European Spine Journal (2019) 28:1793–1803
https://doi.org/10.1007/s00586-019-06022-0

ORIGINAL ARTICLE

Analysis of a customized cervical collar to improve neck posture during smartphone usage: a comparative study in healthy subjects

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Received: 23 February 2019 / Revised: 14 May 2019 / Accepted: 27 May 2019 / Published online: 5 June 2019

Abstract

Purpose A slouching posture during smartphone usage increases gravitational loadings on the cervical spine, which may lead to neck pain and degeneration. The objective of the present study was to investigate the head, neck and trunk angles in different smartphone-usage postures, as well as the posture-correction effects and comfort scores of three neck collars.

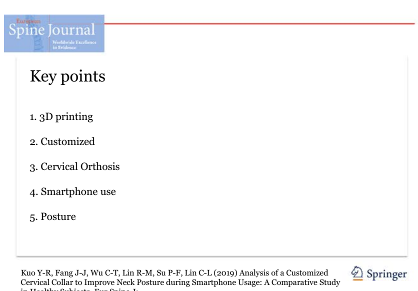
Methods This was a prospective cohort study in which 41 healthy young subjects aged 18–25 were recruited. The head, neck and trunk angles were measured in all participants during a neutral position and three smartphone-using postures, including sitting with and without back support and standing. The postural correction and comfort scores of three collars (Aspen Vista, Sport-aid and our customized 3D printed collars) were compared.

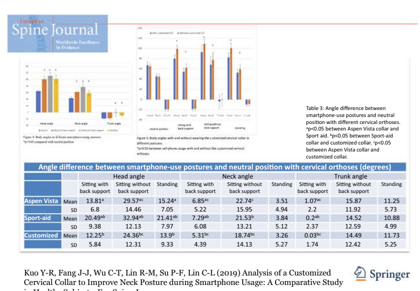
Results Smartphone use increased the head and neck flexion angles in all postures, and sitting without back support showed the greatest head and neck flexion angles. The posture-correcting effect of the customized collar was better than the Aspen Vista and Sport-aid collars. In addition, the customized collar was more comfortable to wear than the other two collars in most contact areas.

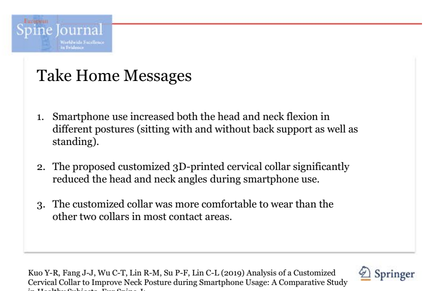
Conclusion Smartphone use increased both the head and neck flexion in different postures, and the proposed customized 3D-printed cervical collar significantly reduced the head and neck angles.

Graphical abstract

These slides can be retrieved under Electronic Supplementary Material.







Keywords Customized · 3D printing · Cervical orthosis · Postures · Smartphone use

The authors Kuo and Fang contributed equally to this research, and both are first coauthors.

Electronic supplementary material The online version of this article (https://doi.org/10.1007/s00586-019-06022-0) contains supplementary material, which is available to authorized users.

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Introduction

With the advancement of modern technology, the use of handheld electronic devices has become indispensable in daily life. However, using such devices can lead to postural and ergonomic changes, which in turn may cause chronic neck pain and early cervical degeneration. A systemic review revealed that the prevalence of musculoskeletal complaints among mobile device users ranged from 1.0 to 67.8%, with neck complaints showing the highest prevalence rates, ranging from 17.3 to 67.8% [1]. Guan et al. [2] found that subjects displayed a more forward head posture when viewing a mobile phone screen. More specifically, the stress on the cervical spine was shown to reach up to 60 lb when the neck was tilted forward at 60° [3], and the gravitational loading on the cervical spine during tablet computer use (neck flexion posture) was reported to be 3–5 times higher than that in the neutral position [4]. Meanwhile, the upper trapezius muscles showed the highest muscle fatigue rate at a cervical flexion angle of 50° [5]. There is even a term called "text neck," which refers to cervical spinal degeneration resulting from the repeated stress of frequent forward head flexion while looking down at the screens of mobile devices and "texting" for long periods of time [6]. In brief, long-term neck flexion posture could result in muscle fatigue, pain and possible neck disorders. To address this issue, several studies have recommended that subjects remain in a neutral position when using handheld electronic devices to prevent subsequent musculoskeletal disorders [2, 7–10].

To date, various checklists for occupational and ergonomic risk factors have listed neck flexion angles greater than 20° as being high risk for musculoskeletal disorders [11, 12]. Therefore, it is of great importance to prevent excessive neck flexion posture when using smartphones. Yoo et al. [13] found that with the use of a proximity-sensing feedback chair, subjects working on visual displays could maintain a better posture. On the other hand, neck collars have been used in various fields, and we believe that head and neck posture could be maintained by wearing a neck collar. However, current commercial products are designed to fit the general population, and so might cause discomfort for the user due to an improper fit, which in turn, could lead to incompliance and ineffectiveness of maintaining posture. In addition, healthy individuals may not be willing to use such a restrictive device only to prevent potential hazards. Hence, designing an individualized neck accessory that not only fits the target subject perfectly, but is also lightweight and aesthetically pleasing, may be one solution.

With the maturation of 3D printing technology, a variety of customized medical devices have been used clinically or in trials. Therefore, we employed 3D printing technology to create a customized neck collar for individuals and compared its posture-correcting effect during smartphone use with current commercial products. There were two goals for this study: first, to investigate whether different postures during smartphone usage have an impact on the head and neck angles, and second, to evaluate the effectiveness of customized neck collars and compare them with current commercial products.

Materials and methods

This study is a prospective cohort study, level of evidence 2.

Subjects

Forty-one healthy subjects (31 males and 10 females) aged 18–25 were recruited in this study. The exclusion criteria for recruiting subjects included any underlying vertebral disorders, previous operation history on spinal column and chronic pain history. To be qualified for this study, subjects must be able to stand up and sit freely and use a smart phone without any aid. Approval was obtained from our institutional board, and informed consent was acquired from each individual subject.

Cervical orthoses

There were three neck collars used in this study: the Aspen Vista collar (Fig. 1a), the Sport-aid cervical collar (Fig. 1b) and our 3D-printed customized collar (Fig. 1c, d).

Figure 2 illustrates the workflow of creating a customized collar. We used a handheld body surface scanner (Go!SCAN 50, Creaform, Quebec, Canada) to scan the head and neck areas of each subject. The camera calibration process was activated before use each time. Subjects were asked to sit on a chair with a back rest at a − 14.5° leaning angle during the entire scanning process. The digital image around each person's frontal neck area was carefully examined to capture missing parts by repeated scanning. Then, the scanned image was loaded into a brace-generating application developed by our research team in order to construct a customized brace. The coverage area included the area below the lip, chin to mandibular angle and all the way down to the subclavicular region. Areas near the trachea, hyoid bone and thyroid cartilage were left open to reduce discomfort (Fig. 1d). The digital cervical brace model was constructed via a series of geometric processes in mesh removals, including voids filling and smoothing, solid objects generating with given thickness, model smoothing, peripherals adding, venting holes and Boolean subtracting. The cervical brace was then fabricated by a fused deposition modeling (FDM) 3D printer with biodegradable polylactide (PLA) materials.

Experimental setup

Based on the measurement of postural angles reported in the literature [2, 9, 14–18], we used colored stickers and polystyrene balls to attach to the subjects' landmarks before testing. As shown in Fig. 3c, the landmarks

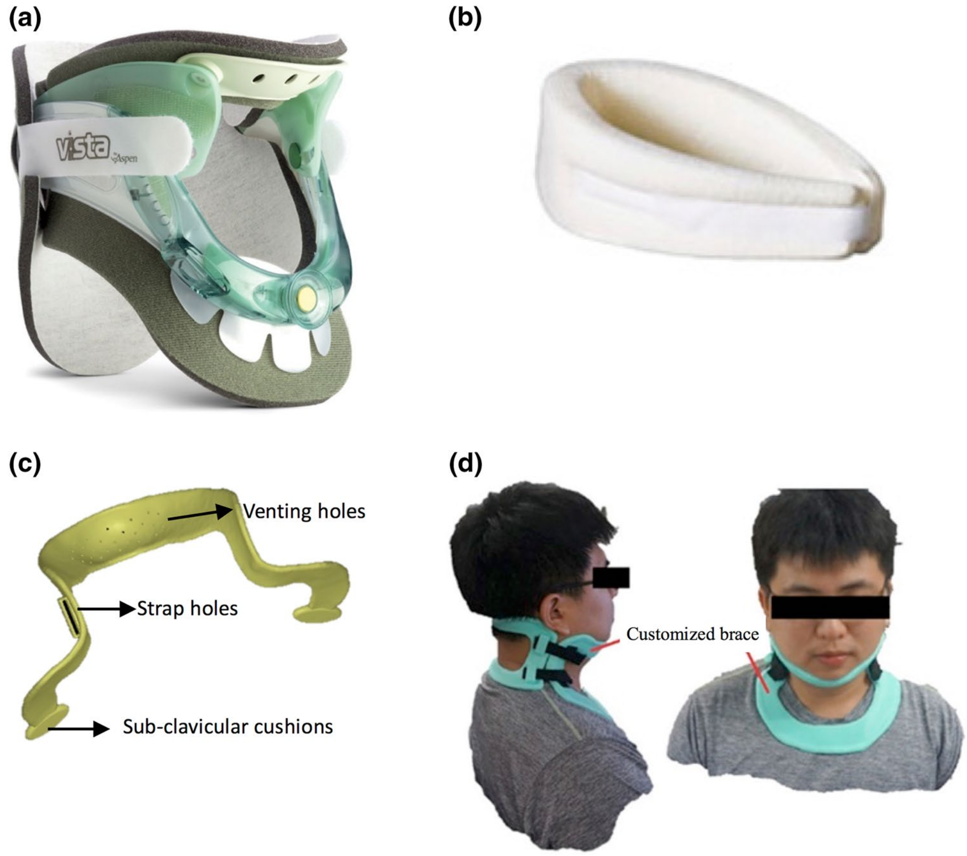

Fig. 1 Three cervical orthoses used in this study: **a** Aspen Vista collar; **b** Sport-aid cervical collar; **c** 3D customized cervical collar and; **d** customized collar worn by a test subject in the frontal and lateral views

included the lateral canthus (C), tragus (T), spinous process of C7 (C7), 15 cm below the spinous process of C7 (C7′), and greater trochanter (GT).

In the experimental environment settings, a digital camera (Nikon D7000, Nikon Corporation, Japan) with a 35-mm focused lens was set on a tripod and placed 3 meters from the right side of the subject (Fig. 3a, b). The camera height was set horizontally to align with the subject's shoulder. A 300 g plumb was hung at the end of a string and fixed to the ceiling. We also marked a bright color on the string to form a vertical line for the test. The string was set 0.5 m behind the seat and retained still before testing.

During each smartphone-usage posture, videos were recorded with the camera, after which the head, neck and trunk angles were automatically calculated by a computer based on the videos. The head angle was defined as the included angle between the line connecting C and T and the vertical line; meanwhile, the neck angle was identified as the included angle between the line connecting T and C7 and the vertical line. And, the trunk angle was defined as the included angle between the line connecting C7 and GT and the vertical line (Fig. 3). Starting from the vertical line, angles were defined as positive if they were clockwise and negative if counterclockwise.

Head and neck angles in different smartphone-using postures

In this part of the study, subjects were asked to remain seated in a relaxed posture without using a smartphone (neutral position) for 30 s, followed by three different postures while using a smartphone, with each posture being maintained for 5 min and resting for 1 min in between. These postures included sitting and leaning against the back of the chair, sitting and not leaning against the back of the chair and standing (Fig. 4). Two images per second were captured from the recorded video files (720p/30fps), for a total of 60 images from the neutral position and 600 images from each of the smartphone-using postures. The first image of each series was processed so that only surface landmarks remained in the image, which was then set as a reference. Head, neck and trunk angles were automatically measured using MATLAB software with the above-mentioned digital camera. All landmarks were integrated and computed to obtain the means of the head, neck and trunk angles as well as their standard deviations.

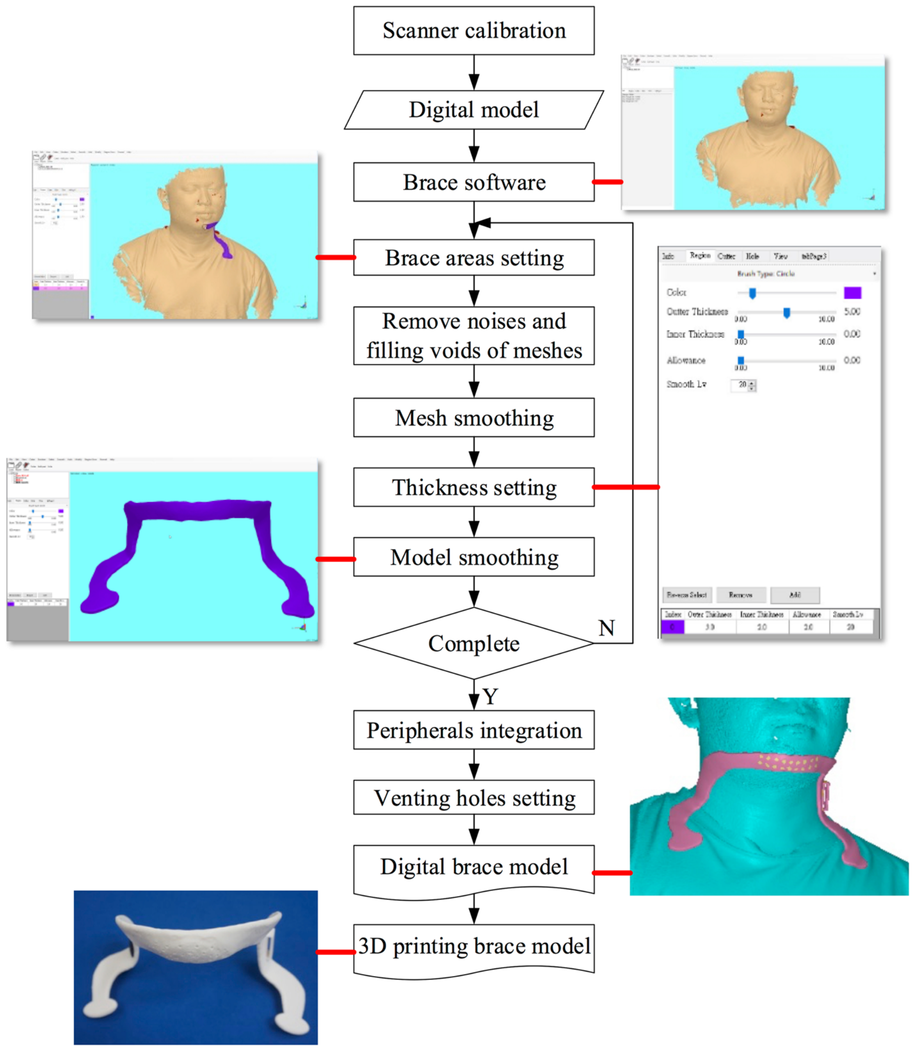

Fig. 2 Workflow for creating a customized cervical collar

Posture-correcting effects and comfort ratings of different cervical orthoses

Subjects were asked to use smartphones with three kinds of cervical orthoses (customized, Aspen Vista, and Sport-aid collars). Videos were taken from both the neutral and smartphone-using postures. The head, neck and trunk angles were then measured based on the obtained images. Questionnaires regarding the comfort level over various contact areas of the orthoses were given to all subjects, with grading ranging from 1 (the least comfortable) to 7 (the most comfortable). The contact areas of the brace on the skin include the chin, neck, shoulders, subclavicular area and posterior neck.

Statistical analysis

Statistical analysis was performed with SPSS software (version 17.0; SPSS, Chicago, IL). A priori power analysis was calculated based on a pilot study that used 10 participants in each group. The results established that a sample size of at least 30 participants per group would provide a study power of 0.85 at a two-sided 0.05 significance level (α). Data were expressed as means ± standard deviations (SD). Side-by-side bar charts were used to depict the comparison results. Nonparametric statistical analysis and the aligned rank test were applied to compare the angles among different postures, body angles and cervical orthoses. If statistical significance was present, Friedman tests were then used for post hoc analysis. We calculated the inter-rater validity of the questionnaires regarding comfort level, for which Cronbach's α value was 0.87. All statistical tests were 2-sided, with $p < 0.05$ accepted as statistically significant.

Results

In a neutral sitting position without using a smartphone, the head, neck and trunk angles were 65.19° ± 5.47°, 43.43° ± 5.13° and − 19.2° ± 3.57°, respectively. The angle differences mentioned below were calculated by subtracting

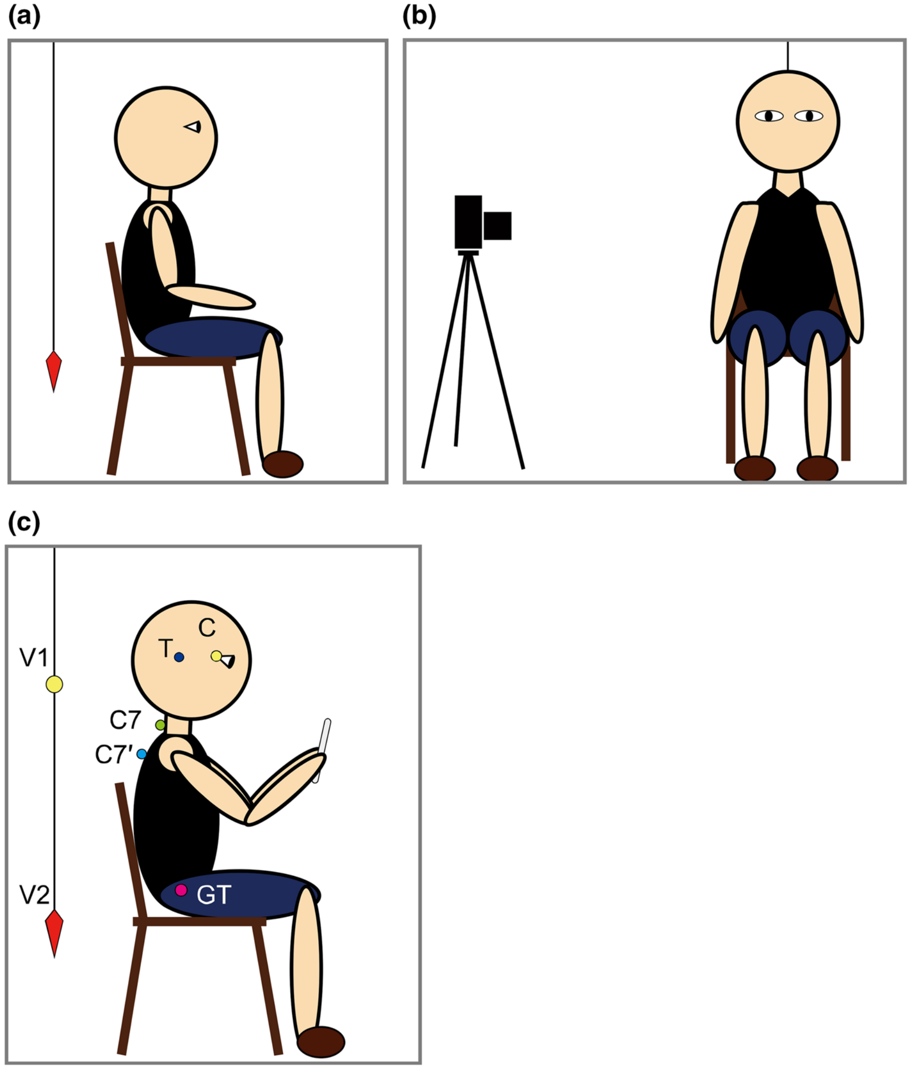

Fig. 3 **a** Lateral setting; **b** frontal setting; and **c** sitting posture when using a smartphone. Lateral canthus (C), tragus (T), spinous process of C7 (C7), 15 cm below the spinous process of C7 (C7′), and greater trochanter (GT). Color marked on string (V1) and plumb (V2) at the end of the string

the angles of the neutral position from the angles of the smartphone-using postures.

Head, neck and trunk angles in different smartphone-using postures (Table 1, Fig. 5)

The head and neck angles were significantly increased in all three smartphone-using postures compared to the neutral position ($p < 0.05$). The angle differences when sitting without back support were significantly higher than those when sitting with back support and standing ($p < 0.05$), while there was no significant difference between sitting with back support and standing. For the trunk angles, the angle differences were significantly increased when standing and sitting without back support ($p < 0.05$) compared to the neutral position. The angle difference when sitting with back support was also considerably smaller than that when sitting without back support and standing ($p < 0.05$). Among the three postures, the head, neck and trunk angle differences were the greatest when sitting without back support ($p < 0.05$).

Comparison of head, neck and trunk angles between wearing and not wearing the customized cervical orthoses (Table 2, Fig. 6)

The head and neck angles were significantly increased in all smartphone-using postures, both with and without the customized cervical collar. Among the three smartphone-using postures, sitting without back support showed the greatest head, neck and trunk angle increases, for both with and without a customized cervical collar. Nevertheless, the head and neck angle differences were significantly reduced during all smartphone-using postures while wearing the customized cervical collar as compared to without ($p < 0.05$).

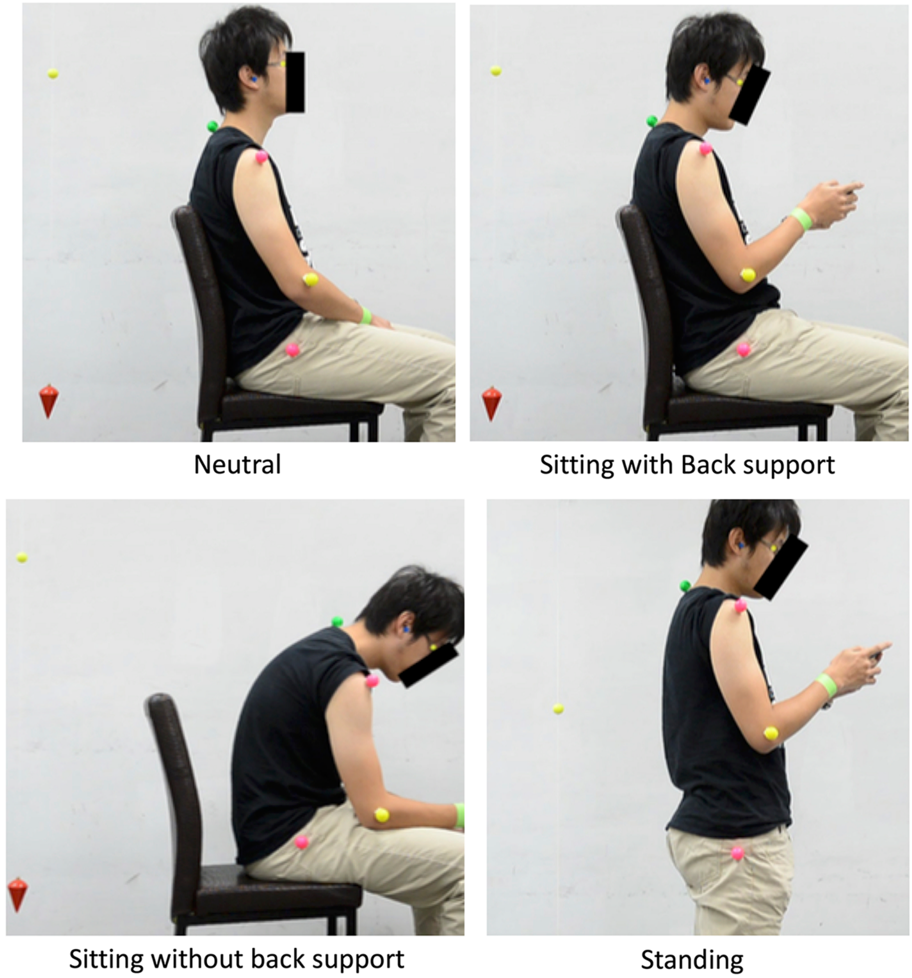

Fig. 4 Different smartphone-using postures

Table 1 Angle difference between neutral position and smartphone-use postures

		Head angle	Neck angle	Trunk angle
Sitting with back support	Mean	35.23^{a*}	19.08^{a*}	1.08^{ac}
	SD	9.59	7.08	2.9
Sitting without back support	Mean	45.46^{ab*}	34.09^{ab*}	17.39^{a*}
	SD	11.93	12.86	11.43
Standing	Mean	36.25^{b*}	15.45^{b*}	10.11^{c*}
	SD	11.17	7.11	3.76

*$p < 0.05$ compared with neutral position

[a]$p < 0.05$ between sitting with and without (w/o) back support

[b]$p < 0.05$ between sitting without back support and standing

[c]$p < 0.05$ between sitting with back support and standing

Comparison of head, neck and trunk angles among different cervical orthoses during smartphone usage (Table 3)

Among all three smartphone-using postures, the greatest head and neck angle differences were found when sitting without back support, regardless of which cervical collar was used. However, the customized cervical collar decreased the head angle difference more than did the Aspen Vista and Sport-aid collar ($p < 0.05$). In terms of neck angle difference, the customized cervical collar decreased the angle difference more than did the Aspen Vista and Sport-aid collar ($p < 0.05$), but no statistical significance was noted between the Aspen Vista and Sport-aid collars. When sitting with back support, the customized cervical collar and Aspen Vista collar both decreased the

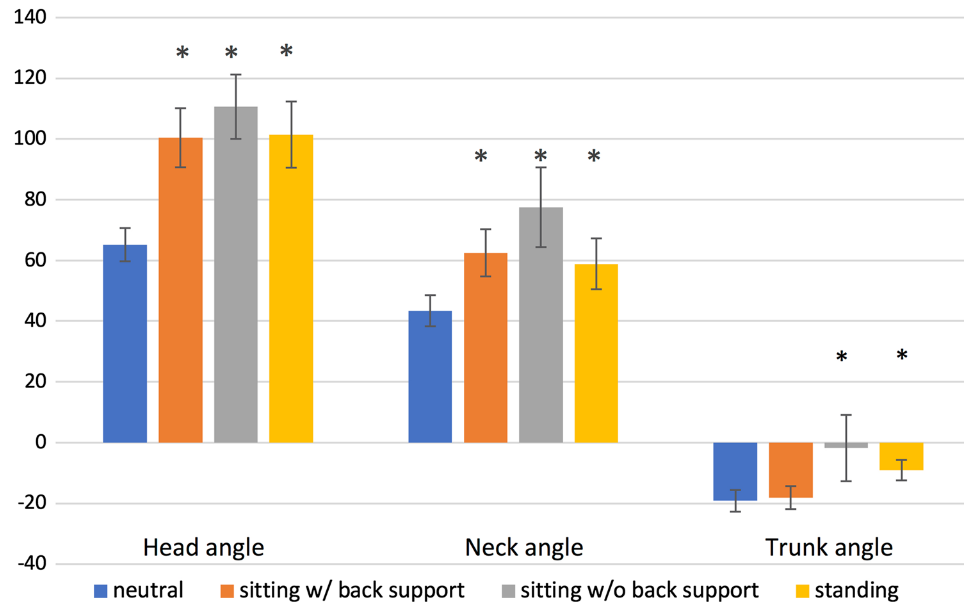

Fig. 5 Body angles in different smartphone-using postures. $*p<0.05$ compared with neutral position

Table 2 Angle difference between smartphone-use postures and neutral position with and without customized cervical orthoses

		With customized CO			Without customized CO		
		Head angle	Neck angle	Trunk angle	Head angle	Neck angle	Trunk angle
Sitting with back support	Mean	12.62*	9.22*	0.53	34.31	17.71	0.81
	SD	5.95	5.9	1.88	8.87	5.98	3.16
Sitting without back support	Mean	24.7*	22.28*	15.03	43.97	32.5	17.04
	SD	12.24	13.9	12.63	12.04	13.77	12.51
Standing	Mean	14.28*	6.76*	9.37*	35.8	14.73	9.77
	SD	9.37	6.34	4.78	11.85	7.02	4.2

$*p<0.05$ compared with not wearing customized CO

head angle difference more significantly than the Sport-aid collar. With respect to neck angle difference, the customized cervical collar decreased the angle difference more than did the Aspen Vista and Sport-aid collars ($p<0.05$). And when standing, the customized cervical collar and Aspen Vista collar both significantly decreased the head angle difference; however, there was no significant difference in neck angle among the three collars.

The comfort ratings of the three collars (Table 4)

The comfort scores of the customized cervical collars were higher than those of the other two collars in all contact areas except the sub-clavicular region. Overall, the customized cervical collar ranked first for comfort among all three collars, followed by the Aspen Vista collar then Sport-aid collar, although the differences did not reach statistical significance.

Discussion

In the present study, we found that smartphone use increased the head and neck flexion when sitting with and without back support and standing, among which sitting without back support showed the greatest head angle and neck angle flexion. We endeavored to customize a prototype neck accessory that not only fits the individual subject perfectly, but is also aesthetically pleasing and convenient to wear. The results revealed that the customized cervical collar significantly reduced the degree of head and neck angle difference during smartphone usage. The effect of the customized cervical collar was better than both the rigid collar (Aspen Vista collar) and soft collar (Sport-aid collar). Similarly, the mean comfort score of the customized cervical collar was also higher than those of the other two collars in all contact areas, except the sub-clavicular region.

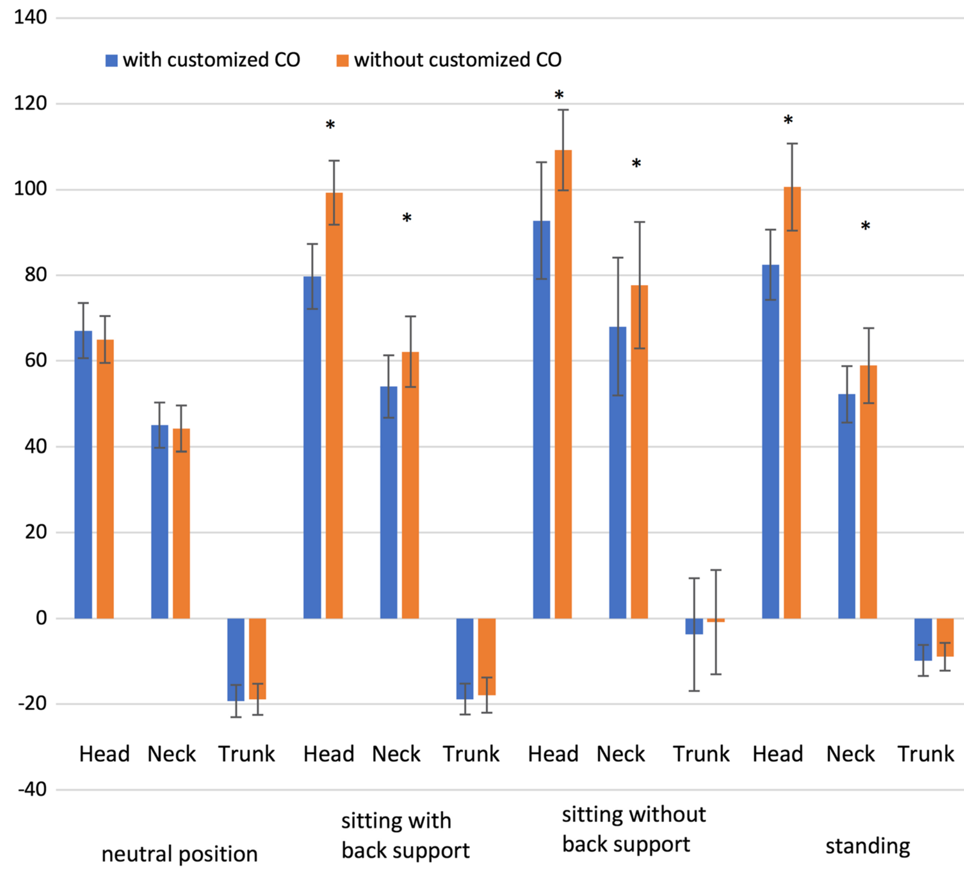

Fig. 6 Body angles with and without wearing the customized cervical collar in different postures. *$p < 0.05$ between smartphone usage with and without the customized cervical orthoses

Table 3 Angle difference between smartphone-use postures and neutral position with different cervical orthoses

		Head angle			Neck angle			Trunk angle		
		Sitting with back support	Sitting without back support	Standing	Sitting with back support	Sitting without back support	Standing	Sitting with back support	Sitting without back support	Standing
Aspen Vista	Mean	13.81[a]	29.57[ac]	15.24[a]	6.85[ac]	22.74[c]	3.51	1.07[ac]	15.87	11.25
	SD	6.8	14.46	7.05	5.22	15.95	4.94	2.2	11.92	5.73
Sport-aid	Mean	20.49[ab]	32.94[ab]	21.41[ab]	7.29[ab]	21.53[b]	3.84	0.2[ab]	14.52	10.88
	SD	9.38	12.13	7.97	6.08	13.21	5.12	2.37	12.59	4.99
Customized	Mean	12.25[b]	24.36[bc]	13.9[b]	5.31[bc]	18.74[bc]	3.26	0.03[bc]	14.49	11.73
	SD	5.84	12.31	9.33	4.39	14.13	5.27	1.74	12.42	5.25

[a]$p < 0.05$ between Aspen Vista collar and Sport-aid

[b]$p < 0.05$ between Sport-aid collar and customized collar

[c]$p < 0.05$ between Aspen Vista collar and customized collar

Cervical orthoses are widely used clinically, the usage of which ranges from muscle spasm to cervical instability. The main objectives are to allow the neck to rest and provide support, to enable the muscles to relax and to permit any inflammation to subside [19]. In addition, neck collars should also act as a reminder to restrict head and neck motions and to partially relieve the gravitational stress due to weight transfer [20]. Since a collar supports a portion of the head weight, the cervical spine is partially unloaded. Be that as it may, the supportive effects may vary due to different collar materials and designs, as well as patient compliance [5, 19, 21, 22]. Yoon et al. [23] reported that the use of a cervical brace decreased the forward head posture and thoracic kyphosis during visual display terminal work. Commercial neck collars can be roughly classified into three types: hard collars, soft collars and adjustable collars. Soft collars are composed

Table 4 Comfort ratings of different cervical orthoses

		Aspen Vista	Sport-aid	Customized
Chin	Mean	4.6	4.83	5.2
	SD	1.5	1.58	1.24
Neck and shoulder	Mean	5.27	4.73	5.83
	SD	1.62	1.36	1.56
Subclavicular area	Mean	5	5.57	4.83
	SD	1.49	1.5	1.53
Posterior neck	Mean	5.1	4.83	5.27
	SD	1.49	1.44	1.44
Overall	Mean	5	4.83	5.4
	SD	1.17	1.15	0.89

of foams and centered on the cervical spine; hard collars are constructed of plastics and foams, which surround the neck at the occipital bone, mandible, sternum and clavicle; and adjustable collars are equipped with straps and buttons that fit different neck lengths. A previous study compared the effects of restricting the cervical range of motions of four different neck collars (hard collar, soft collar, Plastazote collar and custom fit collar) and found that the custom fit collar along with the Plastazote collar provided the best restricting effects, whereas the soft collar was the worst [19]. It was also reported that a soft collar does not adequately immobilize the cervical spine compared to a rigid cervical brace [24].

Our customization process was based on the hypothetical forces according to a previous study, and thus, the chin, sub-clavicular and neck were chosen as the supporting parts [25]. Areas near the trachea, hyoid bone and thyroid cartilage were left open to reduce discomfort, as proposed by Goutcher et al. [26] and Powers et al. [21]. The results in the present study also suggest that the 3D-printed cervical collar had the best restricting effect, while the Sport-aid (soft) collar had the worst stabilizing effect during smartphone usage.

The use of electronic devices has been associated with negative musculoskeletal symptoms, particularly in the neck and shoulder region [27]. These symptoms may be related to prolonged head and neck flexion postures, which in turn increase the mechanical stress on the neck. We believe that our 3D-printed cervical orthosis can be used to correct the slouching posture during smartphone usage. Doing so may be of benefit to frequent users of smartphones, thereby preventing overly flexed neck postures and the subsequent early degeneration of the cervical spine. Hansraj et al. [3] used the finite element model to assess stresses in the cervical spine and found that the force exerted on the cervical spine was the least at 0 degrees of neck flexion. Other studies have also suggested that one's posture should remain in a neutral position during the usage of electronic devices, which indicates better ergonomics [2, 7, 8]. We applied this concept when scanning the surface anatomy of the neck for the customization of the orthoses. However, supporting the neck might induce increased loading on the shoulder and elbow. The duration and frequency of use, as well as the weight of the mobile device, could also affect the load on the upper extremities. Accordingly, to prevent musculoskeletal symptoms/discomfort due to mobile phone use, it is recommended that one should support the forearm and prevent forward head and neck bending [10].

It has been reported that the head and neck flexion angles were reduced when a computer display is set at a subject's eye height (high display: head flexion 75.2°, neck flexion 55.2°), compared with one set at desk height (mid display: head flexion 90°, neck flexion 61.3°) and paper on a desk (book display: head flexion 109.3°, neck flexion 80.5°) [28]. In the present study, the head, neck and trunk angles (99.27°, 62.17°, and − 17.89°, respectively) were between the mid display and book level during smartphone use without a customized cervical collar. With the aid of the customized cervical collar, the head angle (79.72°) and neck angle (54.04°) were similar to the angles with a high display. Therefore, it could be concluded that the customized cervical collar improved smartphone-use posture via a smaller neck flexion degree. Specifically, the head and neck flexion angles were, respectively, decreased by 20 and 10 degrees. Hansraj et al. [3] reported that the loading on the cervical spine increased by 10 lb for every 15-degree increase of neck flexion. With the aid of a cervical orthosis, the cervical spine would not be subject to additional loading, and thus, the incidence of neck pain and possible degeneration could be lowered.

The head and neck angles in the present study were $101.44° \pm 10.91°$ and $58.88° \pm 8.39°$ during smartphone use in the standing position, which were greater than those in a previous study (head $95.22° \pm 11.31°$ and neck $51.23° \pm 9.73°$ [2]. It is noted that the difference in angle-measuring methods may bring about such discrepancies. The angles measured in our study were averages from 5 min of use, while only a single smartphone-using posture was assessed in [2]. Hence, the increased angles might be due to muscle fatigue after 5 min of use. A similar method of video-recording was used in a previous study to increase reliability [20]. Accordingly, the current measurements may represent actual smartphone use more accurately.

Neck support can be categorized into soft- and strong-support orthoses [29]. While strong-support orthoses effectively restrict the cervical range of motion, they cause discomfort in long-term use; in contrast, soft-support orthoses are more comfortable to wear, but allow a greater degree of movement. Therefore, in prescribing cervical orthoses, one should strike a balance between the aimed degree of postural correction and comfort level. Two studies on the assessment of cervical orthoses included a subjective rating of comfort. Karason et al. used a scale from 1 to 5 for the subjective assessment of comfort level (5 being the most comfortable) of four different orthoses, of which the Aspen Vista was found to be the most comfortable compared with the Philadelphia, Miami J and Stiffneck collars [30]. However, a negative correlation was noted between the comfort rating and the degree of immobilization. Schneider et al. [22] then proposed that, for conditions requiring support but not rigid immobilization, the Aspen Vista collar provided adequate support and ranked high in comfort level. Thus, we chose the Aspen Vista collar as the rigid collar in the present study. Although the results showed that the head and neck flexion angles were improved with the use of all three neck collars, the customized cervical collar provided better postural correction than the Aspen Vista collar.

The comfort ratings were based on questionnaires filled out by subjects, the results of which showed that our customized cervical collar had a higher comfort score than the other two collars. The coverage area of the customized cervical collar was designed to be smaller than the other two collars, which might contribute to its higher comfort score. In a separate study, four different cervical orthoses were tested, and results showed that the level of discomfort increased over a 4-hour period of use [29]. In the present study, subjects were asked to wear each neck collar continuously for only for 5 min, which likely would not cause the significant discomfort experienced by longer periods of wear. Further studies can therefore be conducted on the evaluation of the possible advantages of customized cervical orthoses after long-term wear.

One of the concerns regarding long-term cervical immobilization is decreases in neck muscle mass and strength. Muscular atrophy was identified 1 month after external cervical fixation with a Halo vest, and despite progressing sequentially [31], it was reversible after removal of the Halo vest. In the present study, the effect of neck collars on muscle mass could not be determined owing to the brief duration of use. However, our aim was to provide a means of postural correction during smartphone use, and neck collars could be removed when one is not using a smartphone. Moreover, we believe that a better posture can be trained during the collar-use period and be maintained thereafter without the use of the orthosis. In addition, strengthening and stretching of neck muscles may also help decrease fatigue and correct posture [7, 32].

It should be noted that there are some limitations in this study. We focused on the effects of cervical collars on the sagittal planes of the subjects, at which place the flexion/extension motion was recorded. However, an effective cervical collar stabilizes not only the flexion/extension plane, but also the lateral bending and axial rotation planes. Therefore, further studies should be conducted to evaluate the stabilizing functions of these two motions. Further, this study lacks data pertaining to the effect of collar use over an extended duration; hence, further studies should be conducted regarding this issue.

Conclusion

This study showed that smartphone use increases head and neck flexion in different postures, including sitting with or without back support and standing, among which sitting without back support showed the greatest head and neck flexion. Wearing a 3D-printed customized cervical collar significantly reduced the head and neck angles during all three smartphone-using postures and offered better performance than both rigid (Aspen Vista collar) and soft (Sport-aid collar) cervical orthoses.

Acknowledgements The authors would like to acknowledge the funding support from Taiwan Ministry of Science and Technology (MOST 105-2218-E-006-006, MOST 106-3114-E-006-010, MOST 106-2314-B-039 -038).

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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