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Sex and Height Influence Neck Posture When Using Electronic Handheld Devices

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With increased tablet ownership in the United States comes increased levels of neck flexion compared to desktop or laptop computer use, and these neck postures have been linked to increases in neck pain. Importantly, tablet viewing postures can be achieved in multiple ways and could be determined by the morphology of the individual and/or other extraneous factors. In this study, we aim to preliminarily evaluate how neck postures vary during tablet use among individuals and link this variation to other factors such as sex, height, weight, presence/absence of temporomandibular joint disorder (TMD), and morphology of the head and neck. We analyzed two-dimensional landmarks placed on lateral-view radiographs of 22 participants (10 female and 12 male) seated in neutral, upright, fully flexed, semi-reclined, and reclined postures. We utilize geometric morphometric techniques, which are advantageous for evaluating shape variation and have not been extensively applied to biomechanical analyses. We found skeletal morphology to be significantly related to sex and height in all but the neutral posture ($P < 0.05$), and weight was marginally significantly related to shape in the semi-reclined posture ($P = 0.047$). Morphologically, male participants exhibited more flexion at the articulatio atlantooccipitalis than females, and females showed greater mandibular protrusion than males, although this result is likely related to height. No relationship was found between posture and TMD. This research establishes a framework for future work that uses geometric morphometric analyses to evaluate how neck postures vary in relation to TMD. Clin. Anat. 00:000–000, 2019.

Key words: neck posture; mobile computing; tablet computer; temporomandibular joint disorder

INTRODUCTION

In the United States, ownership of handheld devices such as tablets and smartphones has increased from 4% to >50% from 2010 to 2018 (Pew Research Center, 2018). Pearson (2015) and Gallup (2015) show that tablet usage surpasses laptop/desktop usage in elementary schools and 49% of adults use tablets occupationally. Typically, people use neck flexion when interacting with mobile devices (Steelcase, 2015; Young et al., 2012; Gold, 2012). This posture is linked to neck pain development (Lau et al., 2010; Grob et al., 2007; Ariens et al., 2011) and the total time spent using a mobile device on a typical day is significantly associated with neck pain reporting (Berolo et al., 2011). Several studies have focused on the risks and benefits associated with

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workplace tablet use (Vasavada et al., 2015; Douglas and Gallagher, 2017, 2018; Weston et al., 2017); however, little research exists regarding how this affects the comorbid diseases of temporomandibular disorder (TMD) and cervical spine disorder (CSD). While TMD and CSD are diagnosable conditions, the underlying causes of both are relatively unknown, although many authors suggest that height and sex are potential causal factors. Via assessment of cervical spine posture as documented in radiographic images, this study aims to assess how factors such as sex, height, weight, and TMD status are related to neck posture during handheld device use.

Links between TMD and Lordosis Cervicis

Lordosis cervicis (the natural forward curvature of the vertebrae in the neck region) in modern humans is related to a greater range of motion, while in neck flexion and extension compared to other primates and this morphology has been linked to the unique bipedal locomotion found in humans (Manfreda et al., 2006; Arlegi et al., 2017). Many authors have established that proper lordosis cervicis is essential for oral breathing (as opposed to nasal breathing), upright posture, a forward gaze, mastication, vocal production, and shock-absorption during movement (Laskin et al., 2006; Straker et al., 2008; Young et al., 2012; Huggare and Houghton, 1996; Cuccia et al., 2008; Diebo et al., 2016; Been et al., 2017). There are significant differences in lordosis cervicis by sex, with females having greater lordosis at the topmost portion of the spine (Foramen magnum to C3) while male lordosis is greater at the base of the cervical vertebrae (C3-C7) (Grave et al., 1999; Been et al., 2017; Ezra et al., 2017). Loss of lordosis in many patients has been associated with neck and back pain, TMD, rapid maxillary expansion, an inability to maintain a horizontal gaze, malocclusion, and changes in growth patterns of the dentofacial and craniofacial regions (Lau et al., 2010; Shan et al., 2013; Silva et al., 2009; Festa et al., 2003; Grob et al., 2007; Sonnesen et al., 2007; Cuccia et al., 2008; Diebo et al., 2016; Been et al., 2017).

Disorders of the articulatio temporomandibularis (also known as the temporomandibular joint or TMJ) involve a general description of pain or pathologies affecting the masticatory apparatus and the TMJ and/or related structures (Kraus, 2007; Armijo-Olivo et al., 2010; Speciali and Dach, 2015). Frequently, the etiology of TMD in any given patient is unclear and this disorder may be caused by many factors (Kraus, 2007; Armijo-Olivo et al., 2010). Importantly, TMD is frequently associated with headaches, lumbar back pain, neck pain, ear aches, altered cervical posture, malocclusion, mandibular condylar hypoplasia, and many general bodily "imbalances" (Shan et al., 2013; Silva et al., 2009; Drangsholt and LeResche, 1999; Sonnesen et al., 2007; Armijo-Olivo et al., 2010; Sancini et al., 2013; Walczyńska-Dragon et al., 2014:1; Speciali and Dach, 2015; Suriani Ribeiro et al., 2015). These conditions are comorbid with TMD, with causal relationships often unclear. Connections between these ailments are often attributed to cervical and masticatory muscle dysfunction (Fricton et al., 1985; De Wijer et al., 1996a, 1996b; Simons, 1999; Visscher et al., 2001; Fink et al., 2002; Armijo-Olivo et al., 2010; Arlegi et al. 2017) and the convergence of nerves receiving stimulus from the craniofacial and cervical regions (Kerr, 1972; Hu et al., 1984, 1992, 1993; Sessle et al., 1986; Sonnesen et al., 2007; Spadero et al., 2014; Speciali and Dach, 2015). Many reports show higher instances of cervical pain in patients with TMD, with specific focus on pain at C1-C3 (Armijo-Olivo et al., 2010; Suriani Ribeiro et al., 2015). Notably, some studies have found that the most severe cases of TMD occur in females (Paolo et al., 2013; Silveira et al., 2007), but TMD may be independent of sex (Suriani Ribeiro et al., 2015). Sex also may be related to neck pain development, as Grade I TMD (low intensity and few activity limitations) is more common in females compared to males (Cote, 2004).

Previous research focuses on static radiographic images and the use of either linear or angular measurements to statistically determine correlations between neck posture, sex, height, and mandibular pain. However, little previous research has used a comprehensive analysis, like landmark or three-dimensional analysis, of skeletal morphology in the angulation of cervical vertebra in patients with TMD. Pachioni et al. (2013) concluded that there is no statistical difference in head and cervical spine posture in patients with and without TMD. However, a longitudinal study conducted by Paolo et al. (2013) found that up to 46% of patients with TMD had spinal pain in relation to posture. Similarly, Rakesh et al. (2014) and Pereira de Farias Neto et al. (2010) suggest that abnormal head and body posture may be an initial cause of TMD, with their patients also exhibiting cervical hyperlordosis. The relationship between angulation of the cervical spine in relation to the TMJ has yet to be explored, but two- or three-dimensional shape analysis can help explore the workings and constraints on skeletal form and function (O'Higgins et al., 2010).

Geometric Morphometrics as a Way to Examine Cervical Spinal Postures

Geometric morphometric (GM) analysis has been used in anthropological, biological, and morphological studies to assess patterns of shape variation (e.g., Adams et al., 2004; Mitteroecker and Gunz, 2009; Cooke and Terhune, 2015). These methods use landmark data to quantify variations in form (i.e., size + shape) among specimens/groups using multivariate methods (O'Higgins et al., 2010; Cooke and Terhune, 2015). Various studies have used GM to assess sexual dimorphism, character displacement, craniofacial shape, and beyond in both extant and extinct species (Adams and Rohlf, 2000; Franklin et al., 2006; Kaliontzopoulou et al., 2007; Pierce et al., 2008) to attempt to discern relationships and/or evolutionary trends. No study at present has used these techniques to assess cervical spinal morphology and head/neck postures in humans, and the use of GM in biomechanical and/or kinematic analyses has been limited (but see Manfreda et al., 2006; Arlegi et al., 2017; Torres-Tamayo et al., 2017). With such a drastic increase in handheld device usage in the past decade, further investigation into its effect on bone morphology is warranted. Furthermore, comorbid diseases TMD and CSD can impact jaw positioning and neck posture during tablet use. Given its potential advantages, the purpose of this study is to use GM to examine how neck postures may be related to jaw positioning and external factors such as TMD, height, weight, and sex using GM techniques.

MATERIALS AND METHODS

Participant Information

Twenty-two participants (12 male and 10 female) were included in this study. Participants were screened to determine absence of previous neck or spinal injuries, chronic headaches, allergy to rubbing alcohol, pregnancy, and exposure to any of the following within the past 2 years: lumbar spine x-ray, upper GI tract x-ray, barium enema x-ray, or any CT scans. Participants were asked a series of questions that correspond to the variables listed in Table 1. All methods were approved by the University of Arkansas Institutional Review Board and Arkansas Department of Health, and participants provided written informed consent.

Radiograph Information

A licensed radiologist technician at the Pat Walker Health Center on the University of Arkansas campus took all radiographs at an average distance of 1.82 m away from the participant. Disposable lead 2 mm biomarkers (Penn-Jersey X-Ray, Morrisville, PA) were placed on the spinous process of C7, sternum, commissura lateralis palpebrarum (outer canthi), and meatus acusticus externus (external auditory meatus). Lateral-view radiographs were taken with each participant in five neck postures as defined in Table 1. Images were taken in the following order: neutral, full-flexion, and a randomization of the tablet postures (i.e., upright, semi-reclined, and reclined). For the semi-reclined and reclined posture, the chair back was reclined to 15° and 30°, respectively. The participant sat while holding the tablet in their hand, with no instructions as to the angle of the tablet to allow for a natural posture. While the radiograph was taken, participants were instructed to look at a piece of tape in the center of the tablet and were given a 30 second rest after each radiograph.

TABLE 1. Variables for subjects in sample

Variables	Description
Sex	Female or male
Age	Age of subject (in years)
Weight	Weight of subject (in pounds)
Height	Height of subject (in centimeters)
TMD	Presence or absence of pain at the TMJ (yes/no) Pain with jaw movement (yes/no) Noise with TMJ movement (yes/no) If TMJ pain was present, had they consulted a doctor to address the discomfort? (yes/no)
Neck postures	
Neutral	Participant seated with arms in lap looking straight forward at a fixed point on the wall
Maximum neck flexion (full flexion)	Participant seated with their neck bent forward as far as possible
Upright seated	Reading a tablet in a seated posture
Semi-reclined	Reading a tablet when seated in a semi-reclined position, with the participant's truck reclined at 15° relative to the vertical
Reclined	Reading a tablet when seated in a reclined position, with the participant's trunk at 30° relative to the vertical

Landmark Placement

X-ray images were initially generated as DICOM files to retain its original dimensions. However, DICOM files are not compatible with the software used to collect landmarks for this analysis (tpsDig; Rohlf, 2016). Thus, for each image, a scale factor was measured three times by author CM on the original DICOM in the software ImageJ (Rasband, 2012). Images were then exported from ImageJ for further analysis. An error study, where a subset of images from three individuals were landmarked three separate times by author CM, was performed to determine that landmarks could be reliably placed on the radiographic images. Landmarks were placed on images using the program tpsDig (Rohlf, 2016). For each image (n = 110; 5 images/participant), the scale was set based on the mean of the three scale factors measured in ImageJ. A total of 43 fixed landmarks established by various sources (e.g. Buikstra & Ubelaker, 1994; Howells, 1973, etc.) (Table 2) represented the shape of the cervical spine, cranium, and mandible, and 44 semi-landmarks were employed to more fully describe mandibular shape and position (Fig. 1). All landmarks were inspected and (if necessary) adjusted by authors CBY and CET.

Statistical Analysis

Landmark data were analyzed using GM techniques (Rohlf, 1999). First, the entire data set (i.e., all participants/postures) was subjected to a generalized Procrustes analysis (GPA) that translates all the landmark configurations to the same location, scales the landmark configurations to the same size, and orients the landmark configurations to the same position; size of the configuration is retained as a separate variable, centroid size (CS). In this analysis, semi-landmarks were allowed to slide to minimize bending energy (Gunz et al., 2005; Gunz and Mitteroecker, 2013). Following GPA, principal component analysis (PCA) was performed to visualize shape variation. Thin plate splines (TPS) and wireframe diagrams were

TABLE 2. Landmark placement definitions

Landmark #	Landmark definition
1	Commissura palpebrarum[a]
2	Tragus[a]
3	Prominentia laryngea[a]
4	Sternum[a]
5	Spinous process of C7[a]
6	Protuberantia occipitalis externa[a]
7	Nasospinale
8	Prosthion
9	Tip of upper central incisor (incision)
10	Tip of lower central incisor
11	Infradentale
12	Gnathion
13	Posterior-most point behind last upper molar
14	Center of occlusal surface on last upper molar
15	Center of occlusal surface on last lower molar
16	Posterior-most point behind last lower molar
17	Gonial angle
18	Superior-most point on the condylus mandibulae
19	Center of articulatio atlantooccipitalis
20	Anterior tubercle of C1
21	Posterior tubercle of C1
22	Anterosuperior corner of C2 vertebral body
23	Anteroinferior corner of C2 vertebral body
24	Posteroinferior corner of C2 vertebral body
25	Posterosuperior corner of C2 vertebral body
26	Spinous process of C2
27	Anterosuperior corner of C3 vertebral body
28	Anteroinferior corner of C3 vertebral body
29	Posteroinferior corner of C3 vertebral body
30	Posterosuperior corner of C3 vertebral body
31	Spinous process of C3
32	Anterosuperior corner of C4 vertebral body
33	Anteroinferior corner of C4 vertebral body
34	Posteroinferior corner of C4 vertebral body
35	Posterosuperior corner of C4 vertebral body
36	Spinous process of C4
37	Anterosuperior corner of C5 vertebral body
38	Anteroinferior corner of C5 vertebral body
39	Posteroinferior corner of C5 vertebral body
40	Posterosuperior corner of C5 vertebral body
41	Spinous process of C5
42	Anterosuperior corner of C6 vertebral body
43	Anteroinferior corner of C6 vertebral body
44	Posteroinferior corner of C6 vertebral body
45	Posterosuperior corner of C6 vertebral body
46	Spinous process of C6
47	Anterosuperior corner of C7 vertebral body
48	Anteroinferior corner of C7 vertebral body
49	Posteroinferior corner of C7 vertebral body
50	Posterosuperior corner of C7 vertebral body
51	Os hyoideum
52	Mandible semi-landmarks

[a]Removed from final analysis.

used to describe shape variation along each PC axis. Procrustes distances between the means of each posture were calculated, with a permutation test (10,000 iterations) employed to assess the significance of these differences.

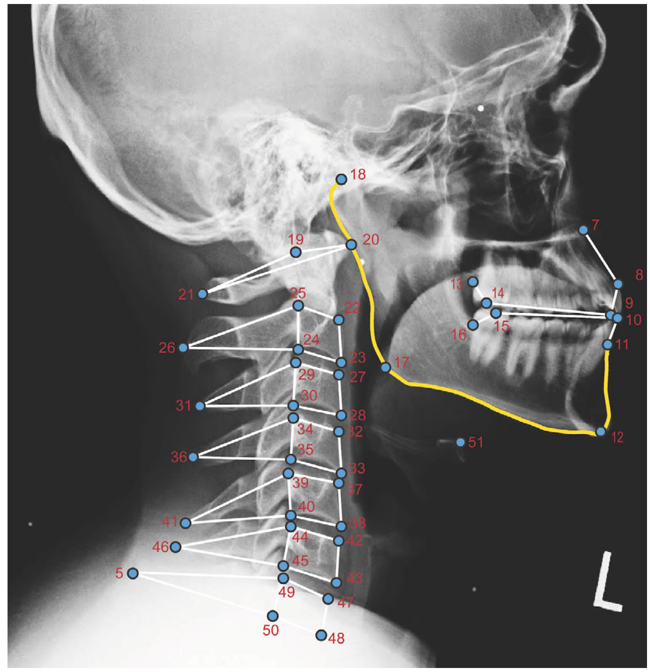

Fig. 1. Landmark and semi-landmark placement. Fifteen semi-landmarks were placed along the curve from the processus coronoideus to gonial angle, 15 semi-landmarks were placed along the curve from the gonial angle to the tuber omentale, and 10 were placed from the tuber omentale to infradentale. These semi-landmarks are represented with a yellow line. [Color figure can be viewed at wileyonlinelibrary.com]

The data set was subsequently subdivided by position and separate GPA and PCA (with corresponding TPS grids) were conducted for each subset. For each position, a series of additional analyses were run. First, one-way Procrustes analysis of variance (ANOVA) was used to examine the impact of sex and TMD on shape variation. Second, separate multivariate regressions of the Procrustes coordinates of shape on the natural log-transformed CS, weight, and height were conducted to examine the influence of these independent variables on shape variation in the neck and cranium. For both the ANOVAs and the multivariate regressions, significance of the observed relationships was assessed via permutation tests (10,000 iterations).

All analyses were conducted using the R package *geomorph* (Adams et al., 2018) and the program MorphoJ (Klingenberg, 2011). Critical alpha was set at $P = 0.05$ for all analyses.

RESULTS

Males in our sample are significantly taller than females ($t = 4.55$, $P < 0.001$), with an average height of 181.59 ± 8.61 and 166.91 ± 5.96 cm, respectively. Males are also slightly older than females ($t = 2.33$, $P = 0.03$), with an average age of 21.83 ± 1.27 and

20.70 ± 8.61 years, respectively. Weight averages are also slightly higher in males than females at 172.97 ± 26.64 and 144.20 ± 23.87 lbs. Only three participants reported TMD presence (one male and two females).

All Neck Postures

The PCA clearly separated neck postures along PC1 (Fig. 2), where the neutral neck and fully flexed neck postures were completely nonoverlapping and falling at either end of this axis. All other neck postures overlapped and were indistinguishable on PC1. Shape variation along this axis (which represents 40.65% of sample variance) thus represents variation in neck posture among individuals (Figs. 2 and 3).

PC2 (21.36% of sample variance; Figs. 2 and 3) appears to represent interindividual differences, since participants remain in roughly the same position along this axis regardless of neck posture. This axis also represents some components of mandibular size and shape; individuals with increased mandibular robusticity tend to fall more negatively on this axis than individuals with more gracile mandibular morphology.

PC3 (12.67%; Fig. 3) partially separates participants based on cervical and os hyoideum (hyoid bone) morphology related to sex, with participants displaying a more inferiorly placed os hyoideum, robust mandible, and neutral neck posture falling more positively. PC4 (4.4%) mostly shows variation in mandibular protrusion with some component of mandibular shape and neck posture (Fig. 3).

Procrustes distances (Table 3) between group means for each posture reflect shape variation primarily observed on PC1, with neutral and fully flexed postures significantly different from each other ($P < 0.0001$) but statistically indistinguishable from all other postures.

Neutral

In the neutral neck position, PC1 represents 41.58% of the sample variance. Variation along this axis represents differences in cervical curvature and length and mandibular position relative to the cervical spine (Fig. 4). For example, the negative end of PC1 shows a lesser degree of cervical spine curvature and shorter cervical spine with a mandible positioned more anteriorly relative to the cervical spine. Subsequent PCs explain 18.31%, 10.67%, 6.15%, and 4.35% of the variation in the neutral neck posture (Table 4); these PC axes represent idiosyncratic variation rather than meaningful patterns.

ANOVAs for both TMD and sex (Table 5) were not significant, and neither were the multivariate regressions (Table 5) of shape on CS, weight, or height.

Upright

In the upright data set, PC1 (34.43% of sample variance) is primarily related to mandibular shape, with increased mandibular robusticity falling more negatively and more gracile mandibles more positively (Fig. 4). Subsequent PC axes explain 23.72%, 9.63%, and 7.47% of the variation shape in the upright posture (Table 4) and represent idiosyncratic variation among individuals.

ANOVAs (Table 5) found no significant difference in relation to TMD but did identify differences in shape between males and females ($P = 0.028$). Multivariate

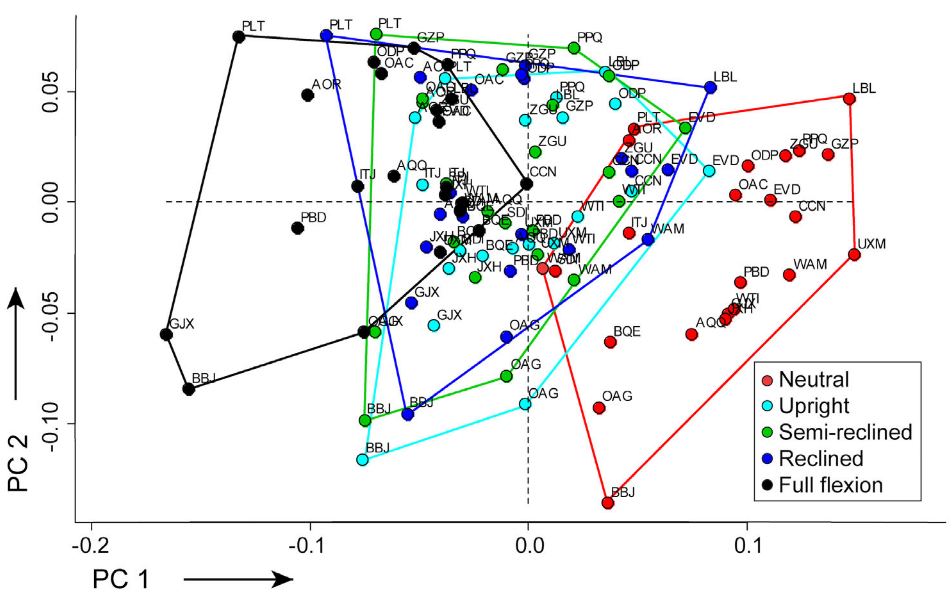

Fig. 2. PC1 versus PC2 of data set including all subjects and postures. Subjects are denoted by three letter codes, allowing us to trace where individuals fall on each PC axis; for example, subject BBJ is the most negatively situated individual on PC2 in all neck postures. [Color figure can be viewed at wileyonlinelibrary.com]

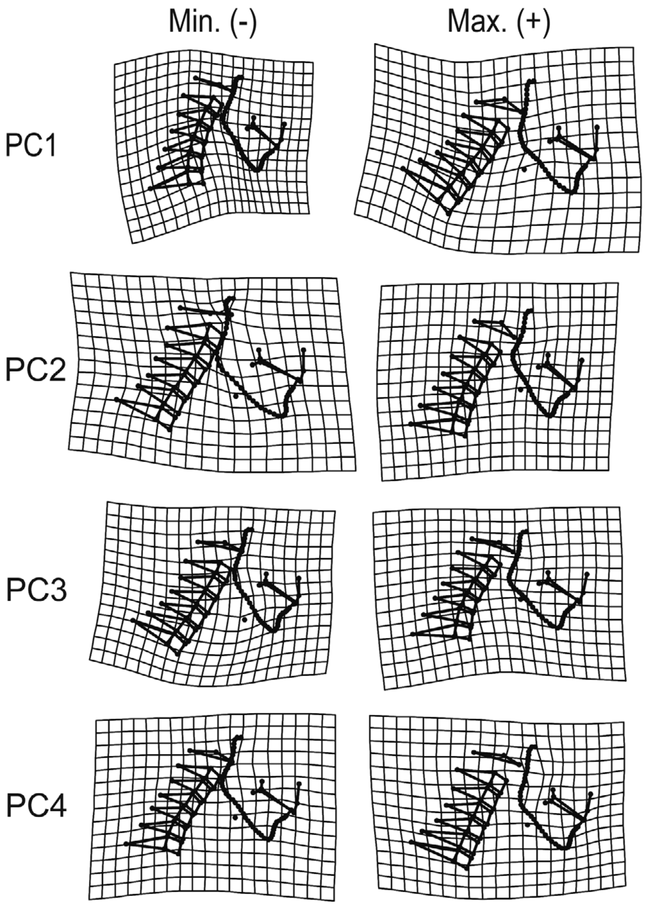

Fig. 3. Thin plate spline (TPS) grids illustrating the shape variation at the ends of the first four PC axes for the data set including all subjects and neck postures.

regression (Table 5) of shape on CS and weight were not significant ($P > 0.05$), but the multivariate regression of shape on height was $P = 0.0075$. TPSs from the multivariate regression of shape on height indicate that smaller individuals have a shorter cervical spine with a more protruded mandible, while taller individuals have a longer cervical spine and a less protruded mandibular posture (Fig. 5).

Semi-Reclined

In the semi-reclined data set, PC1 (35.07% of sample variance) represents variation in cervical spine length and curvature as well as mandibular protrusion and robusticity (Fig. 4). Subsequent PC axes explain 25.12%, 8.10%, 5.99%, and 5.24% of the variation in the semi-reclined position (Table 4) and represent idiosyncratic variation among individuals.

ANOVAs indicate no significant difference in shape between individuals with and without TMD; however, males and females differed in shape ($P = 0.026$). Multivariate regression of shape on CS was not significant ($P > 0.05$), but multivariate regressions of shape on weight and height were significant ($P = 0.047$ and 0.001, respectively). TPSs indicate that shorter individuals have a shorter cervical spine that is slightly more flexed than taller individuals and have a more protruded mandible in this posture (Fig. 5).

Reclined

PC1 (32.34% of sample variance) in the reclined posture was again related to cervical length, flexion, and mandibular shape/position (Fig. 4). Subsequent PC axes explain 27.45%, 10.90%, 6.72%, and 4.36% of the shape variation in the reclined posture (Table 4); again, these PC axes represent idiosyncratic variation among individuals.

ANOVA results (Table 5) indicate no difference in shape between individuals with and without TMD ($P > 0.05$). However, the ANOVA comparing shape in relation to sex was significant ($P = 0.002$). The multivariate regression (Table 5) of shape on CS and weight was not significant, but the multivariate regression of shape on height was ($P = 0.001$). As with several of the other postures, TPS grids (Fig. 5) demonstrate that shorter individuals have a shorter cervical spine with a more protruded mandible, while taller individuals have a longer cervical spine with a less protruded mandible.

Full-Flexion

PC1 (35.68% of sample variance) indicates that individuals falling more negatively on this axis exhibit more inferior curvature (i.e., C6-C7) in the cervical spine and a more retruded mandible (Fig. 4). Conversely, the positive end of PC1 represents anterior curvature in the middle of the cervical spine and a more protruded mandible. Subsequent PC axes explain 25.78%, 8.67%, 6.83%, and 4.80% of the shape variation in the full-flexion posture (Table 4) and represent idiosyncratic variation among individuals.

TABLE 3. Procrustes distances (upper right triangle) and *P*-values (lower left triangle) associated with tests of differences between postures. Bolded values are statistically significant at *P* < 0.05

Procrustes distances	Neutral	Upright	Semi-reclined	Reclined	Full flexion
Neutral	–	0.096	0.10	0.10	0.16
Upright	**<0.0001**	–	0.01	0.02	0.06
Semi-reclined	**<0.0001**	1.00	–	0.01	0.06
Reclined	**<0.0001**	0.70	0.99	–	0.06
Full flexion	**<0.0001**	**<0.0001**	**0.0002**	**0.0001**	–

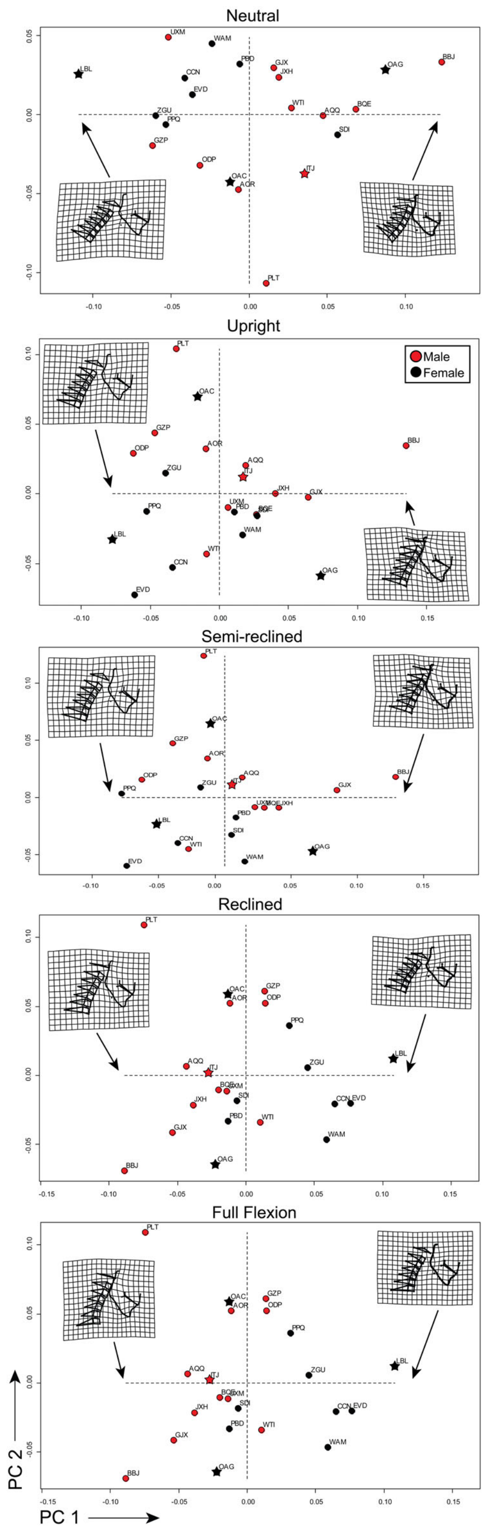

Fig. 4. PC1 versus PC2 for each neck posture with thin plate spline (TPS) graphs illustrating the positive and negative ends of the PC1 axis. Starred individuals reported the presence of TMD. [Color figure can be viewed at wileyonlinelibrary.com]

TABLE 4. Percent variance explained along principal components axes 1-5 for each neck posture

Posture	PC1	PC2	PC3	PC4
Neutral	41.58	18.31	10.67	6.15
Full flexion	35.68	25.78	8.67	6.83
Upright	34.43	23.72	9.63	7.47
Semi-reclined	35.07	25.12	8.1	5.99
Reclined	32.34	27.44	10.9	6.72

ANOVAs (Table 5) found no significant difference in shape for individuals with TMD versus those without but did find a significant difference in shape between sexes ($P = 0.0096$). The multivariate regressions (Table 5) of shape on CS and weight were not significant, but the multivariate regression of shape on height was significant ($P = 0.003$). TPSs from the multivariate regression of shape on height indicate that shorter individuals have a shorter cervical spine with a mandible more anterior in relation to the cervical spine, while taller individuals exhibit a larger and longer cervical spine with a more posteriorly placed mandible closer to the cervical spine (Fig. 5).

In the reclined and full-flexion postures, PC1 indicates a separation of males and females. No other postures showed definitive patterns of male and female separation along either PC1 or PC2 (Fig. 2).

DISCUSSION

The goal of this research was to evaluate how cervical spinal and jaw postures vary in relation to neck flexion, as might be employed during handheld device use, and as related to factors such as height, weight, and sex. We further evaluated the relationship of neck posture to TMD status. Using GM techniques, we observed variation in how participants adopt particular flexed neck postures primarily in relation to sex and height. We also observed considerable idiosyncratic variation in how participants adopt particular postures.

Analyses where all participants and postures were combined indicate that the primary factor influencing shape variation in this analysis is degree of neck flexion; neutral (i.e., not flexed at all) and full-flexion postures were significantly different from one another in morphospace and were significantly different from all other postures. However, intermediate levels of flexion (i.e., the upright, semi-reclined, and reclined postures) were not significantly different from one another. Importantly, the second axis describing shape variation primarily separated out participants, indicating that individuals tend to vary consistently from one another in how they adopt all neck postures, and the third axis observed differences in shape related to sex (primarily in mandibular shape and protrusion).

When the data were analyzed separately for each posture, we consistently observed significant differences in neck posture related to sex and height (which

TABLE 5. Results of the one-way ANOVAs testing the difference between shape with TMD presence or absence and males and females. Results from multivariate regression of shape on centroid size (CS), weight, and height for each posture. Bolded values are significant (P < 0.05)

	TMD			Sex			CS		Weight		Height	
	df	*F*	*P*	*df*	*F*	*P*	R^2	*P*	R^2	*P*	R^2	*P*
Neutral	21	−1.35	0.92	21	1.57	0.07	0.04	0.46	0.08	0.12	0.09	0.053
Upright	21	−0.39	0.63	21	1.95	**0.03**	0.06	0.27	0.08	0.09	0.14	**0.0075**
Semi-reclined	21	−0.05	0.66	21	1.99	**0.03**	0.06	0.27	0.10	**0.047**	0.17	**0.001**
Reclined	21	−0.77	0.77	21	2.67	**<0.00**	0.06	0.29	0.08	0.09	0.16	**0.0014**
Full flexion	21	−0.73	0.76	21	2.24	**0.01**	0.06	0.28	0.07	0.19	0.17	**0.0027**

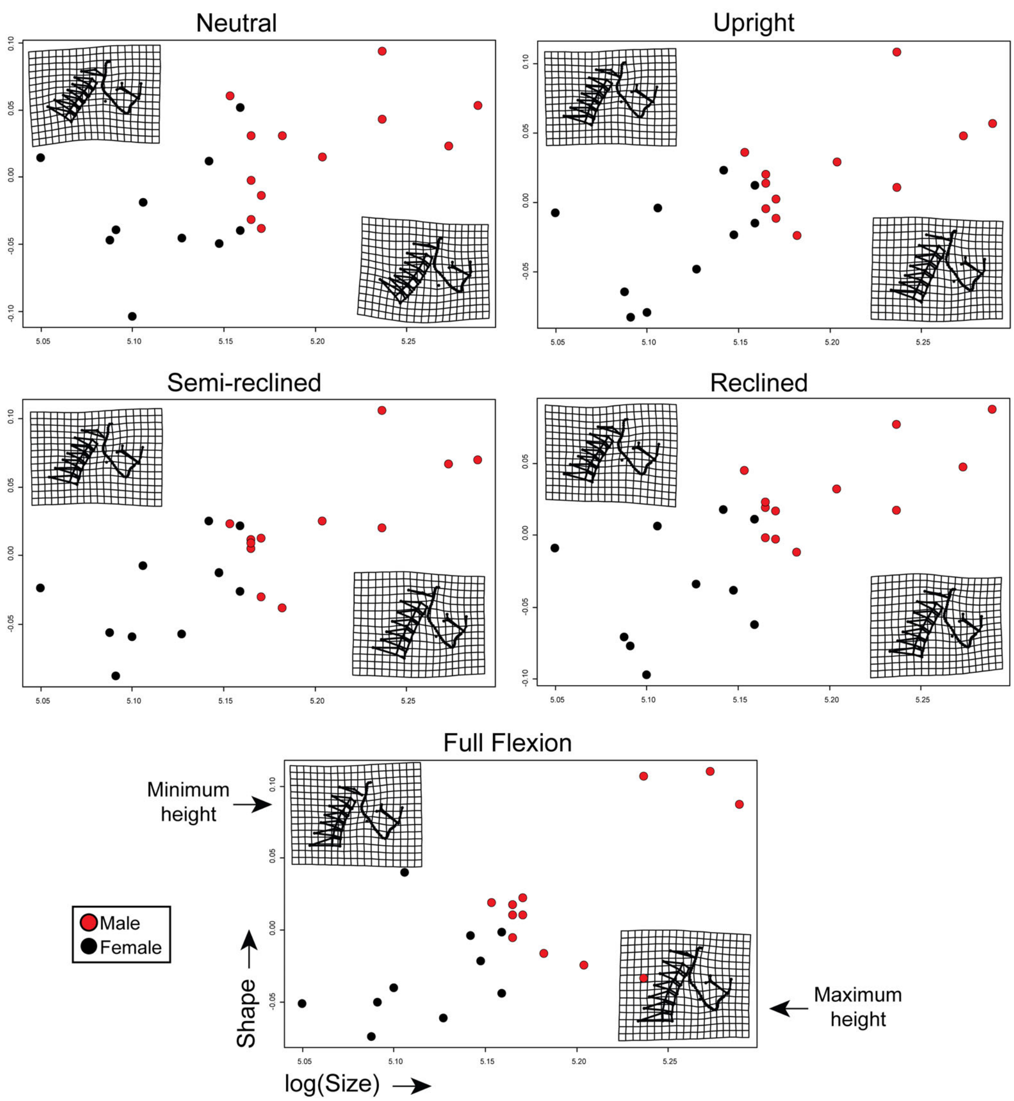

Fig. 5. Multivariate regression plots of shape (via Procrustes coordinates) on height for each posture. Thin plate spline (TPS) grids illustrate the shape for minimum and maximum height in each multivariate regression. [Color figure can be viewed at wileyonlinelibrary.com]

themselves are related in our sample) in all positions except neutral, supporting previous literature (Grob et al., 2007; Sonnesen et al., 2007; Cuccia et al., 2008; Been et al., 2017; Ezra et al., 2017). Notably, we observed no significant differences related to any factors in the neutral neck posture. We suggest that this may be due to the controlled nature of the neutral posture in this experiment. Specifically, participants were asked to focus on a specific spot in front of them regardless of other factors. No other posture was subject to this amount of control, and individuals made their own estimations of positioning for the remaining neck postures. These data suggest that individuals vary in how they adopt flexed neck postures such as those utilized during handheld device use, and how participants adopt these postures may in part be related to their sex and/or height, which themselves are related.

Except for the neutral position, common patterns of shape variation were observed across all postures, with shorter individuals/females having shorter cervical spines and slightly more protruded mandibles than taller individuals. The well-documented differences in mandibular shape between males and females (i.e., males have more angular gonial regions and protruding tuber omentale (mental eminence) (Krogman and Iscan, 1986; Huggare and Houghton, 1996; Ezra et al., 2017) may drive some of these observed differences, but these results clearly indicate that how neck postures are adopted is related to height and/or sex, likely as a function of the length of the cervical spine or the degree of lordosis cervicis. For example, males/taller individuals achieve neck flexion via increased flexion at the articulatio atlantooccipitalis, whereas females/shorter individuals achieve the same results by protruding their mandibles and also slightly increasing flexion at their remaining cervical vertebral joints (Been et al., 2017; Ezra et al., 2017). This could potentially indicate that males have increased flexion at the articulatio atlantooccipitalis because they do not have increased flexion there to begin with, whereas females do. Because females have already reached the maximum articulatio atlantooccipitalis flexion possible, they instead spread this flexion across more of their cervical vertebrae. These data support previous research (Huggare and Houghton, 1996) indicating that because there is a significant relationship between mandibular length, stature, and posture, males with loss of lordosis may be at higher risk for craniofacial changes during growth.

These findings are particularly relevant for considerations of cervical spinal and TMJ disorders and the relationship between TMD and CSD, as well as the relationship between neck posture and tablet use. Neck flexion has previously been linked to neck pain development (Grob et al., 2007; Ariens et al., 2011). Our results support these conclusions by indicating a difference in cervical kinematics based on changes in the five neck postures assessed here. While some studies suggest differences in neck position between reclined and upright seated positions (Douglas and Gallagher, 2017, 2018; Weston et al., 2017), ours do not statistically distinguish these positions in morphospace. Similarly, multiple studies indicate a relationship between the cervical spine and TMD (Fricton et al., 1985; De Wijer et al., 1996a; Simons, 1999; Visscher et al., 2001; Fink et al., 2002; Grob et al., 2007; Armijo-Olivo et al., 2010), but our investigation does not corroborate these results. Similar to Pachioni et al. (2013), we did not find any significant differences in cervical kinematics between participants with versus without TMD in any neck posture. However, our results could be a product of our sample having only three participants with reported TMD. Furthermore, Suriani Ribiero et al. (2015) found a similar number of male and female participants with TMD, but TMD tended to be more severe in female participants. Our results do not support or refute this finding due to few participants reporting TMD and no significance regarding this factor for any neck posture. However, the increased mandibular protrusion we observed in females may be adding more stress to the neck which could be affecting the severity of pain associated with TMD.

There are several limitations of the work presented here. First, our sample size is small and homogenous (e.g., participants ranged from 19 to 24 years); further work with increased samples would be important for verifying the patterns observed here. Importantly, we are unable to separate out the effects of height and sex, given that these two variables are related in our sample. A larger study incorporating taller females and shorter males, as well as a greater number of individuals who have experienced TMD, could help parse out the effects of sex and height as well as any potential links between neck posture and TMD status.

In conclusion, our results suggest that postures adopted with tablet use vary in relation to height and/or sex. When using tablets or other handheld devices, morphological differences between males and females require different positioning of the jaw and neck. Taller individuals (males in our study) flex their necks more at the articulatio atlantooccipitalis than females, which is likely because their cervical spine is longer and requires more flexion to tilt their heads to a similar angle as females. These postural differences may influence cervical spine and mandibular development if tablets and handheld devices are used throughout ontogeny. Furthermore, females exhibit more mandibular protrusion with tablet use than males. This effect may have implications for mastication while using tablets or other handheld devices (i.e., at a dining table or on a couch), or for ligament and muscle strain that may be experienced when the head and neck are held in these positions for long periods of time. This could be linked to increased levels of CSD and TMD frequently observed in females, though additional study is warranted.

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CONFLICT OF INTEREST

There are no known conflict of interest among the authors of this manuscript.

AUTHOR CONTRIBUTIONS

Concept/design: CBY, ANR, KMG, CET. Manuscript writing: CBY, ANR, CET. Data analysis/interpretation: ANR. Landmark placement: CM. Supporting biomechanical x-ray study, x-ray data: ECD, KMG. Securing funding: KMG. Statistical analysis/interpretation, financial support: CET. Final approval of manuscript: CBY, ANR, CM, ECD, KMG, CET.

DATA ACCESSIBILITY STATEMENT

Due to the use of live human subjects for this pilot study data, we cannot make the data open access. However, data are available upon request with the corresponding author at cbyoakum@email.uark.edu.

REFERENCES

Adams DC, Rohlf FJ. 2000. Ecological character displacement in Plethodon: Biomechanics differences found from a geometric morphometric study. PNAS 97:4106–4111.

Adams DC, Rohlf FJ, Slice DE. 2004. Geometric morphometrics: Ten years of progress following the 'revolution'. Ital J Zool 71:5–16.

Adams DC, Collyer M, Kaliontzopoulou A. 2018. Geometric Morphometric Analyses of 2D/3D Landmark Data. CRAN.

Ariens G, Bongers P, Douwes M, Miedema M, Hoogendoorn W, van der Wal G, Bouter L, van Mechelen W. 2011. Are neck flexion, neck rotation and sitting at work risk factors for neck pain? Results of a prospective cohort study. Occup Environ Med 58: 200–207.

Arlegi M, Gómez-Olivencia A, Albessard L, Martínez I, Balzeau A, Arsuaga JL, Been E. 2017. The role of allometry and posture in the evolution of the hominin subaxial cervical spine. J Hum Evol 104:80–99.

Armijo-Olivo S, Fuentes JP, da Costa BR, Major PW, Warren S, Thie NMR, Magee J. 2010. Reduced endurance of the cervical flexor muscles in patients with concurrent temporomandibular disorders and neck disability. Manual Ther 15:586–592.

Been E, Shefi S, Soudack M. 2017. Cervical lordosis: The effect of age and gender. Spine J 17:880–888.

Berolo S, Wells RP, Amick BC. 2011. Musculoskeletal symptoms among mobile hand-held device users and their relationship to device use: A preliminary study in a Canadian university population. Appl Ergon 42:371–378.

Buikstra J, Ubelaker D. 1994. Standards: For Data Collection from Human Skeletal Remains. Fayetteville, AR: Arkansas Archaeological Survey. p 1–218.

Cooke SB, Terhune CE. 2015. Form, function, and geometric morphometrics. Anat Rec 298:5–28.

Cote P, Cassidy DJ, Carroll LJ, Kristman V. 2004. The annual incidence and course of neck pain in the general population: A population-based cohort study. Pain 112:267–273.

Cuccia AM, Lotti M, Caradonna D. 2008. Oral breathing and head posture. Angle Orthod 78:77–82.

De Wijer A, De Leeuw JRJ, Steenks MH, Bosman F. 1996a. Temporomandibular and cervical spine disorders: Self-reported signs and symptoms. Spine 21:1638–1646.

De Wijer A, Steenks MH, de Leeuw JR, Bosman F, Helders PJ. 1996b. Symptoms of the cervical spine in temporomandibular and cervical spine disorders. J Oral Rehabil 23:742–750.

Diebo BG, Challier V, Henry JK, Oren JH, Spiegel MA, Vira S, Tanzi EM, Liabaud B, Lafage R, Protopsaltis TS, Errico TJ, Schwab FJ, Lafage V. 2016. Predicting cervical alignment required to maintain horizontal gaze based on global spinal alignment. Spine 41:1795–1800.

Douglas EC, Gallagher KM. 2017. The influence of a semi-reclined seated posture head and neck kinematics and muscle activity while reading a tablet computer. Appl Ergon 60:342–347.

Douglas EC, Gallagher KM. 2018. A radiographic investigation of cervical spine kinematics when reading a tablet in a reclined trunk position. Appl Ergon 70:104–109.

Drangsholt M, LeResche L. 1999. Temporomandibular disorder pain. In: Crombie I, Croft P, Linton S, LeResche L, Von Korff M, editors. Epidemiology of Pain. IASP: Seattle, WA. p 203–233.

Ezra D, Masharawi Y, Salame K, Slon V, Alperovitch-Najenson D, Hershkovitz I. 2017. Demographic aspects in cervical vertebral bodies' size and shape (C3-C7): A skeletal study. Spine J 17:135–142.

Festa F, Tecco S, Dolci M, Ciufolo F, Di Meo S, Filippi MR, Ferritto AL, D'Attillio M. 2003. Relationship between cervical lordosis and facial morphology in Caucasian women with a skeletal class II malocclusion: A cross-sectional study. J Craniomandibular Practice 21:121–129.

Fink M, Tschernitschek H, Stiesch-Scholz M. 2002. Asymptomatic cervical spine dysfunction (CSD) in patients with internal derangement of the temporomandibular joint. J Craniomandibular and Sleep Practice 20:192–197.

Franklin D, Freedman L, Milne N, Oxnard CE. 2006. A geometric morphometric study of sexual dimorphism in the crania of indigenous southern Africans. S Afr J Sci 102:229–238.

Fricton JR, Kroening R, Haley D, Siegert R. 1985. Myofascial pain syndrome of the head and neck: A review of clinical characteristics of 164 patients. Oral Surg Oral Med Oral Pathol 60:615–623.

Gallup, Washington D.C. 2015. Most U.S. workers see upside to staying connected to work. URL: http://www.gallup.com/poll/168794/workers-upside-staying-connected-work.aspx

Gold JE, Driban JB, Thomas N, Chakravarty T, Channell V, Komaroff E. 2012. Postures, typing strategies, and gender differences in mobile device usage: An observational study. Appl Ergon 43:408–412.

Grave B, Brown T, Townsend G. 1999. Comparison of cervicovertebral dimensions in Australian Aborigines and Caucasians. Eur J Orthod 21:127–135.

Grob D, Frauenfelder H, Mannion AF. 2007. The association between cervical spine curvature and neck pain. Eur Spine J 16:669–678.

Gunz P, Mitteroecker P. 2013. Semilandmarks: A method for quantifying curves and surfaces. Hystrix 24:103–109.

Gunz P, Mitteroecker P, Bookstein FL. 2005. Semilandmarks in three dimensions. In: Slice DE, editor. Modern Morphometrics in Physical Anthropology. Boston, MA: Springer. p 73–98.

Howells WW. 1973. Cranial variation in man: A study by multivariate analysis of patterns of difference among recent human populations. In: Paper of the Peabody Museum of Archaeology and Ethnology. Vol. 67. p 1–259.

Hu JW, Sessle BJ, Amano N, Zhong G. 1984. Convergent afferent input patterns in medullary dorsal horn (trigeminal subnucleus caudalis): A basis for referred orofacial pain? Pain 18:S281.

Hu JW, Sessle BJ, Raboisson P, Dallel R, Woda A. 1992. Stimulation of craniofacial muscle afferents induces prolonged facilitatory effects in trigeminal nociceptive brain-stem neurons. Pain 48:53–60.

Hu JW, Yu XM, Vernon H, Sessle BJ. 1993. Excitatory effects on neck and jaw muscle activity of inflammatory irritant applied to cervical paraspinal tissues. Pain 55:243–250.

Huggare J, Houghton P. 1996. Associations between atlantoaxial and craniomandibular anatomy. Growth Dev Aging 60:21–30.

Kaliontzopoulou A, Carreter MA, Llorente GA. 2007. Multivariate and geometric morphometrics in the analysis of sexual dimorphism variation in *Podarcis* lizards. J Morphol 268:152–165.

Kerr FWL. 1972. The potential of cervical primary afferents to sprout in the spinal nucleus of V following long term trigeminal denervation. Brain Res 43:547–560.

Klingenberg CP. 2011. MorphoJ: An integrated software package for geometric morphometrics. Mol Ecol Resour 11:353–357.

Kraus S. 2007. Temporomandibular disorders, head and orofacial pain: Cervical spine considerations. Dent Clin North Am 51:161–193.

Krogman WM, Iscan MY. 1986. The Human Skeleton in Forensic Medicine. Springfield, IL: Charles C. Thomas. p 1–516.

Laskin DM, Greene C, Hylander WL. 2006. Functional Anatomy and Biomechanics of the Masticatory Apparatus. New York, NY: Quintessence Pub Co. p 1–34.

Lau KT, Cheung KY, Chan MH, Chan KB, Lo KY, Wing Chiu TT. 2010. Relationships between sagittal postures of thoracic and cervical spine, presence of neck pain, neck pain severity and disability. Man Ther 15:457–462.

Manfreda E, Mitteroecker P, Bookstein FL, Schaefer K. 2006. Functional morphology of the first cervical vertebra in humans and nonhuman primates. Anat Rec 289B:184–194.

Mitteroecker P, Gunz P. 2009. Advances in geometric morphometrics. Evol Biol 36:235–247.

O'Higgins P, Cobb SN, Fitton LC, Gröning F, Philips R, Liu J, Fagan MJ. 2010. Combining geometric morphometrics and functional simulation: An emerging toolkit for virtual functional analyses. J Anat 218:3–15.

Pachioni FSM, Aoyama AY, Pavia A, Pernas DL, Savian NU, Fregonesi CEPT, de Faria CRS, Ferreira DMA, Pachioni CAS. 2013. Temporomandibular dysfunction: Cephalometric analysis and photogrammetry. ConScientiae Saúde 12:177–184.

Paolo CD, Costanzo GD, Panti F, Rampello A, Falisi G, Pilloni A, Cascone P, Ianetti G. 2013. Epidemiological analysis on 2375 patients with TMJ disorders: Basic statistical aspects. Ann Stomatol 4:161–169.

Pearson HP. 2015. Person student mobile device survey 2015. URL: http://www.pearsoned.com/wp-content/uploads/2015-Pearson-Student-Mobile-Device-Survey-Grades-4-12.pdf.

Pereira de Farias Neto J, Melo de Santana J, Joviniano de Stanana-Filho V, Jose Quintans-Junior L, Paula de Lima Ferreira A, Rigoldi Bonjardim L. 2010. Radiographic measurement of the cervical spine in patients with temporomandibular dysfunction. Arch Oral Biol 55:670–678.

Pew Research Center, Washington, D.C. 2018. Mobile fact sheet. URL: http://www.pewinternet.org/fact-sheet/mobile/

Pierce SK, Angielczyk KD, Rayfield EJ. 2008. Patterns of morphospace occupation and mechanical performance in extant crocodilian skulls: A combined geometric morphometric and finite element modeling approach. J Morphol 269:840–864.

Rakesh N, Devi BKY, Patil DJ, Nagi R. 2014. Assessment of cervical spine postural disorders in patients with temporomandibular dysfunction: A radiographic evaluation. Oral Radiol 30:38–44.

Rasband W. 2012. ImageJ. Bethesda, MD: US National Institute of Health.

Rohlf FJ. 1999. Shape statistics: Procrustes superimpositions and tangent spaces. J Classif 16:197–223.

Rohlf JF. 2016. tpsDig, version 1.4. Department of Ecology and Evolution, SUNY at Stony Brook. URL: http://life.bio.sunysb.edu/morph/

Sancini A, Tomei F, Tomei G, Caciari T, Capozzella A, Di Famiani M, Samperi I, Scala B, Fiaschetti M, Cetica C, Ciarrocca M. 2013. Spinal and temporomandibular disorders in male workers of the state police. Acta Odontol Scand 71:671–675.

Sessle BJ, Hu JW, Amano N, Zhong G. 1986. Convergence of cutaneous, tooth pulp, visceral, neck and muscle afferents onto nociceptive and non-nociceptive neurons in trigeminal subnucleus caudalis (medullary dorsal horn) and its implications for referred pain. Pain 27:219–235.

Shan Z, Deng G, Li J, Li Y. 2013. Correlational analysis of neck/-shoulder pain and low back pain with the use of digital products, physical activity and psychological status among adolescents in Shanghai. PLoS One 8:e78109.

Silva AG, Punt TD, Sharples P, Vilas-Boas JP, Johnson MI. 2009. Head posture and neck pain of chronic nontraumatic origin: A comparison between patients and pain-free persons. Arch Phys Med Rehabil 90:669–674.

Silveira AM, Feltrin PP, Zanetti RV, Mautoni MC. 2007. Prevelência de portadores de DTM em pacientes avaliados no setor de otorrrinolaringologia. Rev Bras Otorrinolaringol 73:528–532.

Simons D. 1999. Travell & Simon's Myofascial Pain and Dysfunction: The Trigger Point Manual. 2nd Ed. Baltimore, MD: Lippincott Williams and Wilkins. p 1–968.

Sonnesen L, Pedersen CE, Kjær I. 2007. Cervical column morphology related to head posture, cranial base angle, and condylar malformation. Eur J Orthod 29:398–403.

Spadero A, Ciarrocchi I, Masci C, Cozzolino V, Monaco A. 2014. Effects of intervertebral disc disorders of low back on the mandibular kinematic: Kinesiographic study. BMN Res Notes 7:1–6.

Speciali JG, Dach F. 2015. Temporomandibular dysfunction and headache disorder. Headache 55:72–83.

Steelcase. 2015. Global posture study. URL: https://www.steelcase.com/content/uploads/2015/01/global-posture-study.pdf

Straker LM, Coleman J, Skoss R, Maslen BA, Burgess-Limerick R, Polluck CM. 2008. A comparison of posture and muscle activity during tablet computer, desktop computer and paper use by young children. Ergonomics 51:540–555.

Suriani Ribeiro D, Gomese Silva B, da Silva Oliveira N, Oliveira Almeida A, Rodrigues dos Santos MG, Cardoso da Silva LG, Vilela Lemos T. 2015. The prevalence of temporomandibular dysfunction in patients with spine pain. Man Ther Posturol Rehabil J 13:1–5.

Torres-Tamayo N, Garcia-Martinez D, Lois Zlolniski S, Torres-Sanches I, Garcia-Rio F, Bastir M. 2017. 3D analysis of sexual dimorphism in size, shape and breathing kinematics of human lungs. Journal of Anatomy 232:227–237.

Vasavada AN, Nevins DD, Monda SM, Hughes E, Lin DC. 2015. Gravitational demand on the neck musculature during tablet computer use. Ergonomics 58:990–1004.

Visscher CM, Lobbezoo F, de Boer W, van der Zaag J, Naeije M. 2001. Prevalence of cervical spinal pain in craniomandibular pain patients. Eur J Oral Sci 109:76–80.

Walczyńska-Dragon K, Baron S, Nitecka-Buchta A, Tkacz E. 2014. Correlation between TMD and cervical spine pain and mobility: Is the whole-body balance TMJ related? Biomed Res Int 2014:1–7.

Weston E, Le P, Marras WS. 2017. A biomechanical and physiological study of office seat and tablet device interaction. Appl Ergon 62: 83–93.

Young JG, Trudeau M, Odell D, Marinelli K, Dennerlein JT. 2012. Touch-screen tablet user configurations and case-supported tilt affect head and neck flexion. Work 41:81–91.