Gait & Posture 67 (2019) 187–193

Contents lists available at ScienceDirect

Gait & Posture

journal homepage: www.elsevier.com/locate/gaitpost

Full length article

Immediate effects of real-time postural biofeedback on spinal posture, muscle activity, and perceived pain severity in adults with neck pain

Yi-Liang Kuo[a], Pei-San Wang[a,b], Po-Yen Ko[c,d], Kuo-Yuan Huang[c], Yi-Ju Tsai[a,*]

[a] Department of Physical Therapy, College of Medicine, National Cheng Kung University, Tainan, Taiwan, ROC
[b] Department of Rehabilitation, Taitung Christian Hospital, Taitung, Taiwan, ROC
[c] Department of Orthopedics, National Cheng Kung University Hospital, Tainan, Taiwan, ROC
[d] Department of Biomedical Engineering, National Cheng Kung University, Tainan, Taiwan, ROC

ARTICLE INFO

Keywords:
Wearable electronic devices
Posture
Electromyography
Neck pain

ABSTRACT

Background: Previous studies have investigated various types of postural biofeedback devices on different body regions to improve posture; however, they focused only on healthy adults without a history of chronic musculoskeletal disorders. In addition, those postural biofeedback devices used in previous studies are often designed for experimental research. The designs are usually bulky with many wires, which is not practical for everyday use.
Research question: The aim of this study was to determine the immediate effect of a commercially available real-time postural biofeedback device on spinal posture, muscle activity, and perceived pain severity in adults with neck pain.
Methods: 21 adults who had chronic or recurrent nonspecific neck pain for more than 3 months and whose pain was induced or aggravated by prolonged computer work were enrolled in this study. Spinal posture (head tilt, neck flexion, cervical and thoracic angles), muscle activity (cervical erector spinae, upper trapezius, and thoracic erector spinae), and self-reported neck and shoulder pain were measured during computer typing tasks, with and without biofeedback.
Results: Compared with the non-biofeedback condition, the biofeedback condition significantly decreased neck flexion, upper cervical, and lower thoracic angles and lowered the activity of the cervical erector spinae. Self-reported neck pain was not influenced by the application of biofeedback, but significantly increased over the 1-hour typing task.
Significance: The application of a commercially available wearable real-time biofeedback device improves sitting posture and reduces muscular activity in adults with nonspecific neck pain during computer work. Future studies should examine the long-term effects of wearable real-time postural biofeedback devices for prevention and management of neck pain.

1. Introduction

Neck pain is a common complaint among office workers who hold a static posture during prolonged computer work [1]. Disability associated with neck pain can reduce work productivity and increase absence from work, leading to substantial economic losses [2]. Neck pain is generally multifactorial in origin, and prolonged static sitting has been identified as a major risk factor for developing neck pain [3,4]. The forward head and trunk flexion postures commonly adopted by computer workers could increase mechanical loading in postural muscles due to the greater gravitational moments from the weight of the head and neck in these postures [4–6]. Increased tension in postural stabilizing muscles and increased compressive loading to the articulations of the cervical spine over time could result in higher risk of neck pain [5]. Therefore, a proper sitting posture is essential for prevention and management of neck pain.

Maintaining a proper sitting posture for prolonged hours is difficult for most individuals, especially for people with neck pain [7,8]. In a previous study, people with neck pain demonstrated progressively increased forward head and thoracic kyphosis postures during a 10-minute computer task; in contrast, healthy controls did not show any significant change in their head posture [7]. Various factors, such as

* Corresponding author at: Department of Physical Therapy, College of Medicine, National Cheng Kung University, No.1, University Road, Tainan 701, Taiwan, ROC.
E-mail address: yijutsai@mail.ncku.edu.tw (Y.-J. Tsai).

https://doi.org/10.1016/j.gaitpost.2018.10.021
Received 1 March 2018; Received in revised form 11 October 2018; Accepted 15 October 2018
0966-6362/ © 2018 Elsevier B.V. All rights reserved.

pain, muscle endurance and proprioception, can influence the ability to maintain an upright sitting posture. Systematic reviews showed evidence of impaired proprioception in people with neck pain [9,10]. Impaired proprioception can result in poor awareness of head-on-trunk orientation and reduced ability to maintain or adjust posture. When information provided by an individual's own sensory system is insufficient, the use of extrinsic feedback (information provided via an external source) seems logical.

Previous studies have used various types of postural biofeedback devices on different body regions to improve posture [11–18]. Those postural biofeedback devices are often designed for experimental research. The designs are usually bulky with many wires that are not practical for everyday use [11,12,16]. More notably, previous studies have focused only on healthy adults without a history of chronic musculoskeletal disorders. With the tremendous progression of the miniaturization technology of microelectromechanical system, some inertial-based postural biofeedback devices are thus developed. Whether a commercially available postural biofeedback device with the characteristics of smaller size, lighter weight, and easier to wear is beneficial for people with neck pain remains unknown, especially during prolonged computer work.

The Lumo Lift (Lumo Bodytech Inc., CA, US) was developed to monitor upper-body posture during daily activities and to provide real-time vibratory feedback to the wearer. The aim of this study was to investigate the Lumo Lift as a real-time postural biofeedback device for modifying spinal posture, muscle activity, and perceived pain severity in adults with existing neck pain during a computer typing task. We hypothesized that participants would exhibit less postural deviation, muscle activity, and perceive less pain under the biofeedback condition than under the non-biofeedback condition. We also hypothesized that the benefits from the biofeedback device on spinal posture, muscle activity, and perceived pain severity might be greater during the later stages of the typing task.

2. Methods

2.1. Participants

This study recruited 21 adults with neck pain from the university campus and nearby communities. The inclusion criteria were (1) chronic or recurrent pain in the head, neck, and shoulder area for more than 3 months and (2) pain induced or aggravated by prolonged computer work. Prospective participants were excluded if they had (1) neuropathic symptoms in the upper extremity; (2) a history of back pain, traumatic injury, or surgery in the spine or abdomen; (3) systematic diseases (eg, rheumatoid arthritis, ankylosing spondylitis), pre-existing medical conditions (eg, CNS lesion, vestibular disorder, cancer), or pregnancy; (4) a body mass index exceeding 30 kg/m^2; or were (5) currently receiving formal medical treatment for neck pain, such as anti-inflammatory medications or physical therapy. The university-affiliated hospital ethics committee approved this study. Before data collection, the experimental procedures were explained to each participant and informed consent was obtained in writing.

2.2. Procedures

Prior to testing, all participants completed a demographic survey. To investigate the immediate effects of real-time postural biofeedback on spinal posture, muscle activity, and self-reported neck and shoulder pain during computer work, the participants performed a 1-hour typing task twice, once with biofeedback and once without, in a random order.

The participants sat on a backless, armless, height-adjustable wooden chair with their hips and knees flexed to 90° (Fig. 1). The participants were instructed to copy and type an electronic book displayed on the same monitor. After completing the first typing task, the participants were allowed to rest as long as necessary until ready for the second typing task. The whole experiment lasted more than 2 h with two segments of 1-hour typing task.

Before the task with biofeedback, the investigator directly attached the Lumo Lift to the participant's skin below the mid-clavicle with surgical tape (Fig. 1). Then, the investigator manually guided the participants to sit with their shoulder blades slightly retracted and thoracolumbar spine extended. This upright sitting posture was used to calibrate the Lumo Lift's target posture. The participants were instructed to return to the target posture immediately whenever they received vibratory feedback from the device.

2.3. Measurements

A 3-dimensional motion analysis system (Vicon Motion Systems Ltd., Oxford, UK) with 6 infrared cameras was used to measure the spinal posture at a sampling rate of 100 Hz. Eleven reflective markers were attached to the canthi of both eyes, tragi of both ears, suprasternal notch, and spinal processes of T1, T3, T5, T7, T9, and T11 for spinal posture measurement (Fig. 1) [19,20]. Muscle activity of bilateral cervical erector spinae [CES], upper trapezius [UT], and thoracic erector spinae [TES] was measured using a surface electromyography (EMG) system (BagnoliTM desktop EMG, Delsys, US) at a sampling rate of 1000 Hz. The placement for six pairs of surface electrodes was shown in Fig. 1. Before electrode placement, the skin was thoroughly prepared using fine sand paper and alcohol wipes.

The intensity of neck and shoulder pain during typing tasks at the beginning and end of the typing tasks was assessed using the numeric rating scale (NRS). Patients were asked to indicate the intensity of their current neck pain using an 11-point scale. The impact of neck pain was assessed by the Neck Disability Index (NDI) prior to testing. The index consists of 10 items, with the score for each item ranging from 0 (no limitations) to 5 (major limitations). A higher value of NRS corresponds to worse pain, and a higher summed score of NDI indicates greater disability associated with neck pain. Both the NRS and NDI demonstrated fair to moderate test-retest reliability in patients with mechanical neck pain [21].

2.4. Data management

The kinematic data were digitized using the Vicon Nexus 1.8.5 (Vicon Motion Systems Ltd., Oxford, UK) and then filtered by a low-pass fourth-order Butterworth filter at 4 Hz. Spinal posture was measured as joint angles or segment inclination angles, including head tilt, neck flexion, upper cervical, lower cervical, upper thoracic, and lower thoracic angles [19,20] (Fig. 2). The neck flexion angle is commonly used to quantify the forward head posture [4,6], with a greater angle suggesting more forward head posture (increased anterior translation of the head). Greater upper thoracic and lower thoracic angles indicate increased thoracic kyphosis.

Raw EMG signals were first filtered by a bandpass fourth-order Butterworth filter at 30–500 Hz to reduce heart and movement artifacts, and subsequently by a bandstop filter at 59.5–60.5 Hz to eliminate power line interference. The filtered EMG data were rectified and smoothed with a root mean square moving average window of 25 ms. The rectified EMG data were then normalized with each participant's mean EMG value during the habitual sitting. The final 30 s of angle and EMG data were averaged for the 5th, 15th, 25th, 35th, 45th, and 55th minutes of typing for statistical analysis.

2.5. Statistical analysis

Descriptive statistics were used to summarize the demographic characteristics of the participants and all dependent variables. We used 2-way analyses of variance with repeated measures to identify any statistically significant differences in dependent variables between the 2 test conditions (with and without biofeedback) at all measurement

Fig. 1. Experimental set-up. The computer workstation consisted of a standard computer desk (75-cm height), a standard keyboard, a mouse, and a 20-inch monitor. The Lumo Lift (indicated by the arrow) was attached to the skin below the left mid-clavicle. Six pairs of surface electrodes were placed on bilateral cervical erector spinae (2 cm lateral to the spinous process of C4), upper trapezius (at the midpoint between the spinous process of C7 and the acromion), and thoracic erector spinae (5 cm lateral to the spinous process of T4), and a reference electrode was placed over the right olecranon process.

times (6 time points). The Greenhouse–Geisser correction was used to adjust the degrees of freedom when the sphericity assumption was violated. Post hoc comparisons with Bonferroni corrections were used to follow up a significant main effect. All statistical analyses were performed using IBM SPSS Statistics version 20 (IBM Corp., US) with the significance level set at 0.05.

3. Results

We recruited 13 women and 8 men with nonspecific neck pain (age, 23.8 ± 3.5 years; height, 165.2 ± 9.0 cm; weight, 57.7 ± 11.0 kg) to participate in this study. All the participants were right-hand dominant, and spent a substantial amount of time sitting (12.5 ± 5.5 h) and using computers (8.0 ± 4.7 h) each day. The average duration of neck pain was 2.6 ± 1.6 years, and the average NDI score was 7.0 ± 3.8 (out of a possible 50). The average NRS scores for participants reporting neck and shoulder pain in the past month were 3.5 ± 1.5 and 3.6 ± 1.9, respectively.

The kinematic data for spinal posture are summarized in Table 1. There was no significant interaction effect between biofeedback condition and time for any spinal angle. Neck flexion, upper cervical, and lower thoracic angle were significantly smaller with biofeedback than without. The mean differences in the neck flexion, upper cervical, and lower thoracic angles between the 2 conditions were 3.3° (95% CI 1.8°–4.7°), 3.3° (95% CI 1.7°–5.0°), and 1.6° (95% CI 0.4°–2.7°), respectively (Fig. 3). Although time had a significant main effect on the head tilt and upper cervical angles, Bonferroni-corrected pairwise comparisons did not show any significant difference between time points.

The EMG data for the bilateral CES, UT, and TES are summarized in Table 2. There was no significant main effect of time or interaction effect for any tested muscle. Participants under the biofeedback condition exhibited lower activity of the right and left CES by 24.9% (95% CI 8.4%–41.5%) and 24.6% (95% CI 7.7%–41.5%), respectively (Fig. 4).

The NRS scores for neck pain and shoulder pain are illustrated in Fig. 4. The interaction between biofeedback condition and time had no significant effect on neck or shoulder pain (neck: $F = 0.332$, $p = 0.571$; shoulder: $F = 0.579$, $p = 0.456$). The self-reported NRS scores for neck and shoulder pain were influenced by time (neck: $F = 20.398$, $p < 0.001$; shoulder: $F = 22.678$, $p < 0.001$), but not by condition (neck: $F = 0.745$, $p = 0.398$; shoulder: $F = 0.066$, $p = 0.800$). On average, neck pain significantly increased from an NRS score of 1.5 at the beginning of the typing task to 3.1 at the end (with a mean difference of 1.6, $p < 0.001$, 95% CI 0.9–2.4), and shoulder pain scores significantly increased from 1.8 at the beginning to 3.7 at the end (with a mean difference of 1.8, $p < 0.001$, 95% CI 1.0–2.7).

4. Discussion

This is the first investigation that uses a wearable postural biofeedback device for real-time correction of sitting posture in adults with neck pain. The participants showed significantly reduced neck flexion, upper cervical, and lower thoracic angles when performing the task with biofeedback than without biofeedback. Participants adopted a less ideal posture in the absence of biofeedback. Our study indicated that the Lumo Lift caused immediate reductions in forward head and thoracic kyphotic posture in adults with neck pain during computer work.

In this study, greater kinematic changes were observed in the cervical region despite that the Lumo Lift was attached on the thorax. This result may be explained by the interdependence and inherent mobility among different spinal regions. The thoracic spine (especially the upper

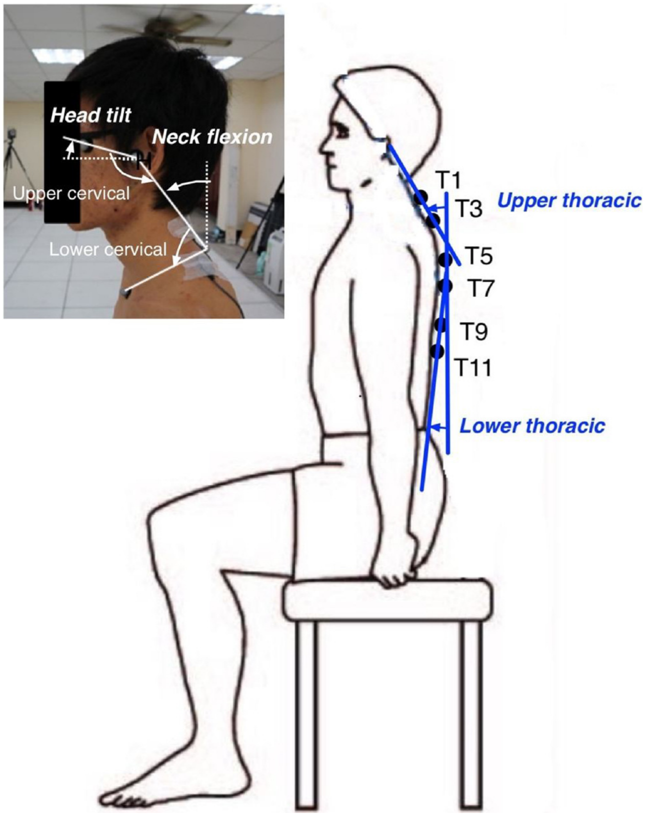

Fig. 2. Definition for head tilt, neck flexion, upper cervical, lower cervical, upper thoracic, and lower thoracic angles. Head tilt: angle between the line connecting the canthus and the tragus of the ear and the horizontal plane; neck flexion: angle between the line connecting the tragus of the ear and the T1 and the vertical plane; upper cervical: angle formed by the canthus, the tragus of the ear, and the T1; lower cervical: angle formed by the tragus of the ear, the T1, and the suprasternal notch; upper thoracic: angle between the line connecting the T1 and T3 and the line connecting the T5 and T7; lower thoracic: angle between the line connecting the T5 and T7 and the line connecting the T9 and T11. Decreased head tilt, upper cervical, and lower cervical angles indicate flexion. Decreased neck flexion, upper thoracic, and lower thoracic angles indicate extension. T1, T3, T5, T7, T9, and T11: spinous processes of the 1 st, 3rd, 5th, 7th, 9th, and 11th thoracic vertebrae.

region) with the attachments to the ribs and sternum is relatively more rigid than the cervical spine. When the participants received vibratory feedback from the device, they may naturally adjust their sitting posture by moving the parts with least resistance within the kinematic chain of the spine.

The participants in our study exhibited lower CES activity during the biofeedback condition. The lower CES activity is presumably associated with less anterior translation of the head (indicated by reduced neck flexion angle), decreasing the moment arm of the head and neck with respect to the cervical spine [22]. The biofeedback condition abated forward head posture, lowering the CES activity needed to support the weight of the head and neck.

In contrast to our findings of no significant changes in UT activity during the biofeedback condition, Yoo and Park [17] found that the application of auditory biofeedback significantly decreased forward head angle and reduced UT activity in young, healthy computer workers. Conflicting results have been reported regarding the relationship between forward head posture and UT activity. Studies have suggested that lower neck angles lead to increased muscle activity [23,24], while others have found no relationship between muscle activity and head and neck posture [25,26]. Compared with asymptomatic controls, participants with neck pain have exhibited a higher level of UT activity when resting their fingers on the keyboard and an inability to relax the neck muscles, even after completing the task [27–29]. Our findings suggested no significant postural effect on UT activity, which may indicate maladaptive behavior of the UT in response to neck pain, rather than adaptive behavior to biomechanical loads.

We found a reduced lower thoracic angle under the biofeedback condition, but no significant changes in TES activity. This result was not surprising because the EMG electrodes for the TES were placed in the upper thoracic spine at the level of T4 instead of in the lower thoracic spine. O'Sullivan et al. [30] found that TES activity was significantly influenced by different upright sitting postures compared to slump sitting. Our participants performed typing tasks, whereas participants in the O'Sullivan et al. study sat quietly with their arms relaxed at their sides. The computer workstation or the typing tasks may have prevented our participants from adopting a more slumped sitting position, which limits the kinematic changes and thus the TES activity.

Although significant effects were found in some spinal angle and EMG measurements, neither neck pain nor shoulder pain was significantly reduced with biofeedback. Changes in spinal posture and muscle activity may not have been adequate to produce a clinically meaningful reduction in pain during a single session with biofeedback. Non-physical factors, such as personality and psychosocial stress, can

Table 1
Mean and standard deviation of spinal angles (degree) under 2 conditions across time points.

Variable	T5	T15	T25	T35	T45	T55	Condition	Time	Condition × Time
Head tilt							p = 0.363	p = 0.046	p = 0.079
No biofeedback	12.6 ± 7.9	10.7 ± 8.0	12.1 ± 8.5	11.6 ± 7.8	12.0 ± 8.0	11.6 ± 8.5			
Biofeedback	11.6 ± 8.0	11.3 ± 8.0	12.1 ± 7.9	12.7 ± 7.7	12.6 ± 7.8	13.3 ± 8.6			
Neck flexion							p < 0.001	p = 0.141	p = 0.200
No biofeedback	58.2 ± 5.8	57.9 ± 5.7	57.7 ± 5.7	57.6 ± 5.5	57.9 ± 5.3	58.2 ± 5.6			
Biofeedback	55.8 ± 5.1	55.4 ± 5.2	54.6 ± 5.3	54.0 ± 5.3	54.2 ± 5.7	54.0 ± 5.4			
Upper cervical							p < 0.001	p = 0.032	p = 0.180
No biofeedback	153.4 ± 7.2	150.5 ± 6.0	152.2 ± 7.5	151.2 ± 5.6	152.2 ± 6.7	152.1 ± 6.7			
Biofeedback	149.2 ± 8.3	148.3 ± 8.0	148.3 ± 7.9	148.3 ± 8.0	148.4 ± 7.7	149.1 ± 8.6			
Lower cervical							p = 0.111	p = 0.111	p = 0.638
No biofeedback	64.5 ± 8.3	63.9 ± 8.3	64.8 ± 7.4	64.7 ± 8.0	64.7 ± 8.3	64.9 ± 8.5			
Biofeedback	63.5 ± 7.2	63.5 ± 7.3	63.6 ± 7.2	63.7 ± 7.5	63.8 ± 7.4	64.4 ± 7.3			
Upper thoracic							p = 0.694	p = 0.085	p = 0.892
No biofeedback	20.2 ± 7.3	20.8 ± 7.6	20.7 ± 7.7	21.1 ± 7.6	21.0 ± 7.3	20.9 ± 7.8			
Biofeedback	20.6 ± 7.8	21.2 ± 7.8	21.0 ± 7.7	21.1 ± 7.6	21.2 ± 7.4	21.2 ± 7.4			
Lower thoracic							p = 0.011	p = 0.133	p = 0.403
No biofeedback	15.1 ± 5.0	14.1 ± 4.7	14.8 ± 4.9	14.4 ± 5.3	15.6 ± 5.4	15.2 ± 5.9			
Biofeedback	14.1 ± 5.2	13.5 ± 5.3	12.6 ± 4.7	13.1 ± 5.0	13.2 ± 5.5	13.4 ± 4.5			

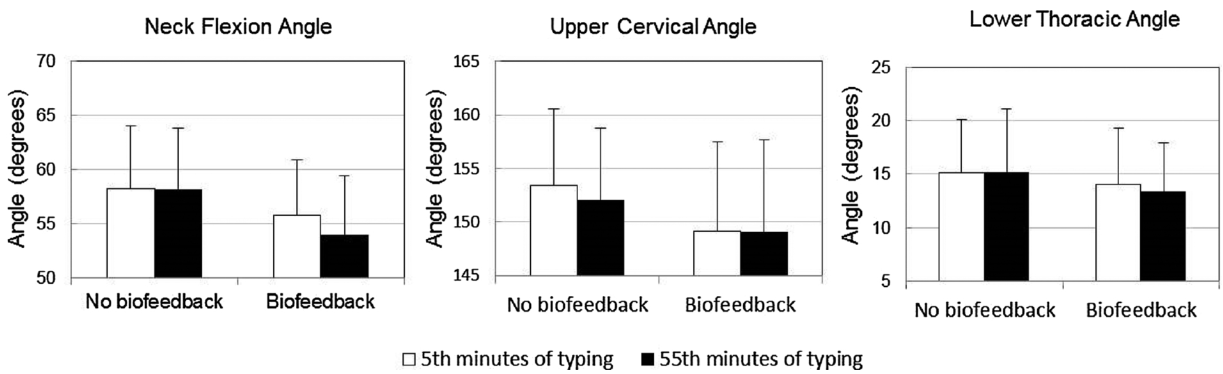

Fig. 3. Mean and standard deviation of spinal posture under two conditions (with and without biofeedback) at the start and finish of the typing task.

also increase mechanical loading and affect the perception of musculoskeletal discomfort [31,32]. Nevertheless, the reduced forward head posture and CES activity found in this study suggests decreased gravitational moment and mechanical loading between the articulation joints of the cervical spine. If a better sitting posture and reduced neck muscle activity with the use of biofeedback could be maintained for longer or more frequently, neck pain might be progressively alleviated. However, such a notion necessitates further investigation.

Some studies have reported that adults, especially those with chronic neck pain, demonstrate a more forward head posture and greater neck and shoulder muscle activity during computer work [7,33]. Our findings indicated that, despite having increased pain over time during the typing task, the participants had similar sitting posture and muscle activity throughout the 1-hour period. A possible explanation is that the participants in this study were young adults with mild neck pain. A 1-hour typing task is physically tolerable for these participants in spite of the increasing levels of pain, as most of them spend approximately 8 h using computers daily.

Postural correction through verbal cueing is commonly used in clinical settings; however, the use of biofeedback in addition to verbal cueing has been shown to be more effective than verbal cueing alone [34]. Real-time postural biofeedback can be provided in several forms, including proximity-sensing chairs [12], harnesses [15,16], and high-density surface EMG systems [34]. In contrast to postural biofeedback devices used in previous studies [12,13,15,16,34], the Lumo Lift is more portable and can be discreetly worn on clothes. Adults with neck pain have shown a reduced ability to maintain an upright posture during prolonged sitting [7,8]; thus, the immediate improvement found in this study supports the potential use of the Lumo Lift as extrinsic feedback for postural awareness during daily computer work.

The Lumo Lift device has the advantage of monitoring and promoting a more upright sitting posture in adults with neck pain; however, this study had some limitations. First, all participants were young adults with mild neck pain. This may limit the generalization of the findings. Second, this study did not measure spinal posture or muscle activity in the lumbar or shoulder regions; therefore, the Lumo Lift's ability to modify round shoulders or lumbar flexion associated with slouched sitting could not be fully understood. We also did not record how frequent the Lumo Lift was triggered. It is possible that the effects of postural biofeedback might be more important during the later stages of the typing tasks when the participants were more tired. In addition, the Lumo Lift was directly attached to the participant's skin instead of worn on clothes because motion analysis measurements require the participants to remove their clothes. Wearing the Lumo Lift on clothes (especially loose tops) during daily living may affect the effect of the device. Finally, the long-term effects of real-time postural biofeedback were not investigated.

5. Conclusions

Adults with neck pain demonstrated less forward head and thoracic kyphotic posture, as well as reduced CES muscle activity while typing with biofeedback; however, self-reported neck and shoulder pain significantly increased over time throughout a 1-hour typing task, with or without biofeedback. Future studies should examine the long-term ability of these devices to promote an ideal sitting posture during

Table 2
Mean and standard deviation of muscle activity (%) under 2 conditions across time points.

Variable	T5	T15	T25	T35	T45	T55	Condition	Time	Condition × Time
Left CES muscle							p = 0.007	p = 0.610	p = 0.167
No biofeedback	154.0 ± 88.6	153.8 ± 78.6	152.7 ± 81.5	162.9 ± 92.0	167.5 ± 85.1	170.0 ± 97.5			
Biofeedback	140.4 ± 83.9	143.3 ± 84.6	132.7 ± 65.3	128.1 ± 86.3	138.0 ± 80.3	130.9 ± 81.0			
Left UT muscle							p = 0.084	p = 0.862	p = 0.138
No biofeedback	509.8 ± 469.5	587.1 ± 466.6	608.0 ± 435.4	699.4 ± 540.8	624.0 ± 597.0	662.3 ± 556.5			
Biofeedback	558.4 ± 551.7	558.4 ± 569.0	556.2 ± 653.1	444.5 ± 478.6	523.4 ± 549.2	475.4 ± 531.5			
Left TES muscle							p = 0.586	p = 0.786	p = 0.783
No biofeedback	146.9 ± 92.5	143.5 ± 83.8	154.0 ± 100.6	137.5 ± 64.6	139.9 ± 61.2	138.5 ± 61.3			
Biofeedback	148.3 ± 65.6	142.4 ± 62.1	150.9 ± 100.2	148.6 ± 92.6	151.1 ± 108.7	161.5 ± 124.9			
Right CES muscle							p = 0.005	p = 0.540	p = 0.234
No biofeedback	158.8 ± 76.1	162.9 ± 66.9	157.4 ± 74.7	166.1 ± 76.8	167.8 ± 79.1	176.1 ± 83.4			
Biofeedback	141.3 ± 61.3	157.9 ± 121.0	136.9 ± 56.9	132.1 ± 67.5	138.8 ± 62.8	132.5 ± 57.8			
Right UT muscle							p = 0.338	p = 0.489	p = 0.419
No biofeedback	569.2 ± 506.0	652.2 ± 652.4	560.6 ± 469.3	637.1 ± 517.2	584.5 ± 478.4	643.1 ± 571.9			
Biofeedback	606.4 ± 605.9	546.4 ± 602.3	496.2 ± 496.5	566.7 ± 625.5	545.9 ± 585.8	518.0 ± 594.1			
Right TES muscle							p = 0.244	p = 0.588	p = 0.309
No biofeedback	145.8 ± 64.1	207.3 ± 265.3	193.7 ± 248.0	190.7 ± 238.8	151.6 ± 92.0	183.0 ± 211.5			
Biofeedback	161.8 ± 96.0	147.2 ± 59.5	139.9 ± 64.7	155.4 ± 80.3	166.8 ± 168.0	153.6 ± 126.4			

Abbreviations: cervical erector spinae (CES), upper trapezius (UT), and thoracic erector spinae (TES).

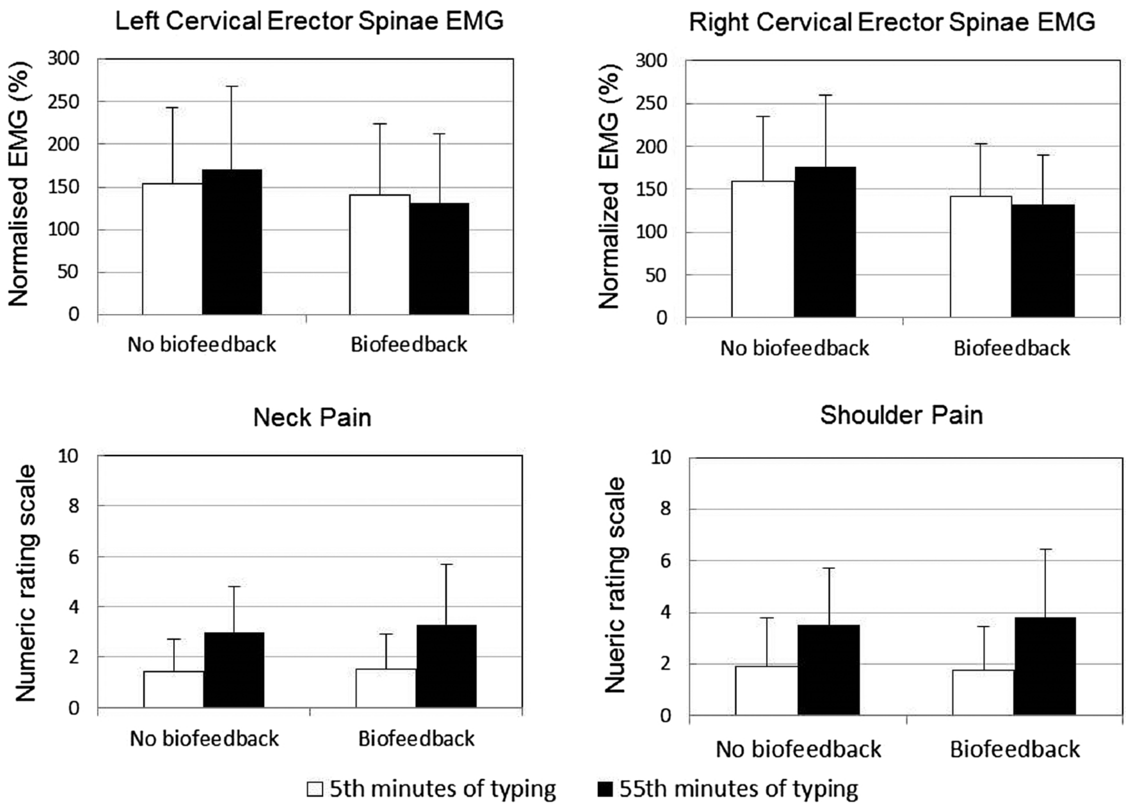

Fig. 4. Mean and standard deviation of muscle activity (left and right cervical erector spinae) and perceived pain severity (neck and shoulder) under two conditions (with and without biofeedback) at the start and finish of the typing task.

computer work, and to prevent or manage neck pain.

Conflict of interest

The authors have no conflict of interest to report.

Funding

This study was funded by the Ministry of Science and Technology of Taiwan (R.O.C.) (grant number MOST 106-2410-H-006-083-MY2) and the National Cheng Kung University Hospital, Tainan, Taiwan (R.O.C.) (grant numbers NCKUH-10506017 and NCKUH-10603030).

References

[1] D.G. Hoy, M. Protani, R. De, R. Buchbinder, The epidemiology of neck pain, Best Pract. Res. Clin. Rheumatol. 24 (2010) 783–792.
[2] E.K. Hansson, T.H. Hansson, The costs for persons sick-listed more than one month because of low back or neck problems. A two-year prospective study of Swedish patients, Eur. Spine J. 14 (2005) 337–345.
[3] G.A. Ariens, P.M. Bongers, M. Douwes, M.C. Miedema, W.E. Hoogendoorn, G. van der Wal, et al., Are neck flexion, neck rotation, and sitting at work risk factors for neck pain? Results of a prospective cohort study, Occup. Environ. Med. 58 (2001) 200–207.
[4] G.P. Szeto, L. Straker, S. Raine, A field comparison of neck and shoulder postures in symptomatic and asymptomatic office workers, Appl. Ergon. 33 (2002) 75–84.
[5] P. Griegel-Morris, K. Larson, K. Mueller-Klaus, C.A. Oatis, Incidence of common postural abnormalities in the cervical, shoulder, and thoracic regions and their association with pain in two age groups of healthy subjects, Phys. Ther. 72 (1992) 425–431.
[6] C.H. Yip, T.T. Chiu, A.T. Poon, The relationship between head posture and severity and disability of patients with neck pain, Man. Ther. 13 (2008) 148–154.
[7] D. Falla, G. Jull, T. Russell, B. Vicenzino, P. Hodges, Effect of neck exercise on sitting posture in patients with chronic neck pain, Phys. Ther. 87 (2007) 408–417.
[8] G.P. Szeto, L.M. Straker, P.B. O'Sullivan, A comparison of symptomatic and asymptomatic office workers performing monotonous keyboard work–2: neck and shoulder kinematics, Man. Ther. 10 (2005) 281–291.
[9] J. de Vries, B.K. Ischebeck, L.P. Voogt, J.N. van der Geest, M. Janssen, M.A. Frens, et al., Joint position sense error in people with neck pain: a systematic review, Man. Ther. 20 (2015) 736–744.
[10] T.R. Stanton, H.B. Leake, K.J. Chalmers, G.L. Moseley, Evidence of impaired proprioception in chronic, idiopathic neck pain: systematic review and meta-analysis, Phys. Ther. 96 (2016) 876–887.
[11] N. Azrin, H. Rubin, F. O'Brien, T. Ayllon, D. Roll, Behavioral engineering: postural control by a portable operant apparatus, J. Appl. Behav. Anal. 1 (1968) 99–108.
[12] W.G. Yoo, C.H. Yi, M.H. Kim, Effects of a proximity-sensing feedback chair on head, shoulder, and trunk postures when working at a visual display terminal, J. Occup. Rehabil. 16 (2006) 631–637.
[13] P.P. Breen, A. Nisar, G. ÓLaighin, 31st Annual International Conference of the IEEE EMBS2009 Evaluation of a single accelerometer based biofeedback system for real-time correction of neck posture in computer users (2018).
[14] D.C. Ribeiro, G. Sole, J.H. Abbott, S. Milosavljevic, The effectiveness of a lumbopelvic monitor and feedback device to change postural behavior: a feasibility randomized controlled trial, J. Orthop. Sports Phys. Ther. 44 (2014) 702–711.
[15] F. O'Brien, N.H. Azrin, Behavioral engineering: control of posture by informational feedback, J. Appl. Behav. Anal. 3 (1970) 235–240.
[16] S.T. Celenay, D.O. Kaya, A. Ozudogru, Spinal postural training: comparison of the postural and mobility effects of electrotherapy, exercise, biofeedback trainer in addition to postural education in university students, J. Back Musculoskelet. Rehabil. 28 (2015) 135–144.
[17] W.G. Yoo, S.Y. Park, Effects of posture-related auditory cueing (PAC) program on muscles activities and kinematics of the neck and trunk during computer work, Work 50 (2015) 187–191.
[18] E. Lou, J. Raso, D. Hill, N. Durdle, M. Moreau, Spine-Straight device for the treatment of kyphosis, Stud. Health Technol. Inf. 91 (2002) 401–404.
[19] J.A. Cleland, J.D. Childs, J.M. Whitman, Psychometric properties of the Neck Disability Index and Numeric Pain Rating Scale in patients with mechanical neck pain, Arch. Phys. Med. Rehabil. 89 (2008) 69–74.
[20] Y. Brink, Q. Louw, K. Grimmer, E. Jordaan, The spinal posture of computing adolescents in a real-life setting, BMC Musculoskelet. Disord. 15 (2014) 212.
[21] Y.L. Kuo, E.A. Tully, M.P. Galea, Video analysis of sagittal spinal posture in healthy young and older adults, J. Manipulative Physiol. Ther. 32 (2009) 210–215.
[22] J.P. Caneiro, P. O'Sullivan, A. Burnett, A. Barach, D. O'Neil, O. Tveit, et al., The influence of different sitting postures on head/neck posture and muscle activity, Man. Ther. 15 (2010) 54–60.
[23] T.H. Lee, J.H. Lee, Y.S. Lee, M.K. Kim, S.G. Kim, Changes in the activity of the muscles surrounding the neck according to the angles of movement of the neck in adults in their 20s, J. Phys. Ther. Sci. 27 (2015) 973–975.
[24] C.S. Enwemeka, I.M. Bonet, J.A. Ingle, S. Prudhithumrong, F.E. Ogbahon, N.A. Gbenedio, Postural correction in persons with neck pain (II. Integrated electromyography of the upper trapezius in three simulated neck positions), J. Orthop. Sports Phys. Ther. 8 (1986) 240–242.
[25] A. Aaras, K.I. Fostervold, O. Ro, M. Thoresen, S. Larsen, Postural load during VDU

work: a comparison between various work postures, Ergonomics 40 (1997) 1255–1268.
[26] K.-J. Lee, H.-Y. Han, S.-H. Cheon, S.-H. Park, M.-S. Yong, The effect of forward head posture on muscle activity during neck protraction and retraction, J. Phys. Ther. Sci. 27 (2015) 977–979.
[27] G.P. Szeto, L.M. Straker, P.B. O'Sullivan, Neck-shoulder muscle activity in general and task-specific resting postures of symptomatic computer users with chronic neck pain, Man. Ther. 14 (2009) 338–345.
[28] D. Falla, G. Bilenkij, G. Jull, Patients with chronic neck pain demonstrate altered patterns of muscle activation during performance of a functional upper limb task, Spine 29 (2004) 1436–1440.
[29] V. Johnston, G. Jull, R. Darnell, N.L. Jimmieson, T. Souvlis, Alterations in cervical muscle activity in functional and stressful tasks in female office workers with neck pain, Eur. J. Appl. Physiol. 103 (2008) 253–264.
[30] P.B. O'Sullivan, W. Dankaerts, A.F. Burnett, G.T. Farrell, E. Jefford, C.S. Naylor, et al., Effect of different upright sitting postures on spinal-pelvic curvature and trunk muscle activation in a pain-free population, Spine 31 (2006) E707–12.
[31] W.S. Marras, K.G. Davis, C.A. Heaney, A.B. Maronitis, W.G. Allread, The influence of psychosocial stress, gender, and personality on mechanical loading of the lumbar spine, Spine 25 (2000) 3045–3054.
[32] S.J. Linton, A review of psychological risk factors in back and neck pain, Spine 25 (2000) 1148–1156.
[33] G.P. Szeto, L.M. Straker, P.B. O'Sullivan, A comparison of symptomatic and asymptomatic office workers performing monotonous keyboard work–1: neck and shoulder muscle recruitment patterns, Man. Ther. 10 (2005) 270–280.
[34] B.M. Gaffney, K.S. Maluf, B.S. Davidson, Evaluation of novel EMG biofeedback for postural correction during computer use, Appl. Psychophysiol. Biofeedback 41 (2016) 181–189.