BIOMEDICAL ENGINEERING | RESEARCH ARTICLE

Effect of prolonged continuous smartphone gaming on upper body postures and fatigue of the neck muscles in school students aged between 10-18 years

Panida Hanphitakphong, Nuanlar Thawinchai* and Somruthai Poomsalood

Abstract: This study investigated the effect of prolonged continuous smartphone gaming on upper body postures and fatigue of the neck muscles in school students. Forty-four students aged between 10 and 18 years were enrolled in this study. All participants were instructed to play an online smartphone game continuously for 20 minutes in a sitting position during dynamic postural analysis. Simultaneously, a wireless surface electromyography (EMG) system was used to collect data from the cervical erector spinae (CES) and upper trapezius (UT) on both sides. The median frequency was considered as an index for muscle fatigue. An inertial measurement unit (IMU) was applied to examine upper body postures kinematics data. The Numeric Rating Scale (NRS-11) was also used to assess self-reported pain intensity in the posterior neck region at pre- and post-game playing. Angles of neck, trunk, left shoulder, and bilateral elbow flexion significantly increased at 10 and 20 minutes (p < 0.05) compared to those at the baseline. Bilateral CES is presented with significantly increased degree of fatigue at...

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PUBLIC INTEREST STATEMENT

Concerns of musculoskeletal health problems related to smartphone use have increased with the growing use of devices, especially in youth. There is a lack of information from prior studies about the appropriate duration of smartphone use with respect to muscle fatigue, particularly in students aged 10-18 years. In this study, prolonged continuous smartphone gaming on upper body postures and fatigue of the neck muscles were determined using electromyography, motion analysis instrument, and subjective pain measurement. It was found that a sustained period of smartphone uses significantly affected awkward posture in upper body region, which can lead to muscle fatigue and discomfort in the posterior neck area. It is suggested that smartphone use should not exceed 10 minutes for students aged 10-18 years with respect to minimize the biomechanical effects in the neck area. Prolonged use of smartphones should be closely monitored, particularly in children and adolescents.
20 minutes (p < 0.05). Neck discomfort significantly increased (p < 0.05) after the completion of the game. These findings revealed that a sustained (20-min) smartphone game playing induced significant awkward posture and resulted in muscle fatigue and discomfort especially in the posterior neck area. It is suggested that prolonged smartphone use should not exceed 10 minutes for students aged 10–18 years with respect to minimizing the biomechanical effects in the neck area. Habitual awkward posture should be carefully noticed during the sustained smartphone use.

**Subjects:** Allied Health; Health Conditions; Allied Health

**Keywords:** Smartphone; upper body postures; neck muscle fatigue; neck discomfort; school students

2. Introduction
Smartphone access and ownership among children and adolescents have grown greatly nowadays, especially the use of multiple applications for gaming (Gunter, 2019; Pew Research Center, 2018). With the growing use of smartphones by vulnerable children and adolescents, concerns about adverse health consequences associated with device overuse have also increased both mental and physical health (Domoff et al., 2019; Sohn et al., 2019). A recent study indicates that excessive smartphone use has negative impacts on sleep quality, physical activities, obesity, headache, and eye strain among children (Domoff et al., 2019). An association was also found between amount of smartphone use and musculoskeletal and visual symptoms of school students aged 10–18 years. Importantly, neck/shoulder region had the highest prevalence rates of musculoskeletal symptoms (Toh et al., 2019), which is similar to the report in other studies conducted by university students (H. J. Kim & Kim, 2015; Namwongsa et al., 2018). However, children, adolescents, and adults have different head-to-body ratio and muscle fiber size during physical growth. Compared to adults, children having a greater head-to-body ratio meanwhile have smaller muscle fiber size (Armstrong & van Mechelen, 2008). As there is an increasing extensive use of smartphones in children and adolescents in a digital society, it may be considered to promote the avoidance of risk factors that could reduce the incidence of musculoskeletal disorders (MSDs) among these populations.

Several studies indicated that a neck flexion posture, the most common posture among smartphone users while using a smartphone, potentially provided risks for musculoskeletal pain and discomfort in the posterior neck region. Forward head flexion posture produced excessive external flexion force, resulting in a larger load on neck extensors and adjacent connective tissues of the neck to counterbalance the increase in external flexion moment caused by forward moment (Eitivipart et al., 2018; Xie et al., 2017). Consequently, muscle activity of neck muscles particularly cervical erector spinae (CES) and upper trapezius (UT) were increased as well as shifting of the head on the shoulders in a forward direction during the smartphone use. While holding the head in a forward posture, these muscles represent the major muscles for counterbalancing external forces and stabilizing neck and shoulder regions (Namwongsa et al., 2019; Ning, Haung, Hu, & Nimbarte, 2015). It has been proposed that prolonged and continuous contraction of these neck muscles could lead to an increase in neck muscle fatigue. Sustained smartphone use for a long period can result in a certain high level of neck muscle fatigue that eventually cause pain (Park et al., 2017; S. Y. Kim & Koo, 2016). The longer the time period of sustained device use, the more increased severity of awkward position of neck and head may induce a greater mechanical load on the cervical structures (Hansraj, 2014; Park et al., 2017). In prolonged static postures, overloading of neck muscles due to smartphone use may contribute to discomfort and fatigue. Cumulatively, a high level of neck muscle fatigue can eventually cause musculoskeletal injuries and neck pain among smartphone users (Eitivipart et al., 2018; Xie et al., 2017; S. Y. Kim & Koo, 2016). Compared
to the standing position, it has also been indicated that shifting in head–neck angle while using a smartphone seems to occur more than that in a sitting position (Lee et al., 2015; Ning et al., 2015).

In the past few years, some experimental studies have attempted to determine the effectiveness of guideline implementation strategies to reduce the risk of developing pain in the neck region resulting from smartphone use (Namwongsa et al., 2019; S. Y. Kim & Koo, 2016; Park et al., 2017). Among several factors, duration and tasks of smartphone using such as gaming are also known as important risk factors that affect MSDs. Although there is evidence that assists guidance on practice recommendations for preventing the risk of developing MSDs in the neck region among smartphone users, participants recruited in the previous studies were only university students who entered the mature growth phase. There is evidence reporting that children and adolescents are at higher risk for injuries compared to adults. Moreover, problems in the musculoskeletal system during childhood may lead to continuing problems in adulthood (Jones et al., 2007). Hence, the related smartphone activities leading to musculoskeletal pain symptoms in children and adolescents should not be overlooked. Regarding task time, only two updated studies investigated the effect of smartphone use duration on change in muscle activities and fatigue in the neck muscles.

Thus far, only one study reported the appropriate duration of time when using a smartphone for reducing risk of developing MSDs in the neck region. A study by S. Y. Kim and Koo (2016) suggested that smartphone users should avoid using their devices continually for longer than 20 minutes to reduce the risk of musculoskeletal problems, with respect to muscle fatigue and pain in the neck region. Nonetheless, participants recruited into the study were only young adults with forward head posture. Evidence also indicates that just 10 minutes of smartphone use can lead to discomfort in the neck area (S. Y. Kim & Koo, 2016). In a similar way, another study significantly presented with increased neck and trunk flexion at 5, 10, and 15 minutes compared with the outcomes at the start of the smartphone usage. Meanwhile, the muscle activity levels of the bilateral CES showed similar results as that of neck and trunk flexion at each time point. Also, moderate neck discomfort was observed after completing 16-minute playing smartphone game (Park et al., 2017).

As there is an increasing extensive use of smartphones in children and adolescents, it may be considered to promote the avoidance of risk factors that could reduce the incidence of MSDs among these populations. Although there is clear evidence suggesting the correlation between amount of smartphone use and musculoskeletal symptoms in school students aged 10–18 years, currently, there is a lack of studies investigating fatigue and discomfort in the neck muscles during sustained use of smartphones among school students. Since smartphone use in adults is also applied in children and adolescents, especially in the situation of playing online smartphone games, therefore, it is necessary to provide suggestions for the shortest possible time of smartphones use to reduce negative musculoskeletal consequences resulting from smartphone overuse, particularly at an early age. As a result, the purposes of this study were to: 1) examine changes in the upper body postures of smartphone users aged between 10 and 18 years; 2) examine changes in fatigue of the neck muscles over period of 20 minutes during a smartphone game; and 3) examine discomfort levels in the neck region after prolonged continuous smartphone gaming.

3. Methodology

3.1. Study design
The study design was quasi-experiment. It was conducted at the Physical Therapy Laboratory, Faculty of Associated Medical Sciences, Chiang Mai University, Thailand, where the room temperature and the lights were controlled. Evaluation of the upper body posture and neck muscle fatigue was performed among smartphone usage in the users with more than 4 hours daily. The present study was approved by the Ethic Review Board of the Faculty of Associated Medical Sciences,
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Chiang Mai University (Ethic Code: AMSEC-61EX-076). Written informed consent was obtained from the parents or legal guardians of the participants prior to data collection.

3.2. Sample size
A sample size estimation was based on ANOVA: Repeated measures, within factors using a statistical power analysis program (G*Power 3.0.10). The sample size was calculated using effect size of 0.25 (medium). Subsequently, minimal sample size of 42 participants was required to achieve 95% power at a 0.05 significance level to detect differences between three different times. To allow 5% missing data caused by unexpected events, 44 participants were recruited in this study.

3.3. Participants
A total of forty-four healthy smartphone users (21 female and 23 male students) were included in the study. The participants were screened according to the inclusion and exclusion criteria. The criteria for inclusion were: (1) both male and female students (2) age between 10 and 18 years (3) preferred to use their right hand (4) had their own smartphones with screen sizes of 4 to 6 inches (5) spend at least 4 hours per day on their smartphones (6) had at least 3 months of experience with smartphones (7) had experience in playing the Fruit Ninja online game and (8) usually operated smartphone in sitting posture and/or had no physical difficulties in using smartphones while sitting. Subjects were excluded if they (1) had MSDs or pain in the upper body region (2) had uncorrected visual impairment (3) had history of orthopedic surgery to the spine in previous 6 months (4) had spinal deformities such as kyphosis or scoliosis (5) had heavy activities or vigorous exercises, particularly in the upper body that may contribute to pain and fatigue before 24 hours prior to data collection and (6) took muscle relaxants before 24 hours prior to data collection.

3.4. Experimental protocol
All participants were given a brief period (30 seconds) to familiarize themselves with the task before beginning the measurements in an isolated laboratory space. Then, each participant was asked to record the level of discomfort in their neck region using an 11-point (0–10) numerical rating scale (NRS). After that, all participants played Fruit Ninja, an online smartphone game, which required high level cognitive concentration and fast bilateral finger movements to acquire a high score. The participants used their own smartphones and were instructed to hold the device with both hands in a landscape orientation while performing the task. They were seated in an adjusted-height chair without armrests and back support with 90-degree hip, knee, and ankle flexion and feet flat on the smooth ground. The participants’ feet were positioned at shoulder-width apart and were well-placed on the ground floor. They were instructed to hold a smartphone with both hands at a level of their preference. All participants were instructed to fully focus on the online game for 20 minutes to achieve their highest score. While conducting a task in sitting, the participants were asked to maintain a comfortable sitting posture without lower limb movements. Finally, each participant was asked to record the level of discomfort in their neck region again at the end of experiment.

3.5. Outcome measures
Three outcome measurements were used to examine upper body postures, fatigue of the neck muscles, and neck discomfort in the gaming task via smartphone. The outcome measures used were wireless surface electromyography (EMG) system, inertial measurement unit (IMU), and 11-point (0–10) numerical rating scale (NRS). The upper body postures and fatigue of neck muscles were synchronously recorded during the smartphone use. All objective outcome measures were performed at baseline, mid-way, and post-experiment period. Measuring subjective outcome was performed in pre- and post-playing game.

3.5.1. Measurement of upper body postures
The upper body kinematics data were recorded using three iso-inertial unit STT-IJS (STT Systems, San Sebastian, Spain)-based technology. The upper body postures involved the neck flexion angle,
trunk flexion angle, bilateral shoulder flexion angles, and bilateral elbow flexion angles. The STT-IBS® is a 9-degrees-of-freedom inertial measurement unit that unites an accelerometer, a gyroscope, and a magnetometer on each of its axes. The relative orientation, acceleration, and position (along the X, Y, Z axes) of the STT-IBS® sensors are measured by this system. The information collected is sent to a computer with a Bluetooth-enabled host. The raw signals are processed online using iSens software (STT-Systems®, Spain), which provides the angular position of each STT-IBS. The 10 STT-IBS units were placed on the forehead, middle chest, middle trunk, middle back, arm, forearm, and wrist of the upper limbs with straps. After determining a reference position, the angular position was measured by the software as a projection of the vector position of each sensor in the corresponding plane indicated by the reference sensor. This is a completely wireless system and the posture data were acquired at a frequency of 100 Hz. Sensor placement for all participants was performed by only one researcher to ensure consistency in data collection. All upper body postures were monitored during continuous smartphone use for 20 minutes. The values at three time points (at baseline, mid-way, and post-experiment period) were used to analyze.

3.5.2. Measurement of fatigue of the neck muscles
A wireless surface electromyography (EMG) system (Plux wireless biosignals S.A., Arruda dos Vinhos, Portugal) was used to collect neck muscle electromyographic activity and process the trimmed EMG signals. Skin preparation was well performed before the data collection. Disposable self-adhesive Ag/AgCl snap electrodes were used for the signal collection. The bipolar electrodes were pre-gelled with 1 cm in diameter and an inter-electrode distance of 2 cm. The surface EMG electrodes were applied to the target muscles according to SENIAM recommendations (Hermens et al., 2000). The target muscles including both sides of the CES and UT muscles. The reference electrode was attached to olecranon process of the participant’s left elbow. To avoid interrater error, placing electrodes for all participants were performed by only one researcher. The CES electrodes were placed parallel to the spine, approximately 2 cm lateral to the C4 spinous process, over the CE muscle belly. The CES electrodes were attached 2 cm lateral to the midpoint between the acromion process and C7 spinous process, over the UT muscle belly (Hermens et al., 2000). In the current study, EMG signals were collected while using a smartphone at different time points (0, 10 and 20 minutes). The duration of the EMG signal collected at each time point is 1 minute. The frequency of EMG data acquisition was set at 2,000 Hz and the bandwidth for the EMG signal noise rejection was set at 20–450 Hz (S. Y. Kim & Koo, 2016). After that, the power spectral frequency analysis was used to investigate muscle fatigue due to the shift of median power frequency (MDF) which is widely used. A downshift of MDF of the EMG signal can indicate muscle fatigue since the process of electrical repolarization of muscle cells is delayed when muscle fatigue takes place (Jang & Ahram, 2014). The power spectrum was analyzed by Fourier Transform method (FFT). Then, the relative changes in the MDF were then used for comparison within group. At each time point, the relative change was used to express the absolute change as a percentage of the value of the indicator from the baseline period. In demonstrating the time effect, the MDF at 10 and 20 minutes was normalized to that at 0 minute (Bobet & Norman, 1984). For the interpretation, the muscle response was considered as higher level of muscle fatigue, if there was a shift of MDF of the EMG signal to the low end (De Luca, 1984).

3.5.3. Measurement of neck discomfort
In this study, neck discomfort (the symptom of discomfort between the neck and the shoulder) (Guzman et al., 2008) was measured before and after the task using the smartphone. Subjectively, levels of discomfort were determined using an 11-point (0–10) numerical rating scale (NRS), where 0 represents no discomfort at all and 10 represents the worst discomfort. Discomfort refers to the state of being tense and feeling pain and/or an absence of comfort or ease (Cameron, 1996). The reliability and validity of the 0 to 10 NRS are well established (Jensen & Karoly, 1992).

3.6. Data analysis
Descriptive statistic was used to analyze characteristics of participant’s variables and Shapiro-Wilk test was used for test of normality. One-way repeated measures analysis of variance (ANOVA) was
used for comparative analysis of the participants’ neck, trunk, shoulders, and elbows angles over time. The independent variables were times at three places, including at the start of gaming experiment, and subsequently, at 10 and 20 minutes during the experiment. Since the EMG responses have a great degree of intra-individual variation, the relative changes in the MDF of the CES and UT muscle groups were used for comparison by one-way repeated measures ANOVA. Means of the relative changes in MDF of the CES and UT muscle groups were used for comparison between 0 min and each time-point. Because the data met an assumption of sphericity, the Bonferroni correction was employed as the post hoc analysis in which significant differences were observed. The Mann-Whitney U-test was performed to analyze neck discomfort score. Numerical data were shown as the Mean±SD. A significant level was set at p < 0.05. Data were analyzed using the SPSS program version 17 (Norusis/SPSS Inc., Chicago, IL, USA).

4. Results

4.1. General characteristics
The total number of participants in the study was 44 (23 males and 21 females). General characteristics of the participants are presented in Table 1.

Data presented as Mean ± SD.

4.2. Neck discomfort
Prior to playing the smartphone game, all participants reported NRS scores of zero. Upon termination of time, all participants reported some degree of neck discomfort (4.70 ± 1.23). The Mann-Whitney U-test revealed significance for the average NRS scores (p < 0.001) in overall and each gender (Table 2).

Data presented as Mean ± SD, ** significant difference at p-value < 0.001 by the Mann-Whitney U-test.

4.3. Upper body postures
Neck and trunk flexion of participants at 10 minutes and 20 minutes of the gaming experiment was significantly greater than that at the beginning of the experiment (p < 0.05). The neck angle of participants increased as the time they spent on playing the smartphone game increased (p < 0.05). The neck angle of participants was approximately 21.70 ± 10.18 degrees at the start of the game, increasing over time to 25.80 ± 11.35 degrees (at 10 minutes) (p < 0.05), and 29.51 ± 12.21 degrees (at 20 minutes) (p < 0.05), respectively (Figure 1a). The trunk angle of participants increased as the time they spent playing the smartphone game increased (p < 0.05). The trunk angle of participants was approximately 14.05 ± 11.93 degrees at the start of the game, increasing over time to 19.83 ± 13.59 degrees (at 10 minutes) (p < 0.05), and 23.15 ± 15.61 degrees (at 20 minutes) (p < 0.05), respectively (Figure 1b). Shoulder flexion showed that the left angle shifted to increase as game time increased. The left shoulder flexion angle was significantly greater at 10 minutes.

| Table 1. General characteristics of participants (N = 44) |
|---------------------------------------------------------|-------------------------------------------------|------------------|
| Characteristics          | Gender      | Male (n = 23) | Female (n = 21) | Total (N = 44) |
| Age (yrs)                |             | 14.04 ± 2.38 | 14.24 ± 2.55 | 14.14 ± 2.44 |
| Weight (kg)              |             | 51.41 ± 8.99 | 47.55 ± 6.48 | 49.57 ± 8.04 |
| Height (cm)              |             | 157.87 ± 11.36 | 152.74 ± 9.24 | 155.42 ± 10.61 |
| Body mass index (kg/m²)  |             | 20.46 ± 1.13 | 20.27 ± 1.23 | 20.37 ± 1.17 |
| Daily smartphone usage (hrs) |         | 4.30 ± 0.47 | 4.38 ± 0.67 | 4.34 ± 0.57 |
Figure 1a,b. Comparison of mean neck and trunk flexion angles across time during smartphone usage (* p < 0.05, ** p < 0.01, and *** p < 0.001). Error bars represent standard error.

Figure 2a,b. Comparison of mean shoulder flexion angles across time during smartphone usage (* p < 0.05, ** p < 0.01, and *** p < 0.001). Error bars represent standard error.

Table 2. Neck discomfort in participants (NRS-11) before and after a 20-minute smartphone usage

| Characteristics | Pretest scores | Posttest scores |
|-----------------|----------------|-----------------|
| Male (n = 23)   | 0.00           | 4.61 ± 1.12**   |
| Female (n = 21) | 0.00           | 4.81 ± 1.36**   |
| Total (N = 44)  | 0.00           | 4.70 ± 1.23**   |

(10.70 ± 11.89 degrees; p < 0.01) and 20 minutes (12.67 ± 12.60 degrees; p < 0.001) compared with baseline values (8.87 ± 10.86 degrees) (Figure 2a). Elbow flexion demonstrated that the angle shifted to increase as game time increased on both sides. The bilateral elbow flexion angle was significantly greater at 10 minutes (Right 101.70 ± 11.44 degrees; p < 0.001 and Left 104.46 ± 12.07 degrees; p < 0.001) and 20 minutes (Right 102.37 ± 11.87 degrees; p < 0.001 and Left 105.86 ± 11.30 degrees; p < 0.001) compared with baseline value (Right 94.58 ± 10.30 degrees and Left 98.35 ± 12.75 degrees). The bilateral elbow flexion angle was significantly greater at 20 minutes (p < 0.001) compared with this value at 10 minutes (Figure 3a,b).

4.4. Fatigue of the neck muscles

The relative changes in MDF of each muscle at each time point were shown in Figure 4 and 5. A graph of the relative changes in the frequency shows that the relative changes in MDF of CES on
both sides shifted to increase as game time increased. The relative changes in MDF of right (94.66 ± 11.58% vs 100%) and left CES (95.37 ± 10.71% vs 100%) were significantly greater at 20 minutes compared with baseline value (p < 0.05 and p < 0.05, respectively) (Figure 4a,b). In addition, Figure 5 shows changing trends of the relative changes in MDF of UT both sides with
increasing time at each point. There was no significant difference in the relative changes in MDF of UT on both sides across time (Figure 5a,b).

5. Discussion
The present study aimed to investigate the effect of prolonged continuous smartphone gaming on upper body postures and fatigue of the neck muscles in school students. The results indicated that angles of neck, trunk, left shoulder, and bilateral elbows flexion significantly increased at 10 and 20 minutes (p < 0.05) in comparison with angles of participants at the baseline. However, no significant difference was identified in the right shoulder over time. Regarding muscle fatigue, bilateral CES muscles showed significantly increased degree of fatigue at 20 minutes (p < 0.05) as compared to baseline. There was no significant difference in the UT muscle on both sides. Additionally, pain intensity in the neck region showed a significant increase after 20-minute playing smartphone game (p < 0.05).

According to the results obtained, these findings are in line with the previous findings that longer periods of smartphone use may result in poor posture and lead to progressive muscle overload in posterior neck. Obviously, increased neck muscle fatigue and pain which could result from continuous static pressure on specific sites were also present at the end of the game. A previous study in young adults found significant fatigue of the UT and CES muscles after 20 and 30 minutes of smartphone usage, respectively (S. Y. Kim & Koo, 2016). Remarkably, fatigue of the CES muscle in the current study occurred sooner than the previous one. In principle, when the head is not in the neutral posture, the weight on the spine dramatically increases with an increase in neck flexion ranging from 10 to 60 pounds at 0 degree to 60 degrees, respectively. An adult’s neck can typically handle approximately 10 to 12 pounds of force in the neutral position (Hansraj, 2014). Fundamentally, children’s heads are larger in relation to their body sizes than adults (Armstrong & van Mechelen, 2008). To resist the greater external neck flexion moment while looking at a smartphone, the extensor muscles are activated to maintain balance of the neck, thereby increasing the load placed on the CES and the trapezius muscles (Xie et al., 2017; Eitivipat et al., 2018; Namwongsaa et al., 2019). Based on our results, it was possible that the neck extensor muscles in children would work harder than in adults while looking down at the device since they have a greater head-to-body ratio. In addition, muscle fiber size is lower in children than in adults. When children maintained their head forward flexion posture for a long period of time, they had earlier onset of fatigue than adult. Also, the participants in our study might exhibit more neck flexion than the participants in the previous study. However, neck posture was not determined in the previous study (S. Y. Kim & Koo, 2016).

It has been indicated that maintaining forward head bending more than 20 degrees of flexion for a prolong period of time could increase the risk of neck injury (Andersen et al., 2003). Our results showed a significant increase in neck flexion posture was found at the start of the gaming experiment (21.7 degrees), at 10 minutes (25.8 degrees), and at 20 minutes (29.51 degrees) which clearly exceeds the recommended limit of neck flexion angle. Thus, a larger amount of muscle force might be required to counterbalance the increased external moment throughout the period of task. Consequently, a significant increase in fatigue of bilateral CES muscle (4.63±5.34%) was demonstrated in the 20-min prolonged playing smartphone games.

A recent pilot study in male college students demonstrated that playing smartphone game induces a significant increase in flexed posture on the neck (66 to 79 degrees) and trunk (104 to 91 degrees) as well as the activity of both CES muscles in just 5 minutes (Park et al., 2017). Our results showed a significant increase in trunk flexion posture was found at the start of the gaming experiment (14.05 degrees), at 10 minutes (19.83 degrees), and at 20 minutes (22.15 degrees). It is difficult to compare our results in studies conducted in college students due to a 2-dimensional photogrammetry approach was used to assess body posture in the previous study. However, an obvious increase in neck discomfort was reported for all participants on a moderate level (4.70 ± 1.23) which is similar to the value of pain intensity found in college
students (severity of pain at 4.2 out of 10). Evidence suggests that children have a lower pain threshold than adults (Saxena et al., 2015). It is likely that the difference in age of participants and game duration and may lead to small differences in pain value.

Our study did not find a significant difference in the fatigue of UT muscles across time points. In agreement with our results, the changes in muscle activity of UT in response to change in posture were not found after 16-minute playing smartphone game in the previous study (Park et al., 2017). This non-significant difference may be due to the UT being passively stretched by the arm weight and smartphone as time developed, resulting in a decreased activity in this muscle (Park et al., 2017). However, fatigue seems greater in the left side of UT muscle than the right side. It might be due to the fact that participants use their left upper arm to keep the device in stable while they use their right upper arm to swipe the screen monitor. In a similar way, the results presenting the CES muscle fatigue level of the right side seemed to be larger than the other. All participants were right-handed. It is possible that the greater movement from the right CES muscle due to high-speed motion could generate higher CES fatigue levels on the same side.

As far as we know, no previous research has investigated upper limb posture during smartphone use. Our results demonstrate that angles of left shoulder and bilateral elbows flexion showed significantly increased at 10 and 20 minutes (p < 0.05) in comparison with angles of participants at the baseline. These results suggest that participants need to increase a clear vision by increasing the neck flexion so they might extend their elbow for providing appropriate eye-screen distance. In addition, the participants might not have an ability to maintain their arms close to the body due to loss of endurance and the need to relieve neck-shoulder region discomfort. Although the right shoulder flexion showed insignificant changes from baseline, the overall right shoulder angle was relatively greater than the left side. This might be due to all participants being right-handed. The left shoulder might be adjusted for balancing a clear vision and maintaining the stability of the device, whereas participants seem more responsive to using their right upper arm throughout the game.

To the researchers’ knowledge, this is the first study that examined the prolonged continuous smartphone use to identify an appropriate duration of playing smartphone game for school students. The quantitative study of the biomechanics of cervical spine in smartphone users who are immature growth is still limited. It may be difficult to compare data reported across studies because of differences in population, task, and instrument. Notably, compared with previous studies conducted in young adults, our study involved a relatively larger sample size (Park et al., 2017; S. Y. Kim & Koo, 2016). To find the natural response, postural evaluation seemed to establish a more real-time than posture examined in previous study (Park et al., 2017). Nevertheless, future research should consider different games and postures such as sitting in a reclined position, lying, and standing in a real-life setting to cover more various situations of smartphone use. Furthermore, future studies are needed regarding carryover effect and rest period to develop evidence-based prevention guidelines related to neck disorders caused by smartphone use.

6. Conclusion
In summary, this study showed that the effect of prolonged continuous smartphone gaming is associated with undesired upper body postures, fatigue of the neck muscles, and neck discomfort. Using smartphones for 20 minutes can produce large awkward posture even lead to muscle fatigue and discomfort especially in the neck region. Furthermore, the cumulative muscle imbalance due to asymmetrical posture may potentially predispose smartphone users to an increased risk of injury. To avoid this, we suggest prolonged smartphone use should not exceed 10 minutes for students aged 10–18 years with respect to minimizing the biomechanical effects in the neck region. Clinically, the results may provide helpful information in preventing the risk of developing neck pain at an early age caused by playing games using a smartphone.
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Conflicts of interests
The authors declare no conflicts of interest.

Practitioner summary
Effect of prolonged continuous smartphone gaming on upper body postures and fatigue of the neck muscles was examined. Forty-four school students (aged 10-18 years) completed electromyography, motion analysis, and subjective pain measurement. A sustained smartphone game playing induced significant awkward posture and resulted in muscle fatigue and discomfort especially in the posterior neck area. To minimize the biomechanical effects in the neck area, prolonged smartphone use should not exceed 10 minutes for lowering the risk of developing neck pain at an early age.

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References
Andersen, J. H., Kaergaard, A., Mikkelson, S., Jensen, U. F., Frost, P., Bonde, J. P., … Thomsen, J. F. (2003). Risk factors in the onset of neck/shoulder pain in a prospective study of workers in industrial and service companies. Occupational and Environmental Medicine, 60(9), 649–654. https://doi.org/10.1136/ oem.60.9.649
Armstrong, N., & van Mechelen, W. (2008). Paediatric exercise science and medicine (pp. 209). Oxford University Press.
Bobet, J., & Norman, R. W. (1984). Effect of load placement on back muscle activity in load carriage. European Journal of Applied Physiology, 53(1), 71–75. https://doi.org/10.1007/BF00964653
Cameron, J. A. (1996). Assessing work-related body-part discomfort: Current strategies and a behaviorially oriented assessment tool. International Journal of Industrial Ergonomics, 18 (5–6), 389–398. https://doi.org/10.1016/0169-8141(95)00101-8
De Luca, C. J. (1984). Myoelectrical manifestations of localized muscular fatigue in humans. Critical Reviews in Biomedical Engineering, 11(4), 251–279.

Domoff, S. E., Borgen, A. L., Foley, R. P., & Moffett, A. (2019). Excessive use of mobile devices and children’s physical health. Human Behavior and Emerging Technologies, 1(2), 169–175. https://doi.org/10.1002/ hbe2.145
Eitvipart, A. C., Viriyarojanakul, S., & Redhead, L. (2018). Musculoskeletal disorder and pain associated with smartphone use: A systematic review of biomechanical evidence. Hong Kong Physiotherapy Journal, 38 (2), 77–90. https://doi.org/10.1142/ S1013702518000010
Gunter, B. (2015). Children and mobile phones: Adoption, use, impact, and control (pp. 44–45). Emerald Publishing.
Guzman, J., Hurwitz, E. L., Carroll, L. J., Haldeman, S., Côte, P., Carragee, E. J., … Cassidy, J. D. (2008). A new conceptual model of neck pain: Linking onset, course, and care. The bone and joint decade 2000–2010 task force on neck pain and its associated disorders. Spine (Phila Pa 1976), 15(33), 514–23. https://doi.org/10.1097/BRS.Ob013e318164F3eb
Hansraj, K. K. (2014). Assessment of stresses in the cervical spine caused by posture and position of the head. Surgical Technology International, 25, 277–279.
Hermens, H. J., Freriks, B., Desselhorst-Klug, C., & Rau, G. (2000). Development of recommendations for SEMG sensors and sensor placement procedures. Journal of Electromyography & Kinesiology, 10(5), 361–374. https://doi.org/10.1016/s1050-6411(00)00027-4
Jang, R., & Ahram, T. (2016). Advances in physical ergonomics and human factors: Part II. United States of America: AHFE Conference.
Jensen, M. P., & Karoly, P. (1992). Pain-specific beliefs, perceived symptoms severity, and adjustment to chronic pain. Clinical Journal of Pain, 8(2), 123–130. https://doi.org/10.1097/00002508-199206000-00010
Jones, G. T., Silman, A. J., Power, C., & Macfarlane, G. J. (2007). Are common symptoms in childhood associated with chronic widespread body pain in adulthood? results from the 1958 British birth cohort study. Arthritis & Rheumatology, 56(5), 1669–1675. https://doi.org/10.1002/art.22587
Kim, H. J., & Kim, J. S. (2015). The relationship between smartphone use and subjective musculoskeletal symptoms and university students. Journal of Physical Therapy Science, 27(3), 575–579. https://doi.org/10.1589/jpts.27.575
Kim, S. Y., & Koo, S. J. (2016). Effect of duration of smartphone use on muscle fatigue and pain caused by forward head posture in adults. Journal of Physical Therapy Science, 28(6), 1669–1672. https://doi.org/10.1589/jpts.28.1669
Lee, S., Kang, H., & Shin, G. (2015). Head flexion angle while using a smartphone. Ergonomics, 58(2), 220–226. https://doi.org/10.1080/00140139.2014. 967311
Namwongsa, S., Puntumetakul, R., & Neubert, M. S. (2018). Factors associated with neck disorders among university student smartphone users. Work, 63(1), 367–378. https://doi.org/10.3233/WOR-182819
Namwongsa, S., Puntumetakul, R., Neubert, M. S., & Boucaut, R. (2019). Effect of neck flexion angles on neck muscle activity among smartphone users with and without neck pain. Ergonomics, 62(12), 1524–1533. https://doi.org/10.1080/00140139.2019.166152
Ning, X., Huang, Y., Hu, B., & Nimbarate, A. D. (2015). Neck kinematics and muscle activity during mobile device operations. International Journal of Industrial Ergonomics, 48, 10–15. https://doi.org/10.1016/j. ergon.2015.03.003
Park, J. H., Kang, S. Y., Lee, S. G., & Jeon, H. S. (2017). The effects of smart phone gaming duration on muscle activation and spinal posture: Pilot study. Physiotherapy Theory and Practice, 33(8), 661–669. https://doi.org/10.1080/09593985.2017.1328716

Pew Research Center. (2018). Teens, social media & technology. https://www.pewresearch.org/internet/2018/05/31/teens-social-media-technology-2018/

Saxena, I., Kumar, M., Barath, A. S., Verma, A., Garg, S., & Kumar, M. (2019). Effect of age on response to experimental pain in normal Indian males. Journal of Clinical and Diagnostic Research, 9(9), CC05–CC08. https://doi.org/10.7860/JCDR/2015/15385.6516

Sohn, S., Rees, P., Wildridge, B., Kalik, N. J., & Carter, B. (2019). Prevalence of prevalence of problematic smartphone usage and associated mental health outcomes amongst children and young people: A systematic review, meta-analysis and GRADE of the evidence. BMC Psychiatry, 19(1), 356. https://doi.org/10.1186/s12888-019-2350-x

Toh, S. H., Coenen, P., Howie, E. K., Mukherjee, S., Mackey, D. A., & Stroker, L. M. (2019). Mobile touch screen device use and associations with musculoskeletal symptoms and visual health in a nationally representative sample of Singaporean adolescents. Ergonomics, 62(6), 778–793. https://doi.org/10.1080/00140139.2018.1562107

Xie, Y., Szeto, G., & Dai, J. (2017). Prevalence and risk factors associated with musculoskeletal complaints among users of mobile handheld devices: A systematic review. Applied Ergonomics, 59, 132–142. https://doi.org/10.1016/j.apergo.2016.08.020