Armrests and back support reduced biomechanical loading in the neck and upper extremities during mobile phone use

Karthreek Reddy Syamala, Ravi Charan Ailneni, Jeong Ho Kim, Jaejin Hwang

ABSTRACT

Mobile phone use is known to be associated with musculoskeletal pain in the neck and upper extremities because of related physical risk factors, including awkward postures. A chair that provides adequate support (armrests and back support) may reduce biomechanical loading in the neck and shoulder regions. Therefore, we conducted a repeated-measures laboratory study with 20 participants (23 ± 1.9 years; 10 males) to determine whether armrests and back support during mobile phone use reduced head/neck flexion, gravitational moment, and muscle activity in the neck and shoulder regions. The results showed that the chair support (armrests and back support) reduced head/neck flexion (p < 0.001), gravitational moment (p < 0.001), and muscle activity (p < 0.01) in the neck and shoulder regions significantly compared to no chair support. These results indicate that a chair with adequate support can be an effective intervention to reduce the biomechanical exposures and associated muscular pain in the neck and shoulders during mobile phone use.

1. Introduction

Because of the rapidly-developing technology and various useful features of mobile phones, more people use them for longer periods on a daily basis (Ko et al., 2016; Shan et al., 2013). Approximately 77% of the U.S. population uses mobile phones (Smith, 2017; Gold et al., 2012) for an average of 3–4 h per day (Lipsman, 2017).

Despite the benefits of mobile phones, their use can increase risks of musculoskeletal pain in the neck and upper extremities (Gustafsson et al., 2010; Kim, 2015; Xie et al., 2016). Head and neck postures play a vital role in cervical spine stress and associated neck pain (Lee et al., 2015b; Straker et al., 2009). A previous study demonstrated a positive relation between neck flexion and force acting on the neck; neck stress increased from approximately 5 kg (no flexion) to 27 kg (at 60° neck flexion) (Hansraj, 2014). Previous studies have shown that mobile phone use is associated with prolonged neck flexion (Guan et al., 2016; Vate-U-Lan, 2015) and therefore can increase a risk of neck pain (Kim and Koo, 2016; Lee et al., 2015a; b; Ning et al., 2015).

Further, mobile phone use can produce musculoskeletal pain in the upper extremities. Previous studies have shown that mobile phone use is associated with repetitive movements and awkward postures of the fingers and wrist (Gilman et al., 2015; Gustafsson et al., 2017, 2016; Lee et al., 2015b; Xiong and Muraki, 2014). As repetitive movements and awkward postures are physical risk factors for musculoskeletal fatigue and pain known well (da Costa and Vieira, 2010; Gallagher and Heberger, 2013), mobile phone use can increase a risk of developing musculoskeletal pain in the wrist and fingers.

Previous studies in conventional computer settings with keyboards and mice have shown that these awkward postures and related musculoskeletal pain in the upper extremities and neck can be reduced significantly by adjusting the display location and providing adequate arm and wrist supports (Onyebeke et al., 2014; Visser et al., 2000; Zhu and Shin, 2012). For example, having a screen at eye level reduces neck flexion, but at the expense of increased muscular loading in the shoulder/upper extremity regions (Straker and Mekhora, 2000). To avoid this trade-off, armrests would be useful to alleviate physical demands on the shoulders/upper extremities.

Such ergonomic interventions used in conventional computer settings can reduce awkward head/neck postures and associated musculoskeletal pain during prolonged mobile phone use effectively. However, little research has evaluated systematically the efficacy of adequate ergonomic controls to reduce biomechanical exposures during seated mobile phone use. Therefore, the goals of this study were two-fold: 1) to quantify the kinematics of the head/neck, gravitational moment, and muscle activity in the neck during mobile phone use objectively, and 2) evaluate the effects of armrests and back support on the biomechanical measures aforementioned.
To achieve our study goals, we tested two primary hypotheses: 1) The gravitational moment of the neck increases as the vertical location of a mobile phone lowers (from eye to lap level: Fig. 1) and 2) Armrests and back support during mobile phone use reduce the muscle activity in the neck and shoulder regions. This study result can be used to develop evidence-based ergonomic recommendations to reduce a risk of musculoskeletal pain in the neck and upper extremities during mobile phone use.

2. Methods

2.1. Participants

Twenty young adult participants (Average age: 23 ± 1.9 years old) with an equal sex distribution were recruited through e-mail solicitations in a university community. All participants were experienced mobile phone users (average mobile phone use experience: 6.6 ± 1.9 years) without current (past 7 days) musculoskeletal pain and a history of musculoskeletal disorders in the neck and upper extremities. A University’s Institutional Review Board approved our experimental protocol and all participants gave written consent before participating in this study.

2.2. Experimental protocol

In a repeated-measures laboratory experiment, 20 participants were asked to use their own mobile phones under eight different experimental conditions (4 different mobile phone positions and 2 different chair supports). Four phone locations included eye, chest, lap, and a self-selected position, and two different chair support conditions included support (armrests and back support) and no support (Fig. 1). Participants self-selected the gaze distance (between the eyes and mobile phone) for each condition (eye: 26–29 cm; chest: 30–33 cm; lap: 47–53 cm; self-selected: 39–43 cm). For the self-selected position, participants were allowed to choose their preferred mobile phone positions with and without chair supports, respectively. The presentation order of the 8 experimental conditions was randomized and counterbalanced to minimize potential systematic biases.

Prior to the experiment, the chair height was adjusted according to ANSI/HFES standards (2007). Briefly, the chair height was adjusted to allow participants’ feet to relax on the ground with their thighs parallel to the floor. During each task, participants were asked to accept a series of standardized, general open-ended questions from a researcher and answer them via text messages for 5 min using their phones. Five-minute breaks were given between the texting sessions to minimize residual fatigue effects of a previous session.

2.2.1. Kinematic data

During the texting sessions, kinematic data from the head and neck were sampled at 100 Hz using an 8-camera optical motion capture system (Flex 13; Optitrack; Natural Point, OR) with reflective markers. Using double-sided tape, 9 14-mm reflective markers (M4, Optitrack) were attached bilaterally on the canthus, tragus, C7 spinous process, sternal notch, vertex of the head, and top and bottom of a mobile phone (Fig. 1). Raw kinematic data were filtered by a digital zero-phase 4th-order Butterworth filter with a cutoff frequency of 6 Hz (Motive, Optitrack). Using a custom-built Matlab program (R2015a, The MathWorks, Natick, MA), the head, neck, and cranio-cervical angle, gravitational moment, and gravitational moment-arms on the neck (Fig. 2) were calculated according to the methods recommended in previous studies (Vasavada et al., 2015; Young et al., 2012). The neck flexion angle was measured between the vertical line and the line from the midtragus (midpoint of the left and right tragus markers) to the C7 spinous...
process (Fig. 2(1)). The head flexion angle was determined by the vertical line and the line from the mid-tragus to the mid-canthus (midpoint of the left and right canthus markers (Fig. 2(2)). The craniocervical angle was defined as an angle between the line from the mid-canthus to the mid-tragus and the line from the mid-tragus to the C7 spinous process (Fig. 2(3)). The location of the cervicothoracic junction (C7-T1) was estimated as the midpoint between the C7 spinous process (Fig. 2(3)). The location of the cervicothoracic junction (C7-T1) was estimated as the midpoint between the C7 spinous process and the sternal notch marker (Vasavada et al., 2001). The center of gravity (COG) of the head was estimated as 17% of the distance from the mid-tragus marker to the vertex of the head marker (Annis, 1978). Briefly, the head mass was estimated using a regression equation as a function of the head circumference and body mass to compute the gravitational moment in the neck (Fig. 2 (4)) (Clauser et al., 1969). The gravitational moment-arm was calculated as the horizontal distance between the C7-T1 and the COG of the head (Fig. 2 (5)). These kinematic variables were summarized using 10th, 50th, 90th percentile values.

### 2.2.2. Electromyography

As the upper trapezius (TRAP) and splenius capitis (SPL) muscles have been extensively studied to quantify muscular loading during conventional computer and mobile device use (Cook et al., 2004; Kim et al., 2014; Shin and Zhu, 2011), TRAP and SPL muscle activities were bilaterally measured at a sampling rate of 1000 Hz using Ag/AgCl surface electrodes (Blue Sensor N-00-S; Ambu; Ballerup, Denmark) and a wireless logger (WBA; Mega Electronics; Kupio, Finland). Skin preparation, muscle identification, and electrode placement were conducted based on the European Recommendation for Surface Electromyography (Hermens et al., 1999). Raw EMG data were processed initially with a band pass filter of 10–350 Hz, and the processed data were rectified and averaged using a 125 ms moving window (MegaWin; Mega Electronics; Kupio, Finland). At the end of each experiment, three Maximum Voluntary Contractions (MVCs) were collected in each muscle with a 2-min break between trials. For the MVCs of TRAP, participants performed a continuous shoulder shrug with their arms at their sides in an upright seated posture against isometric resistance by a researcher (Harms-Ringdahl et al., 1996). The MVCs for SPL were collected while seated participants attempted to move their head backward from a flexed posture against isometric resistance by a researcher (Rang and Shin, 2017). The peak of the 95th %tile root mean square values across three MVCs were used to normalize the EMG data (Odell et al., 2007). Normalized muscle activity (%MVC) was summarized using the amplitude probability density function (APDF) to evaluate ranges of muscle activities during texting for the following: 10th %tile (static), 50th %tile (median) and 90th %tile (peak) (Jonsson, 1982). A greater difference between 10th %tile and 90th %tile values indicates a more dramatic change in muscle activity amplitudes (Szeto et al., 2009).

### 2.3. Data analysis

First, the normality of the data was evaluated using goodness-of-fits (Shapiro-Wilks W tests for a normal distribution and Kolmogorov’s D test for a log-normal distribution) in JMP (13 Pro, SAS Institute; Cary, SC). As parametric are preferred to non-parametric models to avoid loss of information, data distributed normally or log-normally were analyzed using mixed linear models. In a mixed model, phone position and chair supports were included as fixed effects and subject was included as a random effect to account for within-subject correlation. Otherwise, non-parametric tests (Friedman tests) were used to analyze the data in a statistical software, R (R 3.4.0; Development Core Team). As all kinematic data except for neck-flexion were distributed normally, a mixed linear model (JMP 13 Pro, SAS Institute; Cary, SC) was used to determine whether kinematic measures and SPL muscle activity differed depending upon phone position and chair supports. Because SPL muscle activity and neck-flexion data were distributed log-normally, SPL muscle activity and neck-flexion data were transformed using natural logarithm. Then, a mixed linear model (JMP 13 Pro, SAS Institute; Cary, SC) was used to test the study hypotheses. Given non-normality of TRAP muscle activity (EMG), Friedman tests for TRAP muscle activity were used to test our study hypotheses. Post-hoc tests with Bonferroni correction were performed to identify statistically significant differences. Statistical significance was noted when p-values were less than 0.05.

### 3. Results

#### 3.1. Kinematic data

Neck flexion, head flexion, and craniocervical angles differed significantly depending upon phone position and chair support (p < 0.001) as shown in Table 1. Eye (phone position) and chair
supports showed the lowest neck flexion and head flexion angles, and the highest cranio-cervical angle ($p < 0.001$). Lap (phone position) without chair support showed the highest neck flexion and head flexion angles, and the lowest cranio-cervical angle ($p < 0.001$). There were significant interactions between phone position and chair support in the neck flexion angle ($p's < 0.001$), head flexion angle: 10th %tile ($p = 0.007$), 50th %tile ($p = 0.019$), and 90th %tile ($p = 0.010$), and cranio-cervical angle: 10th %tile ($p = 0.002$), 50th %tile ($p < 0.001$), and 90th %tile ($p < 0.001$) (Fig. 3).

Gravitational moment at C7-T1 varied significantly depending upon phone position and chair support. Eye (phone position) and chair support showed the lowest gravitational moment ($p < 0.001$), while lap (phone position) without chair support showed the greatest gravitational moment ($p < 0.001$). There were significant interactions between phone positions and chair support on the gravitational moment ($p's < 0.001$), as shown in Fig. 3.

3.2. Electromyography (EMG)

There were significant differences between phone position and chair support in muscle activity in the upper trapezius (TRAP) and Splenius Capitis (SPL) (Table 2). For TRAP, lap (phone position) and chair support showed the lowest muscle activities, while eye (phone position) without chair support showed the highest muscle activities. For SPL, eye (phone position) and chair support showed the lowest muscle activities, while lap (phone position) without chair support showed the highest muscle activities. Interactions between phone position and chair support were significant in TRAP ($p's < 0.001$), left SPL: 10th %tile ($p = 0.005$), 50th %tile ($p = 0.018$), and 90th %tile ($p = 0.009$), and right SPL: 10th %tile ($p = 0.056$), 50th %tile ($p = 0.027$), and 90th %tile ($p = 0.015$), as shown in Fig. 4.

4. Discussion

This study evaluated whether there were differences in head/neck flexion angle, gravitational moment in the neck, and neck/shoulder muscle activity depending upon phone positions (eye, chest, lap, and self-selected) and chair support (support and no support) during mobile phone use. The results showed that the gravitational moment, flexion angle, and muscle activity in the neck and head were affected significantly by both factors.

4.1. Kinematic data

Kinematic data showed that the chair support (armrests and back support) reduced the neck flexion (8–28%), head flexion (2–14%), and cranio-cervical angles (0.3–6%), and the gravitational moment at C7-T1 (17–36%) significantly in comparison to no chair support. The chair support allowed participants to rest their arms and back, which allowed the head and neck postures to be more neutral; therefore, the head/neck flexion angles and gravitational moment were decreased significantly. This is consistent with previous studies that have shown that proper armrests and back support can affect the head and neck postural alignment positively (Horton et al., 2010), and reduce physical risks in the neck in conventional computer settings (Shin and Zhu, 2011). The results indicated that providing adequate chair support may help reduce a risk of developing neck pain during mobile phone use.

Neck and head postures also were affected significantly by phone position. The head/neck flexion angle and gravitational moment in the neck were highest when a phone was held on the lap, while the corresponding measures were lowest when a phone was held at subject’s eye level. This finding is consistent with previous studies (Douglas and Gallagher, 2017; Vasavada et al., 2015; Young et al., 2012). Greater
neck flexion increases significantly the compressive loads on the cervical spine and associated neck muscular demands to stabilize the head and are associated with the development of neck pain (Adams and Dolan, 2005). Further, the neck flexion when a phone is placed on the lap was rather high (73–76°), indicating substantial biomechanical loading in the neck, as a previous study showed that the neck stress at 60° neck flexion was three-fold higher compared to a neutral posture (Hansraj, 2014). Therefore, neck flexion during mobile phone use in this study appeared to be great enough to increase a risk of musculoskeletal pains in the neck (Hansraj, 2015; Toh et al., 2017), which can explains previous findings in an association between mobile phone use and neck pain (Gustafsson et al., 2017; Ko et al., 2016; Lee et al., 2015b). These results indicated that individuals should avoid holding a phone at lap level to prevent excessive stress in the neck.

Interactions between chair support and location were significant and indicated that the effects of the chair support varied depending upon phone location. Chair support was most effective in reducing awkward posture at a self-selected position. In the self-selected position without chair support, participants preferred to put their arms on their laps, which was the only condition available to support their arms during texting and caused high flexion and gravitational moment in the neck. In contrast, with the chair support, participants were able to rest their arms on the armrests, which elevated a phone’s position and therefore reduced the head/neck flexion and gravitational moment significantly compared to no chair support. In the self-selected position with the chair support, an average neck flexion angle (66°) was lower.

### Table 2

Mean (standard error) normalized muscle activity (%MVC) of upper trapezius and splenius capitis.

<table>
<thead>
<tr>
<th>Muscle</th>
<th>%tile</th>
<th>Phone position</th>
<th>p-value</th>
<th>Chair support</th>
<th>p-value</th>
</tr>
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<tbody>
<tr>
<td></td>
<td></td>
<td>Eye</td>
<td>Chest</td>
<td>Lap</td>
<td>Self-selected</td>
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<tr>
<td>Upper Trapezius (TRAP)</td>
<td></td>
<td>Left</td>
<td></td>
<td></td>
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<tr>
<td>10th</td>
<td>2.8± (0.4)</td>
<td>1.7± (0.3)</td>
<td>1.0± (0.1)</td>
<td>1.3± (0.3)</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>50th</td>
<td>4.2± (0.7)</td>
<td>2.5± (0.4)</td>
<td>1.4± (0.2)</td>
<td>1.7± (0.4)</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>90th</td>
<td>6.3± (1.0)</td>
<td>4.0± (0.7)</td>
<td>2.6± (0.3)</td>
<td>2.7± (0.5)</td>
<td>0.015</td>
</tr>
<tr>
<td>Right</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10th</td>
<td>2.3± (0.4)</td>
<td>1.4± (0.3)</td>
<td>0.6± (0.1)</td>
<td>0.9± (0.1)</td>
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<td>50th</td>
<td>3.7± (0.7)</td>
<td>2.1± (0.5)</td>
<td>0.8± (0.1)</td>
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<tr>
<td>90th</td>
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<td>3.0± (0.7)</td>
<td>1.2± (0.1)</td>
<td>1.6± (0.4)</td>
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<tr>
<td>Splenius Capitis (SPL)</td>
<td></td>
<td>Left</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10th</td>
<td>4.4± (0.4)</td>
<td>5.4± (0.5)</td>
<td>6.5± (0.5)</td>
<td>6.4± (0.6)</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>50th</td>
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<td>7.4± (0.7)</td>
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<td>8.8± (0.8)</td>
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<td>&lt; 0.001</td>
</tr>
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</table>

*Columns with different superscripts denote significant difference in normalized muscle activity among phone positions and between chair supports with α = 0.05. p-values were calculated using Friedman test for TRAP and generalized linear mixed model for SPL.

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Fig. 4. Interaction plots of mean 90th %tile muscle activity of the left/right upper trapezius (TRAP) and left/right Splenius Capitis (SPL). The error bars represent standard errors. Asterisks denote statistical significance at α = 0.05.
compared to the lap level (70°), but still was substantially higher than the eye level (52°). This could affect TRAP muscle activity while texting. Although the eye level resulted in a smaller neck flexion angle, it required greater muscle activities of the TRAP (1.8–2.2%) to hold the phone stable while texting compared to the self-selected position (1.0–1.9%). This biomechanical trade-off might explain why participants preferred to hold their phones above their laps, but below their eye level.

The APDF analyses showed that amplitude ranges (90th %tile-10th %tile) in the postural variables were small during texting (neck flexion: 2.1–4.0°; head flexion: 3.4–6.0°; cranio-cervical angle: 2.0–4.3°; gravitational moment: 0.2–0.4Nmm). This indicated monotonous (static) head/neck postures during mobile phone use, which is similar to a previous finding (Xie et al., 2018). This lack of postural variability could be associated with greater amounts of sustained passive muscular loading and discomfort in the neck and shoulders (Bergqvist et al., 1995; Douglas and Gallagher, 2017). Thus, in addition to providing the chair supports, promoting postural variation and intermittent breaks also is important to alleviate physical stresses in the neck and shoulders.

### 4.2. Electromyography (EMG)

TRAP and SPL muscle activities were significantly lower with the chair support as compared to no chair support condition (Table 2). Lower external moment in the neck and shoulders could explain less muscle activities with chair support. As described earlier, the back support helped keep the head and neck postures more neutral, which significantly reduced the gravitational moment in the neck and therefore lowered SPL muscle activity. This finding is also consistent with a previous study showing that back support significantly reduced neck extensor muscle activities (Douglas and Gallagher, 2017). Lack of armrests would have increased TRAP muscle activity to counterbalance the net gravitational moment by the upper extremities. When armrests were provided, the gravitational force in the upper extremities should have been transferred to the armrests; therefore TRAP muscle activity was reduced (Cook et al., 2004; Erdélyi et al., 1988).

Among the different phone positions, TRAP muscle activity was highest at the eye level (Table 2). Although we did not measure upper extremity joint angles, raising a phone position to the eye level could be related to varying combinations of elbow and shoulder flexion, and scapular elevation, all of which would increase TRAP muscle activity during mobile phone use. In contrast, SPL muscle activity was highest at the lap level, which can be explained by greater neck flexion at the lap level compared to the other, higher locations. The greater neck flexion and gravitational moment at the lap level may have increased muscle activity to counteract the external moment (Douglas and Gallagher, 2017).

Effects of the chair support on muscle activities significantly varied by phone position (Fig. 4). For TRAP muscle activity, the highest reduction occurred at the eye level. The self-selected level demonstrated that the chair support provided the greatest reduction in SPL muscle activity. At the self-selected level with the chair support, the armrests should have significantly reduced the gravitational moment in the neck and associated SPL muscle activity. This finding mirrored the trends in gravitational moment differences across different phone positions (Figs. 3 and 4). This is consistent with a previous study that has found associations between the neck muscle activity and gravitational moment in the neck in flexed postures (McGill et al., 1994). Chair support may have helped participants maintain more upright postures and therefore reduced the force transmitted to their neck and shoulders and associated gravitational moment and muscle activity in the neck (SPL) and shoulder (TRAP) regions.

The APDF analyses showed that the muscle activity variability (a range between 10th and 90th %tile) in TRAP was small with chair support (0.4–1.5%) regardless of phone positions. However, without the chair support, the muscle activity variability in TRAP increased as a phone position was elevated (lap: 0.6–1.6%; chest: 2.7–3.3%; eye: 5.3–5.9%). In contrast, SPL muscle activity showed that muscle activity variability was greater (4.2–6.5%) with no chair support compared to chair support (2.5–5.3%). Regardless of the chair support, muscle activity variability in SPL increased as a phone position lowered (eye: 2.5–5.0%; chest: 3.7–5.3%; lap: 4.8–6.1%). These trends in the muscle activity variability overall paralleled the trends in muscle activities (Fig. 4). Given lack of postural variability identified earlier, more stressful conditions (extreme phone positions without chair support) could have increased both the amplitude and range of muscle activities.

### 4.3. Limitations

Although this laboratory-based study was carefully designed and controlled, it has some limitations. First, testing tasks were relatively brief (5 min). An assessment of short-term physical exposure may not provide representative exposure measures associated with mobile phone use, especially for a prolonged period. Second, the characteristics (e.g., sizes and weights) of mobile phones used in our experiment were not controlled as participants used their own phones for texting tasks. However, the standard deviations (SDs) of major phone dimensions (SDs of the height: 10.6 mm, width: 5.8 mm, depth: 1.4 mm, and weight: 22.5 g) indicate small differences between the phones. Third, although subjective discomfort ratings would provide important implications based on our findings from objective measures, this study did not evaluate subjective measures. Future studies should include subjective assessments to determine whether the objective biomechanical measures are reflected by subjective measures. Fourth, this study did not evaluate anterior deltoid, which was shown to have a major role in forearm support during keyboard use (Cook et al., 2004). Therefore, anterior deltoid would be an important muscle to evaluate during mobile phone use in future studies. Lastly, vision correction information was not collected in this study. As corrected vision could affect participants’ gaze distances while texting, it may be worthwhile to account for corrected vision in future studies. Despite these limitations, this study still showed potential benefits of chair support in reducing postural exposures and associated muscular demand in the neck and shoulder regions during mobile phone use.

### 5. Conclusion

The findings of this laboratory-based study indicate that mobile phone use may increase risks for musculoskeletal pain and injuries in the neck and shoulder regions by increasing muscle activities, neck/ head flexion, and gravitational moment. The results suggest that placing a phone at eye level with adequate body support can reduce the biomechanical stresses in the neck and upper extremities.

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### References


