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Cervical Spine Musculotendon Lengths When Reading a Tablet in Three Seated Positions

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A popular posture for using wireless technology is reclined sitting, with the trunk rotated posteriorly to the hips. This position decreases the head's gravitational moment; however, the head angle relative to the trunk is similar to that of upright sitting when using a tablet in the lap. This study compared cervical extensor musculotendon length changes from neutral among 3 common sitting postures and maximum neck flexion while using a tablet. Twenty-one participants had radiographs taken in neutral, full-flexion, and upright, semireclined, and reclined postures with a tablet in their lap. A biomechanical model was used to calculate subject-specific normalized musculotendon lengths for 27 cervical musculotendon segments. The lower cervical spine was more flexed during reclined sitting, but the skull was more flexed during upright sitting. Normalized musculotendon length increased in the reclined compared with an upright sitting position for the C4-C6/7 (deep) and C2-C6/7 (superficial) multifidi, semispinalis cervicis (C2-C7), and splenius capitis (Skull-C7). The suboccipital ($R^2 = .19–.71$) and semispinalis capitis segment length changes were significantly correlated with the Skull-C1 angle (0.24–0.51). A semireclined reading position may be an ideal sitting posture to reduce the head's gravitational moment arm without overstretching the assessed muscles.

***Keywords**:* musculoskeletal modeling, smartphone, neck, ergonomics, anthropometrics

Wireless technology allows people to consume and transmit information in any posture. Although sitting with the head tilted forward (neck flexion) is the most common posture in mobile technology users, 22% of male and 15% of female college students sit reclined (trunk rotated posteriorly).[1] A semireclined position for mobile use was also reported by 24% of Shanghai adolescents.[2] Assessing the benefits and disadvantages of consuming information in reclined sitting while interacting with technology has applications to areas such as office chair design[3] and airline inflight environments.[4] Since the combination of reclined sitting and neck flexion can alter the biomechanical loads on the spine, the purpose of this study was to assess the influence of trunk position of cervical spine extensor musculotendon length.

Reading in reclined sitting can decrease the magnitude of the gravitational moment that must be counterbalanced by the cervical neck extensors. When reading a tablet in the lap while seated upright, the average head angle (to the vertical) was approximately 55% of the total head flexion range of motion (ROM) compared with approximately 20% in the semireclined seat.[5] Radiographs show that the gravitational moment arm is 5.2 (2.3) cm in reclined and 7.9 (1.9) cm in upright sitting.[6] Cervical spine muscle activity is also decreased when reading a tablet in a reclined trunk position.[5] An office chair designed to support reclined sitting and mobile technology use showed reduced physiological discomfort, neck and upper back discomfort, and reduced thoracolumbar spinal compressive force and shear forces.[3]

There are still many potential disadvantages to using mobile technology during reclined sitting. Although head flexion and moment arm are reduced in reclined sitting, neck flexion as a percent of the total range of motion (%ROM) is higher when reading a tablet from the lap in reclined (71.0 [14.0] %ROM) compared with upright sitting (56.8 [17.3] %ROM).[5] Radiographs confirm that the lower cervical lordosis angle is more flexed when reading a tablet from the lap with the trunk reclined 30 degrees posteriorly.[6] The muscles responsible for producing the extensor torque for maintaining head position during neck flexion originate or insert on each of the cervical vertebrae.[7] As a result, the increased flexion of the lower cervical spine may stretch the tissues posterior to the cervical flexion–extension axis of rotation and result in a muscle length that is less optimal for force development.

The purpose of this study was to determine the normalized cervical spine musculotendon lengths when reading a tablet computer in 4 positions—upright, semireclined, and reclined sitting and maximum flexion—compared with a neutral position. Radiographs were used to characterize the cervical vertebrae and skull position, and a musculoskeletal model was used to estimate musculotendon length in each posture compared with a neutral posture. Our first hypothesis was that the lower cervical spine would show increased flexion during reclined sitting, whereas the skull would be flexed more relative to the horizontal during upright sitting. Our second hypothesis was that: (1) muscles originating on the lower cervical vertebrae would show increased musculotendon lengths during reclined sitting versus upright sitting and (2) muscles originating on the upper cervical spine and the suboccipital muscles would show increased musculotendon length in the upright trunk posture compared with the reclined position. Maximum flexion was included in these analyses to test if these reading postures approached end ROM. Our third hypothesis was that the semireclined

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posture would result in musculotendon lengths between the upright and reclined trunk positions. Because the incidence of neck pain is higher in females than males,[8–10] we added a factor of "sex" to all statistical analyses.

Methods

Participants

Twenty-two participants were recruited to this study over 2 months (12 males and 10 females). Participants were eligible for the study if they had no previous neck or spine injury, no chronic headaches, and had not been exposed to any of the following sources of radiation in the past 2 years: lumbar spine X-ray, upper GI tract X-ray, barium enema X-ray, or any CT scans. For female participants, an additional exclusion criterion was pregnancy or suspected pregnancy. The University of Arkansas Institutional Review Board and Arkansas Department of Health approved all methods, and participants provided written informed consent when they arrived at the facility.

Postures

Five lateral view cervical spine radiographs were taken for each participant (Figure 1):

1. Neutral head position—the participant seated with arms in lap looking straight forward.
2. Maximum neck flexion—the participant seated with their head tilted forward, trying to touch their chin to their chest.
3. Upright seated—reading a tablet in the lap while in a seated posture.
4. Semireclined—reading a tablet in the lap when sitting in a semireclined position with the backrest reclined 15° to the vertical.
5. Reclined—reading a tablet in the lap when sitting in a reclined position, the backrest reclined 30° to the vertical.

Participants sat as far back in an office chair as possible and could not use the chair's armrests. In the reclined conditions, the seat pan stayed fixed while the chair back rotated posteriorly. All participants held the tablet (iPad 2, Apple, Cupertino, CA) in portrait position. The iPad screen was blank, and participants concentrated on a piece of white tape on the top third of the iPad screen. This setup prevented participants from subtle movements of the body that could occur while reading and blur the image.

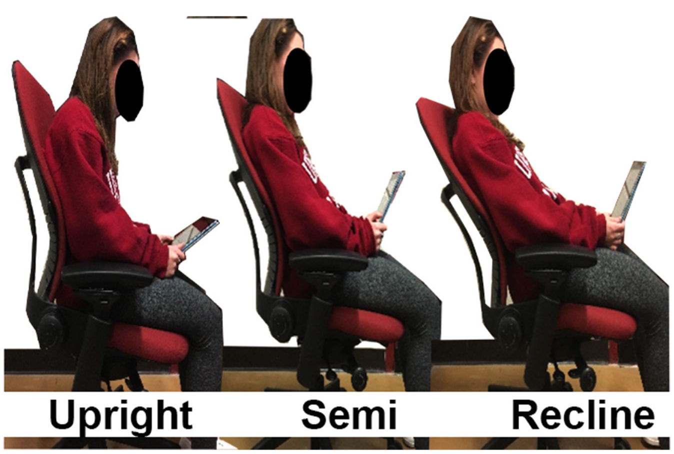

Figure 1 — Three seated reading positions. Participants were not allowed to utilize the armrests. Not shown are the neutral and full flexion positions.

A licensed radiologist technician at Pat Walker Health Center in the University of Arkansas campus took the radiographs. Radiographs were taken at an average distance of 1.82 m away from the participant. Images were first taken in the neutral and full flexion postures followed by the 3 tablet postures in a randomized order. Participants were not instructed on the angle to hold the tablet, which allowed for a more natural observation of the postures. Participants had a 30-second rest between X-rays.

Posture Definition

Vertebral and skull positions and angles were measured on each radiograph by digitizing the corners of each cervical vertebral body C1-C7 and anatomical landmarks on the skull (Figure 2; tpsDig, SUNY Stony Brook). These landmarks were taken from a larger and previously reported data set.[11] Coordinate systems for C2-C7 were defined according to the International Society of Biomechanics recommendations.[12] Vertebral positions were identified as the geometric center of the digitized corner points of the vertebrae. The C2-C7 angles were defined by the vector originating at the geometric center and orthogonal to the line formed by the superior and inferior endplates' midpoints. The C1 vertebra was defined by the midpoint between the posterior and anterior tubercle, and the vector connecting those 2 points defined the C1 angle. Skull position was defined by a point on the tip of the mastoid and skull angle by the vector connecting the mastoid and canthus.

Three kinematic variables were measured on each radiograph: skull angle, skull-C1 vertebra angle, and centroid cervical lordosis angle (CCL). Skull angle was the angle between a vector connecting the mastoid and canthus and a horizontal line (Figure 2).

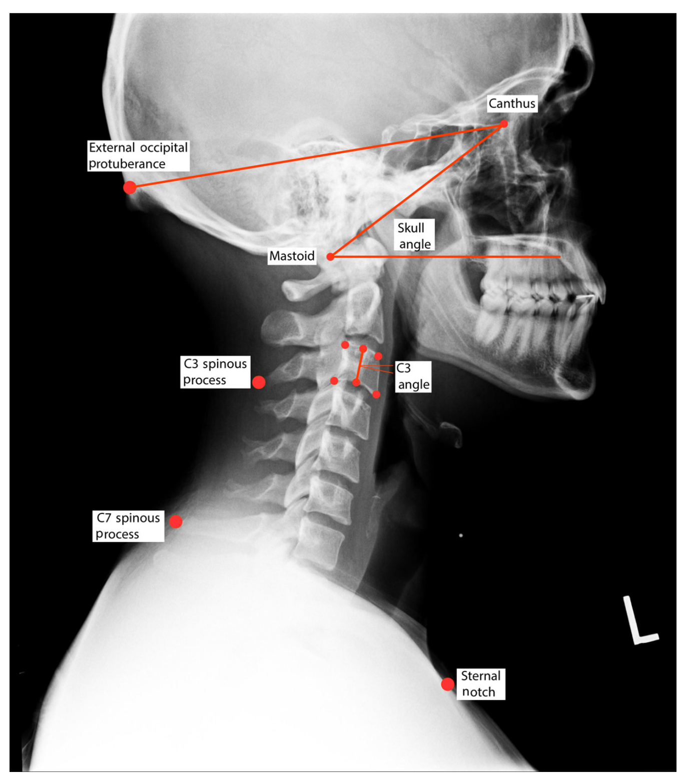

Figure 2 — Sample radiograph in the neutral position.

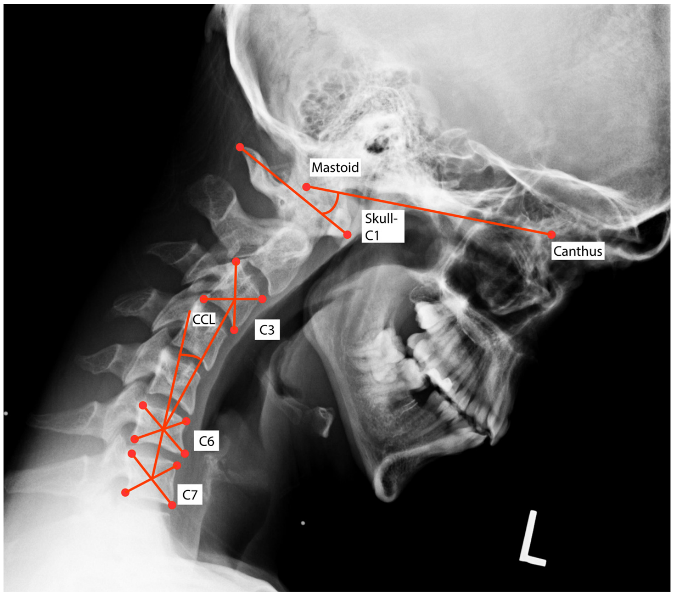

Figure 3 — Sample radiograph in the full flexion position. The figure illustrates the Skull-C1 and Centroid Cervical Lordosis (CCL) measurements.

The Skull to C1 angle was the angle between the skull vector and a vector connecting the anterior and posterior tubercles of the C1 vertebra (Figure 3). The CCL angle (Figure 3) was found by measuring the angle of the intersection between the line connecting the centroids of C6 and C7 and the line from the centroid of C3 to the centroid of C7.[13] All angles from the iPad and maximum flexion radiographs were expressed relative to the neutral radiograph (defined as zero degrees). For each variable, a negative value corresponded to flexion with respect to the neutral position.

Biomechanical Modeling

Radiographic data were used to modify a head and neck model[14] in Software for Interactive Musculoskeletal Modeling (Musculographics, Santa Rosa, CA). Models specific to each subject's posture and size were created. Model head and neck posture were determined by setting the X, Y, and angular positions for each subject's vertebrae (C1-C7) and skull to match radiographic data. The original neck model was modified to include more muscle lines of action (Supplementary Table S1 [available online]; Figure 4). Only muscles with attachments on the skull or cervical vertebrae were included in this analysis. Neck muscle attachments were scaled to vertebral and skull size obtained from each subject's radiographs as in a previous study.[15] Normalized musculotendon length was calculated as the change in musculotendon length relative to the neutral position divided by the neutral position musculotendon length.

Statistical Analysis

All statistics were conducted in JMP (version 15.0; SAS Institute Inc, Cary, NC). The *t* tests were run to assess differences in mass and height between the sexes. A 2-way analysis of variance was run on the 27 musculotendon segments and 3 joint angles with a between factor of SEX (male/female) and within factor of POSTURE (upright/semireclined/reclined/full flexion) with a significance level of $P < .05$. Tukey post hoc tests were run on all significant main effects. Partial

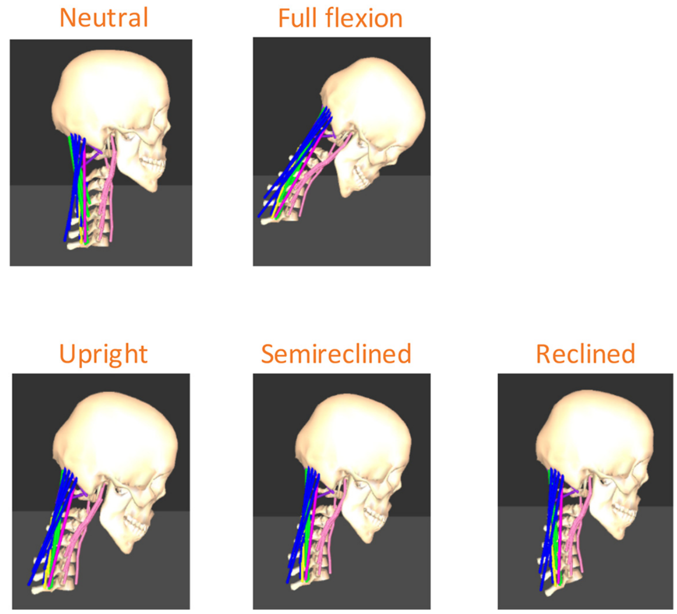

Figure 4 — Sample model outputs for a single participant.

eta squared (η^2_G) was calculated from the analysis of variance table for all muscle segments to quantify the size of the effects.[16] Cohen's *d*[17] values were calculated when the Tukey post hoc tests revealed a significant difference between the upright and reclined reading positions. Correlations (R^2) were also calculated for the association between the joint angles and musculoskeletal segments across the 3 iPad reading conditions. Unless otherwise stated, all values are represented as mean (SD).

Results

One participant (male) was excluded from the final sample because of an occluded landmark. The final sample included 11 males (mean [SD]: 21.8 [1.3] y; 76.5 [9.7] kg; 179.3 [9.1] cm) and 10 females (mean [SD]: 20.7 [.9] y; 65.5 [10.8] kg; 166.9 [6.0] cm). There was a significant difference between sex for mass ($P = .024$) and height ($P < .001$); therefore, we also assessed the variable's association with height when there was a significant main effect or interaction with sex.

There was a main effect of posture for the CCL angle and skull angle ($P < .001$). The CCL angle was most flexed in full flexion (−19 [5.8] degrees) followed by reclined (−15.3 [6.5] degrees), semireclined (−12.7 [7.0] degrees), then upright (−8.9 [7.4] degrees). Each posture was significantly different from each other. Skull flexion angle was the largest in maximum flexion (−53.1 [8.0] degrees) followed by upright (−23.8 [8.5] degrees) and semireclined (−19.2 [8.6] degrees) and reclined (−13.7 [11.4] degrees).

There was a main effect of sex ($P = .005$) for skull angle with respect to the horizontal. Males had greater skull flexion (−31.5 [16.3] degrees) than females (−22.9 [18.4] degrees). Since there was also a significant difference between males' and females' heights, we averaged each participant's skull angle across conditions and performed a correlation against height. The r^2 value was .31 and statistically significant ($P = .008$). Taller individuals demonstrated increased skull flexion.

There were no significant main effects or interactions for Skull-C1 angle. In 46% of the images taken, participants had a flexed Skull-C1 joint compared with their neutral posture, whereas 54% had an extended Skull-C1 joint.

Seventeen of 27 (63%) normalized musculotendon segment lengths demonstrated a significant main effect of posture (Table 1). For all of these segments, full flexion was significantly different from the positions with a longer musculotendon length. The superficial (.24–.26) and deep (.27–.32) multifidi showed the greatest normalized musculotendon lengths during full flexion.

Of the 17 segments with a main effect of posture, 5 musculotendon segments had significantly different normalized musculotendon lengths between the upright position and reclined position. Four of the 5 segments originated at the C7 vertebrae. The deep C4-C6/7 multifidus segment had the largest change in length of all the segments, showing, on average, a 62% increase in the reclined position compared with upright sitting (Table 1). Longus colli (Vertical C1-C6) demonstrated shortening compared

Table 1 Normalized Musculotendon Lengths Changes (Change in Musculotendon Length Relative to the Neutral Position, Divided by the Neutral Position Musculotendon Length) Compared Between Conditions

Segment	*P* value	η^2_G	Normalized musculotendon length (unitless)				Cohen's *d:* upright and reclined
			Upright	Semireclined	Reclined	Flexion	
Multifidus (deep)							
C2-C4/5	<.001	.21	0.17 (0.06)[a]	0.18 (0.07)[a]	0.19 (0.07)[a]	0.26 (0.08)[b]	
C3-C5/6	<.001	.35	0.15 (0.07)[a]	0.16 (0.10)[a]	0.19 (0.11)[a]	0.24 (0.09)[b]	
C4-C6/7	<.001	.32	0.13 (0.12)[a]	0.17 (0.08)[ab]	0.21 (0.07)[b]	0.27 (0.11)[c]	0.81
Multifidus (superficial)							
C2-C4/5	<.001	.24	0.19 (0.07)[a]	0.20 (0.08)[a]	0.20 (0.08)[a]	0.27 (0.09)[b]	
C3-C5/6	<.001	.26	0.19 (0.06)[a]	0.20 (0.07)[a]	0.22 (0.08)[a]	0.28 (0.08)[b]	
C2-C6/7	<.001	.31	0.19 (0.09)[a]	0.22 (0.08)[ab]	0.24 (0.08)[b]	0.32 (0.09)[c]	0.59
Longus capitis							
Skull-C4	.857	.27	–0.01 (0.03)	–0.01 (0.02)	–0.01 (0.02)	–0.01 (0.04)	
Skull-C5	.926	.28	–0.01 (0.02)	–0.01 (0.02)	–0.01 (0.02)	–0.01 (0.04)	
Skull-C6	.876	.26	–0.01 (0.02)	–0.01 (0.02)	–0.01 (0.02)	–0.01 (0.04)	
Skull-C7	.990	.23	–0.01 (0.02)	–0.01 (0.02)	–0.01 (0.02)	–0.01 (0.03)	
Longus colli							
Oblique C1-C5	.690	.21	0.00 (0.2)	–0.01 (0.02)	0.00 (0.02)	–0.01 (0.03)	
Oblique C1-C6	.568	.22	–0.01 (0.02)	–0.02 (0.03)	–0.01 (0.02)	–0.02 (0.03)	
Vertical C1-C6	.002	.26	–0.03 (0.03)[a]	–0.05 (0.03)[ab]	–0.05 (0.03)[b]	–0.06 (0.04)[b]	0.67
Longissimus capitis							
Skull-C7	<.001	.24	0.08 (0.04)[a]	0.09 (0.03)[a]	0.10 (0.03)[a]	0.13 (0.04)[b]	
Obliquus capitis							
Inferior	.135	.25	0.00 (0.02)	0.00 (0.02)	0.00 (0.02)	0.01 (0.03)	
Superior	.508	.36	–0.03 (0.07)	0.00 (0.08)	–0.01 (0.08)	–0.01 (0.11)	
Rectus capitis posterior							
Major	.100	.34	0.01 (0.09)	0.02 (0.08)	0.01 (0.07)	0.05 (0.1)	
Minor	.523	.31	–0.03 (0.07)	0.00 (0.09)	–0.01 (0.10)	–0.02 (0.14)	
Semispinalis capitis							
Skull-C4	.003	.33	0.05 (0.05)[a]	0.05 (0.04)[a]	0.04 (0.04)[a]	0.07 (.05)[b]	
Skull-C5	<.001	.32	0.06 (0.04)[a]	0.06 (0.04)[a]	0.06 (0.03)[a]	0.09 (.05)[b]	
Skull-C6	<.001	.31	0.08 (0.04)[a]	0.08 (0.04)[a]	0.08 (0.04)[a]	0.12 (.04)[b]	
Skull-C7	<.001	.29	0.08 (0.04)[a]	0.09 (0.04)[a]	0.10 (0.04)[a]	0.14 (.04)[b]	
Semispinalis cervicis							
C2-C7	<.001	.30	0.13 (0.06)[a]	0.15 (0.05)[ab]	0.16 (0.05)[b]	0.21(0.06)[c]	0.54
Splenius capitis							
Skull-C4	<.001	.33	0.08 (0.05)[a]	0.07 (0.05)[a]	0.07 (0.05)[a]	0.11 (0.05)[b]	
Skull-C5	<.001	.29	0.08 (0.04)[a]	0.09 (0.04)[a]	0.09 (0.04)[a]	0.13 (0.04)[b]	
Skull-C6	<.001	.27	0.11 (0.04)[a]	0.12 (0.04)[a]	0.13 (0.05)[a]	0.17 (0.04)[b]	
Skull-C7	<.001	.29	0.13 (0.06)[a]	0.15 (0.05)[ab]	0.16 (0.05)[b]	0.21 (0.06)[c]	0.54

Note: Values with the same superscript letter (a, b, or c) indicate that they were not significantly different during post hoc analyses. Cohen's *d* values are reported when there was a significant difference post hoc between the "upright" and "reclined" postures. Guidelines for generalized eta squared (η^2_G): .02 = small effect; .13 = medium effect; .26 = large.[16] Guidelines for Cohen's *d*: small effect = 0.2; medium effect = 0.5; large effect = 0.8.[17]

with neutral with more shortening in the reclined versus upright posture. Finally, the semireclined position was never significantly different from upright or reclined.

There was a main effect of sex for 6 musculotendon segments (Table 2). In all cases, the normalized musculotendon lengths changes with respect to neutral were greater in men than women. There were no significant interactions for any of the musculotendon segments for sex × posture. Three of the segments also had a significant association ($P < .05$) with height. As a person's height increased, the normalized musculotendon length compared with neutral increased as well.

Many normalized musculotendon length changes with respect to neutral were significantly associated with CCL, Skull, and Skull-C1 angle (Table 3, Supplementary Figures S1–S3 [available online]). The Skull and Skull-C1 angles demonstrated the highest number of significant correlations with the musculotendon segments. Although the suboccipital muscles (rectus capitis posterior and obliquus capitis superior) did not demonstrate significant differences across the sitting positions, their normalized musculotendon length changes were significantly correlated to the Skull-C1 angular changes relative to neutral. With an extended Skull-C1 joint, these muscles shortened. With a flexed Skull-C1 joint, these muscles lengthened. The same trend occurred for the semispinalis capitis and the splenius capitis (Skull-C4) segment. Skull angle changes with respect to neutral were correlated with the normalized length changes of the multifidus segments that originate at C6/7 and C5/C6 levels and the lower segments of the splenius capitis. Finally, longissimus capitis, semispinalis capitis, and splenius capitis had significant correlations with the Skull and/or Skull-C1 angle for the semireclined and reclined positions only.

Discussion

We used radiographs and a musculoskeletal model to estimate cervical extensor musculotendon lengths in 3 mobile computing reading postures and maximum neck flexion. Individuals demonstrated more flexion in their lower cervical spine during reclined sitting but had more skull flexion during upright sitting. When using a tablet in a reclined posture, cervical extensor normalized musculotendon lengths of segments originating on the lower cervical vertebrae were increased compared with reading a tablet sitting upright. The upright trunk position did not result in increased musculotendon lengths for segments originating in the upper cervical vertebrae and the suboccipital muscles compared with reclined; however, the Skull-C1 joint angle (which varied significantly among participants) influenced musculotendon length for the suboccipital muscles, semispinalis captitis, and upper segments of splenius capitis. Third, the semireclined trunk position did not produce significantly different musculotendon lengths or kinematics versus the upright or reclined trunk position. Finally, the kinematics and musculotendon lengths were always significantly different from all 3 sitting positions during full flexion.

There was an increase in normalized musculotendon length changes when reclined for the C4-C6/7 (deep) and C2-C6/7 (superficial) multifidus segments and the semispinalis cervicis (C2-C7) and splenius capitis (Skull-C7) segments. The CCL flexion in reclined sitting would lengthen these muscles that all originate on or around the C7 vertebra. Although the skull angle and, subsequently, gravitational moment produced by the head is reduced, this muscle lengthening due to CCL flexion could reduce the force- and moment-producing capabilities of these extensor muscles, increasing loading onto muscles or soft tissues in the spine.

Contrary to the current study and our previous lab work,[5] Weston et al[3] found that neck angle did not differ between the upright and reclined positions. The difference between these 2 results may be due to instructions and viewing angles. Weston et al[3] participants kept a smaller viewing angle by having the smartphone at about chest level in upright and reclined sitting. This posture kept a consistent relative orientation between the head and the trunk. As a result, specific instructions and viewing angles may provide an opportunity to assess a range of risk factors and evaluate best practices for technology use.

Previous work has shown an effect of subject-specific vertebral position and head and neck size on cervical spine musculoskeletal moments.[15] Our study confirmed this with significant associations of musculotendon lengths with cervical spine kinematics, sex, and height. Forty-six percent of images showed participants with flexion of the Skull-C1 joint. This was essential to consider when assessing the suboccipital muscles (obliquus capitis superior and rectus capitis posterior) and semispinalis capitis. If an individual displayed Skull-C1 flexion, they demonstrated a lengthening of those musculotendon segments, which may have reduced their active force-producing capabilities and increased their passive force within the musculotendon segment. If an individual displayed extension at this joint with respect to neutral head position, the segments would shorten and reduce their active force-producing capabilities.

Despite a significant difference between postures, the CCL angle typically correlated with musculotendon segments within the upright

Table 2 Normalized Musculotendon Lengths [Mean (SD)] for Segments That Had Significant Main Effects for Sex

Segment	Females	Males	P value (sex)	R^2 with height
Multifidus (deep) C3-C5/6	0.15 (0.08)	0.23 (0.09)	.020	.04
Multifidus (deep) C4-C6/7	0.14 (0.07)	0.24 (0.11)	.002	.16 ($P = .073$)
Multifidus (superficial) C2-C5/6	0.20 (0.08)	0.25 (0.07)	.023	.13
Multifidus (superficial) C2-C6/7	0.19 (0.07)	0.29 (0.10)	.001	.25 ($P = .021$)
Semispinalis cervicis C2-C7	0.13 (0.04)	0.19 (0.06)	<.001	.23 ($P = .030$)
Splenius capitis Skull-C7	0.13 (0.04)	0.19 (0.07)	.006	.28 ($P = .015$)

Note. For R^2 with height column, only the values with $P < .01$ are shown.

Table 3 Correlation Table (R^2) of Joint Angles With Musculotendon Lengths Across the 3 Different iPad Positions

	CCL			Skull			Skull-C1		
Segment	**Upright**	**Semi**	**Reclined**	**Upright**	**Semi**	**Reclined**	**Upright**	**Semi**	**Reclined**
Multifidus (deep)									
C2-C4/5	0.065	0.07	0.14	0.00	0.07	0.13	0.17*	0.01	0.00
C3-C5/6	0.084	0.10	0.07	0.22**	0.10	0.34***	0.03	0.00	0.02
C4-C6/7	0.090	0.01	0.03	0.33***	0.27**	0.52***	0.11	0.01	0.01
Multifidus (superficial)									
C2-C4/5	0.10	0.05	0.08	0.00	0.11	0.09	0.07	0.00	0.00
C2-C5/6	0.34***	0.20*	0.12	0.01	0.22**	0.23*	0.09	0.01	0.00
C2-C6/7	0.20*	0.07	0.10	0.27**	0.27**	0.49****	0.08	0.01	0.01
Longus capitis									
Skull-C4	0.33**	0.11	0.09	0.02	0.04	0.01	0.03	0.01	0.00
Skull-C5	0.37***	0.12	0.08	0.03	0.01	0.02	0.02	0.01	0.01
Skull-C6	0.30**	0.13	0.11	0.08	0.01	0.04	0.00	0.01	0.01
Skull-C7	0.36***	0.17	0.12	0.01	0.01	0.02	0.00	0.02	0.03
Longus colli									
Oblique C1-C5	0.00	0.01	0.02	0.18*	0.00	0.06	0.09	0.03	0.22**
Oblique C1-C6	0.00	0.00	0.00	0.28**	0.00	0.12	0.14*	0.11	0.20**
Vertical C1-C6	0.12	0.08	0.08	0.22**	0.02	0.16*	0.16*	0.13	0.11
Longissimus capitis									
Skull-C7	0.04	0.00	0.03	0.07	0.31***	0.23**	0.03	0.28**	0.23**
Obliquus capitis									
Superior	0.60****	0.18*	0.29**	0.01	0.10	0.01	0.11	0.40***	0.19**
Inferior	0.13	0.05	0.02	0.17*	0.01	0.00	0.02	0.02	0.03
Rectus capitis posterior									
Major	0.20*	0.08	0.04	0.00	0.09	0.00	0.27**	0.35***	0.40***
Minor	0.18*	0.00	0.00	0.00	0.07	0.02	0.58****	0.63****	0.71****
Semispinalis capitis									
Skull-C4	0.18*	0.04	0.00	0.01	0.17*	0.02	0.39***	0.51****	0.49****
Skull-C5	0.17*	0.06	0.00	0.01	0.21**	0.02	0.25**	0.43***	0.47****
Skull-C6	0.08	0.03	0.00	0.00	0.33***	0.08	0.24**	0.48****	0.35***
Skull-C7	0.08	0.04	0.00	0.05	0.37***	0.15*	0.13	0.47****	0.36***
Semispinalis cervicis									
C2-C7	0.21**	0.12	0.17*	0.25**	0.26**	0.45***	0.09	0.00	0.00
Splenius capitis									
Skull-C4	0.10	0.01	0.01	0.00	0.18*	0.09	0.32***	0.25**	0.26 **
Skull-C5	0.09	0.02	0.01	0.00	0.19**	0.12	0.06	0.16*	0.21**
Skull-C6	0.00	0.01	0.05	0.05	0.38***	0.35***	0.00	0.09	0.04
Skull-C7	0.00	0.01	0.07	0.29**	0.34***	0.48****	0.01	0.03	0.05

Abbreviation: CCL, centroid cervical lordosis.
For significance: *$P < .1$; **$P < .05$; ***$P < .01$; ****$P < .001$.

position. Reclining the seatback may have constrained the CCL angle; therefore, participants altered their skull position to view the iPad. In upright, participants may have used a combination of CCL and skull flexion to look at the tablet (like in a slouched sitting position). The Skull and Skull-C1 joint angles' significant correlations with many of the musculotendon segments support this reasoning.

Studies have found a higher reporting of neck pain in females[8–10]; however, our study found that kinematic and model outputs were correlated with a person's height. Recent work[7] on the same data set from this study used geometric morphometric techniques to evaluate shape variation in the postures. Taller individuals (mostly male) demonstrated increased flexion at the Skull-C1 joint (also reported through angular measurements in the current study).[7] Females exhibited increased mandibular protrusion while using a tablet in their lap.[7] On average, our participants were slightly taller (females = 162.1 cm and males = 176.9 cm) than the 50th percentile in the United States (females = 166.9 cm and males = 179.3 cm).[18] Females in our sample ranged from the 20th (156 cm) to 96th percentiles (174 cm), and males ranged from the 17th (169 cm) to 100th (198 cm).[18] Future studies should match participants by height between sexes or collect across the 5th and 95th percentiles for either height or neck anthropometrics.

It is unknown what amount of musculotendon lengthening of the cervical muscles would be considered "too much" and elicit pain development. Sbriccoli et al[19] showed that applying a 40-N load to the lumbar multifidus muscles in a feline model originally caused approximately an 11-mm displacement. Although they did not measure musculotendon length, they measured creep over time—30 minutes of loading caused a mean displacement of 18 mm or a mean creep of approximately 64%. This change was accompanied by a 69% to 75% decrease in lumbar multifidi muscle activity with spasms noted in the measured muscles. Although there may have been significant differences in normalized musculotendon length changes with respect to flexion for many of these muscles (Table 1), without knowing the resulting pain (if any) that these participants would experience with prolonged tablet or smartphone usage, we cannot say whether a posture would prevent a chronic musculoskeletal disorder. Future work must combine the results of the biomechanical musculoskeletal model with concurrent pain development reports.

A limitation of this study was that we did not include muscles originating inferior to C7 in the model. These muscles, such as the trapezius and the lower portions of other cervical muscles such as semispinalis or splenius, may be more affected by the reclined postures. Second, straight-line paths of muscles were used, which may not accurately represent muscle geometry. Third, there was variation in muscle attachment points between participants, which was not accounted for in the model. Fourth, the sexes were not height matched, and height was used as a proxy for neck length; however, neck length and stature may not be exactly proportional to each other. Finally, the participants were not reading real information on the iPad. This might have altered the iPad's viewing angle and changed the spine kinematics. As mentioned in the Methods section, this was chosen to reduce small movements that could have blurred the images.

In conclusion, this study adds musculotendon segment lengths to the body of literature on mobile devices' musculoskeletal impact. The model results show that normalized musculotendon lengths increased in reclined sitting for some of the muscles originating at C7. The suboccipital muscle lengths were dependent on the Skull-C1 angle.

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