 0.002$) over time.

Conclusion: Our study showed that the feedback system can correct poor posture and reduces unnecessary muscle activation during computer work. The improved neck posture and reduced CES muscle activity observed in this study suggest that neck pain can be prevented. Based on these results, we suggest that the PCF system can be used to prevent neck pain.

INTRODUCTION

The use of computers has become an indispensable aspect of daily life for a significant proportion of the general population. With the rise in remote work due to the COVID-19 pandemic, a new working style that transcends space constraints has emerged [1,2]. Consequently, the utilization of tablet personal computers and computers has surged, encompassing non-contact activities such as video meetings and email communications conducted remotely. Various musculoskeletal diseases related to computer use have been studied since the advent of computers [3]; however, recently, many studies have focused on ergonomic factors that can prevent diseases, emphasizing the importance of improving the quality of life [1,4,5]. As a result, a proactive exploration of work environments and postures that prevent pain and mitigate the associated musculoskeletal disorders (MSDs) have been undertaken [6-8]. These endeavors are aimed at fostering a healthier and more productive work environment.

Neck pain is a common musculoskeletal impairment experienced by computer workers [6]. In a previous survey, approximately 42.9% of computer workers reported neck and back pain [2]. Computer work often require prolonged periods of maintaining a static posture, leading to minimal muscle engagement and potential disruption of proper alignment, resulting in postural imbalances that can contribute to health issues [7,9].

Several postures, such as forward head posture (FHP), round shoulders, and kyphosis, have been identified as being associated with MSDs during computer work. In particular, neck pain in computer workers has been found to be associated with FHP during computer work [10-12]. FHP, characterized by a forward bent posture, is also significantly correlated with neck pain during prolonged periods or repetitive movements [12-14].

An increased angle of neck flexion during the use of visual display terminals (VDTs) is associated with a higher risk of experiencing neck muscle fatigue and pain [15]. Fatigue can also contribute to muscle weakness, leading to a potential destabilization of the neck and shoulder muscles and a reduction in the precision of neck position sense [16,17]. Recent evidence suggests that as neck bending increases during the VDT task, cervical erector spinae (CES) and upper trapezius (UT) muscle activities and fatigue significantly increase [15,18,19]. In addition, the UT muscle activity in the slumped posture has been found to be significantly higher than that in the upright sitting posture [20]. Therefore, posture is closely associated with muscle activity, and previous studies have suggested the importance of posture correction in reducing muscle fatigue [15,21,22].

Ergonomic approaches are required to prevent chronic musculoskeletal pain experienced by computer workers and to provide free activities of daily life [13]. There is a clear need to investigate changes in posture and muscle activity, depending on the presence or absence of posture correction, among healthy participants to enable them to perform computer work with proper posture. We recently developed a wearable and portable motion-detection sensor (MDS) that can provide posture correction feedback (PCF) during computer work. It was designed to determine, evaluate, and provide accurate biofeedback on incorrect postures associated with computer work in ergonomic environments. Existing posture correction studies have found that there is a limit to the use of equipment that does not fully reflect the actual computer work environment or is difficult to use [23-25]. In this study, to address these limitations, a PCF system was employed that minimally disrupted computer work and incurred reduced effort and cost for the participants. Although the CES and UT are crucial muscles that provide stability to the neck and shoulders [16,26], research on muscle fatigue in an ergonomic environment with PCF is still lacking. Therefore, this study compared posture, muscle activity, and muscle fatigue when providing PCF system to computer users. Investigating posture and muscle fatigue allows for more accurate and discriminatory test results regarding neck pain, so further research is needed.

This study aimed to examine changes in: 1) neck posture and muscle activation of the CES and UT over time, and 2) neck posture and muscle activation of the CES and UT based on the presence or absence of a PCF during computer typing.

MATERIALS AND METHODS

1. Participants

Twenty healthy young adults (11 males and 9 females) who worked with a computer for at least 4 hours a day and 5 days a week participated in this study (Table 1). Prior to the trial, participants had to have a neck disability index score of 4 or less and no neck pain or discomfort [27]. Some participants were excluded from the study, according to Xie and Szeto [28], if they had a history of traumatic injury; spinal or upper limb surgeries; chronic musculoskeletal diseases caused by rheumatoid arthritis, osteoarthritis, or other connective tissue disorders; neurological or orthopedic conditions; or sensory deficits. Experimental protocols have been reviewed and approved by the Institutional Review Board at Yonsei University Mirae campus (IRB no. 1041849-202205-BM-096-01), and all participants were provided detailed information regarding the experiment and consented to participate through written informed consent.

2. Procedures

This was a single-group, repeated-measures study. The experiments were conducted consecutively for one day, and the same experimental procedure was performed under two conditions. Before starting the experiment, the positions of the desk and keyboard were set according to the participants' usual working environments. The height of the chair was set such that the knee and hip joints were flexed at 90° with the feet on the floor. The participants were instructed to focus fully on a

Table 1. Participant demographics (N = 20)

Variable	Value
Age (y)	22.9 ± 3.5
Height (cm)	168.3 ± 7.8
Weight (kg)	64.7 ± 10.9
Neck disability index	2.1 ± 1.6

Values are presented as mean ± standard deviation.

computer task in their usual working posture. They performed the given typing task for 16 minutes under each experimental condition. In the first condition, the participants wore headphones with feedback disabled and engaged in copy-typing tasks for 16 minutes. The copy-typing task on the computer utilized an open-source typing program created by Hancom (Hancom typing, Hangul and Computer). All participants were given a 20 minutes break between sessions to eliminate the carryover effect. In the second condition, the participants wore headphones with feedback enabled and underwent the same computer tasks as the first condition. Data were recorded during the first and second conditions to confirm the changes in muscle activity and angle over time.

3. Kinematic Data

Kinematic data pertaining to the angles of the neck were gathered using two-dimensional motion analysis software (ImageJ, U.S. National Institutes of Health) that captured photographs at 0, 5, 10, and 15 minutes of the experiments. The camera (iPhone 12, Apple Inc.) was positioned on a tripod 1.5 m from the participant's chair. The camera's lens was aligned parallel to the sagittal plane of the dominant side of the participant and positioned at a height corresponding to the acromion. Infrared reflective markers were affixed to the tragus of the ear on the participant's dominant side and the spinous processes of the seventh cervical vertebra (C7) (Figure 1) [10,29]. The neck angle was defined as the angle between the line from the tragus on the dominant side to the C7 spinous process and the intersecting vertical axis [10].

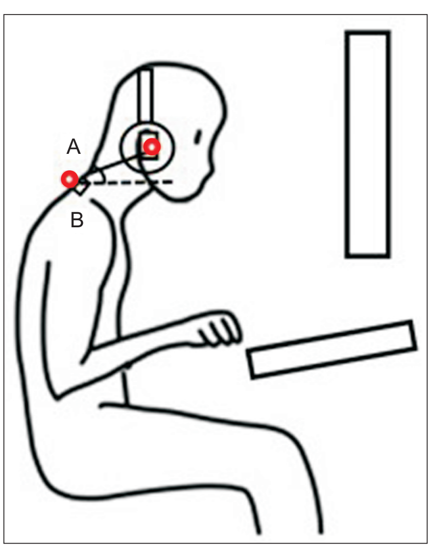

Figure 1. Position of the measured angles and feedback device. (A) Neck angle: a decrease in the neck angle indicates increasing neck flexion, which infers forward head posture. (B) Posture correction feedback devices with motion detection sensors.

4. Kinetic Data

The electromyography (EMG) data were recorded using a Noraxon Ultium EMG sensor system (Noraxon U.S.A. Inc.). The EMG signals were collected at a sampling rate of 1,000 Hz, with a band-pass filter between 20 and 450 Hz, and smoothed through the root mean square (RMS) with a moving window of 50 ms [21]. To reduce skin impedance, the skin was shaved and rubbed with 70% ethyl alcohol before attaching the electrodes. Then, 2 cm bipolar surface electrodes were placed on the dominant side of the CES and UT. The EMG electrodes were placed according to Criswell [30]'s recommendations for the muscle attachment site. The CES electrodes were placed at the C4 level across the muscle belly, parallel to the spine, approximately 2 cm from the midline of the spinous process. The UT electrodes were positioned midway between the lateral edge of the acromion and the spinous process of C7 along the muscular belly of the shoulder ridge. All EMG data were normalized to the RMS amplitude during the reference voluntary contraction (RVC) of each muscle. The assessed muscles were represented as a percentage of the RVC (%RVC) and the amplitude probability distribution function (APDF) value. The %RVC is a fatigue-insensitive measurement method commonly employed to enhance sensitivity during tasks with lower muscle activation, and it is frequently utilized in repeated measurements due to its high test-retest repeatability without significant differences [31,32]. Additionally, the APDF can determine the accumulated fatigue regarding muscle activity over time [29]. The APDF was adopted in this study because of its advantage in regressing the amplitude probability of the RMS value of the EMG signal representing the amplitude. Among the APDF values, the 10% APDF value was selected as an indirect indication of muscular fatigue during continuous sedentary work, such as computer use [29,33,34]. Electrical signals from muscles can be cumulatively converted into muscle load levels according to the %RVC order. The %RVC values were calculated using Excel (Microsoft), and the APDF values were calculated using the MATLAB R2021b program (MathWorks Inc.). Both EMG signal analysis methods required reference values. To obtain the reference values, the participants maintained 90° of shoulder abduction in the scapular plane for 15 seconds and held a 1 kg weight 3 times. The EMG data from each muscle were collected, and for each repetition, only the middle 5-scond of the data were extracted and averaged to calculate the %RVC value [29,35,36].

5. Posture Correction Feedback System

The PCF system was designed for integration into common computer setups for real computer workers. The system consisted of a headphone and a necklace with MDSs, a receiver, and a PCF program (Seedtech Inc.) (Figure 2). The MDS could be used to detect cervical flexion and protraction. The detected angle was sent to a computer-connected receiver that provided auditory and visual feedback signals during a particular time to rectify the forward-bent upper body posture while working on a computer. When the reference angle was exceeded, auditory feedback was provided through a beeping sound, while visual feedback blocked the screen until the posture was corrected. As the program window continued in the background, users could obtain posture correction inputs even when the screen was blocked. The participants could choose between one or both warning signals based on their preferences and work condition. In this study, both auditory and visual feedback were provided by setting the criterion to 15°, which has been reported to double the load on the neck in a previous study [37].

6. Statistical Analysis

Statistical analyses were performed using IBM SPSS 26.0 (IBM

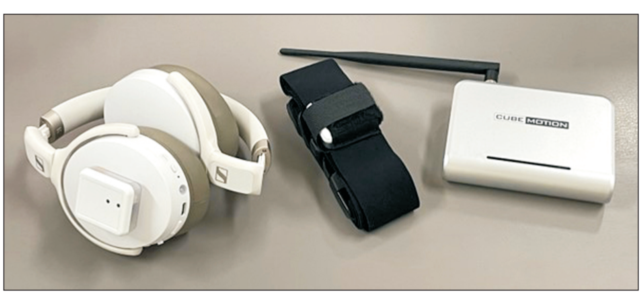

Figure 2. The posture correction feedback system (from the left: headphone, a necklace device with an inertial measurement unit, and a receiver).

Corp.). The postural angle and muscle activity were compared using a two-way repeated measures analysis of variance (PCF × time). The postural angle data were recorded at 0, 5, 10, and 15 minutes in the presence or absence of an inertial measurement unit sensor. Muscle activity data were also recorded at four locations to identify the differences in mechanical load at 0–1, 5–6, 10–11, and 15–16 minutes of each session. After confirming a significant difference in the F ratio, a post-hoc analysis was conducted using the Bonferroni method to determine whether there was a statistically significant difference between the averages. Statistical significance was set at $p < 0.05$.

RESULTS

1. Kinematic Data

Significant differences were observed regarding the neck angle depending on the presence of the PCF ($F = 7.401$, $p = 0.014$). However, no significant differences were observed over time (Table 2).

2. Kinetic Data

Significant differences were observed regarding the %RVC at the CES, both in the presence of the PCF ($F = 5.535$, $p = 0.008$) and over time ($F = 14.39$, $p = 0.001$). However, no significant differences were observed regarding any of the variables when examining the %RVC at the UT (Table 3, Figure 3).

After identifying the %RVC of the upper body muscles, we assessed the APDF to identify the accumulated fatigue of muscle activity. The APDF graph of the CES muscle exhibited a rightward shift (from 1 to 4) as computer typing progressed ($F = 4.627$, $p = 0.015$) (Figure 4). In addition, when comparing the graphs based on the presence or absence of feedback, we observed that the graph exhibited a rightward skewness in the absence of feedback ($F = 13.57$, $p = 0.002$). However, the APDF graph of the UT did not show any specific tendency as computer typing progressed.

A significant change in the 10% APDF values of the CES muscle was observed over time, and a post-hoc analysis was

Table 2. Mean ± standard deviation of the neck angle (°) (N = 20)

	0 min	5 min	10 min	15 min	Feedback p-value (F)	Time p-value (F)
Nonfeedback	34.72 ± 6.67	33.32 ± 6.84	33.79 ± 6.89	33.19 ± 7.88	0.014* (7.401)	0.512 (0.799)
Feedback	36.86 ± 6.76	36.58 ± 7.08	37.00 ± 7.42	37.81 ± 7.84		

Values are presented as mean ± standard deviation. *p < 0.05.

Table 3. Mean ± standard deviation of the neck and upper trunk muscle activity (%RVC) (N = 20)

	0 min	5 min	10 min	15 min	Feedback p-value (F)	Time p-value (F)
CES						
Nonfeedback	45.99 ± 25.01	51.12 ± 32.66	53.81 ± 36.67	52.87 ± 29.07	0.008** (5.535)	0.001** (14.39)
Feedback	39.05 ± 20.20	41.96 ± 29.54	43.43 ± 29.16	43.33 ± 27.56		
UT						
Nonfeedback	18.54 ± 18.47	25.10 ± 28.61	28.27 ± 33.08	26.26 ± 23.12	0.116 (2.72)	0.098 (2.46)
Feedback	18.24 ± 20.41	19.76 ± 24.97	20.66 ± 23.16	19.93 ± 21.94		

Values are presented as mean ± standard deviation. %RVC, percentage of reference voluntary contraction; CES, cervical erector spinae; UT, upper trapezius. **p < 0.01.

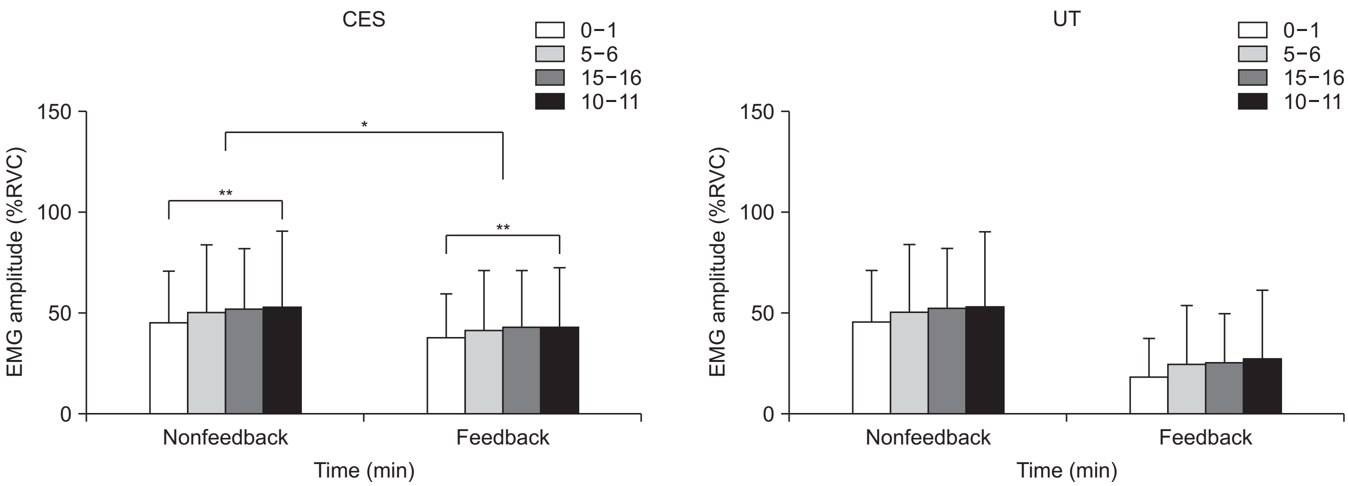

Figure 3. %RVC in the CES and UT. EMG, electromyography; %RVC, percentage of reference voluntary contraction; CES, cervical erector spinae; UT, upper trapezius. *p < 0.05, **p < 0.01.

conducted. Consequently, a significantly greater difference was observed at 15–16 minutes compared to that at 0–1 minute (p = 0.08).

DISCUSSION

This study aimed to confirm the effects of PCF in an ergonomic environment on neck posture and muscle activity in participants during computer tasks. Significant changes were observed in the neck angle and CES muscle activity based on the application of the PCF. In addition, there was a significant difference in muscle activity and APDF values of the CES over time. Regarding the APDF value of the CES, a significant difference was observed between the initial (0–1 minute) and final (15–16 minutes) periods.

In studies that examined postural changes using PCF during computer tasks, significant increases in the extension angle of the upper body were reported before and after use [10,21,38]. The change in the extension of the upper body in a seated posture serves to align the spine in a neutral position, reducing the moment exerted on the spine by narrowing the distance between the head and thoracic vertebrae up to the gravity line. In a study conducted by Ailneni et al. [38], it was observed that the cervical flexion decreased by 8%, and the gravitational moment of the neck decreased by 14% after using PCF sensors during computer tasks. In addition, significant angular changes in neck extension were observed in this study when the PCF system was employed, providing findings similar to those of previous studies.

The use of the PCF resulted in a significant reduction in muscle activity and APDF of the CES in this study, indicating a decrease in neck tension. The CES is responsible for neck stability. It attaches vertically to the spine and plays a crucial role in maintaining neck alignment. Therefore, in an upright sitting posture, the CES can maintain neck alignment along with gravity without requiring significant force. In this study, it was observed that the use of the PCF led to a decrease in the neck flexion angle, suggesting that the reduction in the CES activity may have been the cause of these angle changes. In contrast, it was difficult to observe significant changes in UT activity and

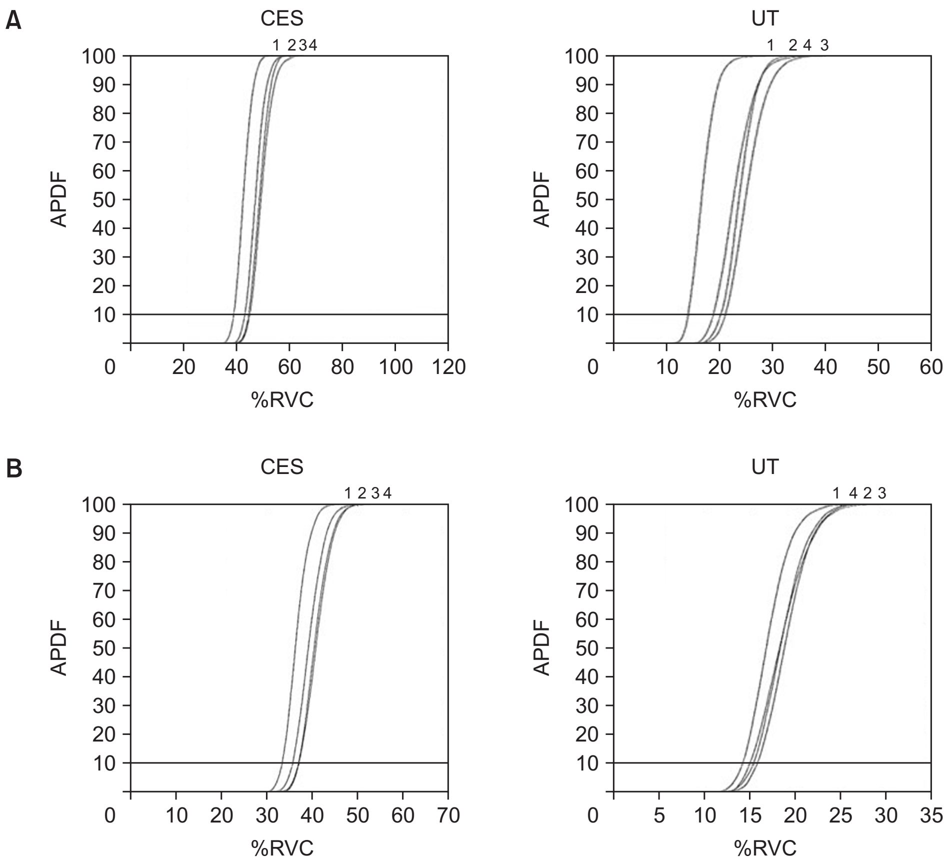

Figure 4. APDF graphs of the CES and UT according to time. Curve 1: 0–1 minute; Curve 2: 5–6 minutes; Curve 3: 10–11 minutes; and Curve 4: 15–16 minutes. The solid line at 'y = 10' means 10% APDF. (A) Without PCF and (B) with PCF. APDF, amplitude probability distribution function; %RVC, percentage of reference voluntary contraction; CES, cervical erector spinae; UT, upper trapezius; PCF, posture correction feedback.

muscle fatigue. The UT is the primary muscle involved in arm elevation and neck extension [36]. Despite anticipating changes in the UT activity with alterations in neck posture, these changes were not observed. To eliminate the influence of variables other than neck posture on the results, we adjusted the desk height according to the participant's elbow height, enabling them to work with both arms resting on the desk. Consequently, it may have been challenging to observe significant changes in the UT activity. The findings of Santiago et al. [39] support our perspective as they reported a considerable decrease in the UT activity during computer typing using forearm support. While the UT is indeed involved in neck extension, its contribution appears insignificant, particularly during gradual movements in static postures such as computer use. Nonetheless, given the evidence from previous studies confirming differences in the UT activity according to neck posture and pain, further investigation is necessary [36,40-43].

A previous study related to computer use did not confirm significant changes in the upper extremity angle and CES and UT muscle activity over time during 1 hour of computer work [19]. Kuo et al. [19] explained that since the spinal segments are interdependently connected, it is possible to adjust the sitting posture naturally by moving the segments with less resistance without significant changes in any segment. Another study that confirmed the difference over time during VDT tasks showed that neck bending increased over time when using a smartphone [29]. Owing to the nature of smartphone operation, the device must be held with either one or both hands and because of the small screen size, strong concentration and load may be involved even in a short time [44]. In contrast to Kuo et al. [19], our muscle activity results revealed a significant increase in the CES activity and APDF over time. Furthermore, when the 10% APDF value, which can indicate muscle fatigue in a static posture, was compared over time, significant muscle fatigue was confirmed at 15–16 minutes compared with 0–1 minute. A high APDF value indicates that muscle overloading occurred over time as the curve moved to the right [29,34]. As the duration of computer work increases, if the head moves forward from the gravitational line due to incorrect posture, an excessive eccentric force may be exerted on the CES to support the increased moment arm [16,38,45]. Since excessive activation of neck muscles is associated with neck pain and MSDs, our results confirm the importance of the PCF.

In our study, we found significant evidence supporting the beneficial effects of the PCF in improving neck angles and reducing CES activity and fatigue. These findings indicate that the PCF can serve as an ergonomic intervention in a work environment. However, this study had certain limitations. First, our study focused on just 20 healthy young participants; therefore, our results may not be generalizable to the posture and muscle activity of all computer workers. To gain a broader understanding, future studies should apply the PCF system to individuals with postural issues such as FHP or kyphosis and verify the outcomes accordingly. Second, the immediate effects of computer use were confirmed by utilizing the PCF for a short time per session, which differs from the actual time spent working with computers. To validate the long-term effects of posture correction, it is necessary to implement a PCF system during the participants' regular working hours in their natural work environment. Moreover, investigating the follow-up results over an extended period would be highly meaningful. Finally, our kinematic data were collected through static photographs and not as time-series data. This was chosen to confirm the time effect by excluding the influence of data (e.g., coughing, scratching the head, and looking at the keyboard) unrelated to the actual postural correction effect that may have occurred during the experiment. However, some studies have attempted to obtain more detailed data by measuring kinematic data for the last 5 minutes of a session or by collecting angle data every 5 minutes over a longer period [19,38]. Thus, future research will require new attempts to collect and analyze kinematic data.

CONCLUSIONS

In this study, we observed that as the duration of computer use increased, the CES muscle activity increased. This can lead to muscle fatigue, which causes neck pain and MSDs. Our study showed that the PCF system led to improvements in neck posture and a decrease in the CES muscle activity, indicating a reduction in fatigue. These findings suggest that the provision of the PCF is a potential approach to prevent neck pain associated with poor posture in the context of computer use, which is becoming increasingly prevalent in modern society.

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CONFLICTS OF INTEREST

No potential conflicts of interest relevant to this article are reported.

AUTHOR CONTRIBUTION

Conceptualization: Subin Kim, CY, Seohyun Kim, GH, OL. Data curation: Subin Kim, Seohyun Kim. Formal analysis: Subin Kim, CY. Funding acquisition: CY, OL. Investigation: Subin Kim, OL. Methodology: Subin Kim, OL. Project administration: CY. Resources: Subin Kim. Software: Subin Kim, Seohyun Kim, GH, OL. Supervision: CY, OL. Validation: Subin Kim, CY. Writing - original draft: Subin Kim. Writing - review & editing: Subin Kim, CY, Seohyun Kim.

ORCID

Subin Kim, https://orcid.org/0000-0003-2068-9290
Seohyun Kim, https://orcid.org/0000-0002-6978-200X
Gyuhyun Han, https://orcid.org/0000-0002-7738-4271
Onebin Lim, https://orcid.org/0000-0002-5281-3463

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