Master's Thesis

Investigation of neck muscular load among young adults when using smartphone while walking

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ABSTRACT

It is widely understood that frequent and prolonged use of smartphones may cause neck-shoulder pain. However, few studies have reported such risks for neck-shoulder problems associated with the use of a smartphone while walking. Because smartphone use while walking is a very common behavior among smartphone users, investigation of relevant ergonomic risks is also necessary. The aim of this thesis research was to investigate potential ergonomics risk factors among smartphone users, especially when using smartphone while walking. This thesis presents a series of cross-sectional and experimental studies that have independent research questions and discusses the results of them in an integrated form.

Study 1 was aimed to objectively assess the angle and duration of head-down of smartphone users during a typical working day via naturalistic data collection. Thirty-one asymptomatic young participants conducted their typical activities while their head tilt angle and smartphone app usage records were collected simultaneously for 8 hours. It was found that study participants spent 125.9 minutes (median usage duration) on their smartphones with significantly larger head-flexion angle ($p < 0.05$) than when they were not using the phone. Head-down posture greater than 30° was found to be more common when using the phone, while mild flexion within the range of 0° to 20° was more common when they were not using the phone.

Study 2 was aimed to quantify the head down position when using a smartphone while walking. Head tilt angle was measured from twenty-eight young smartphone users when conducting one-handed web-browsing and two-handed texting while walking a 60-meter outdoor walkway. Study results showed that the median head tilt angle during texting (38.5°) was significantly greater ($p<0.05$) than that of web-browsing (31.1°), indicating greater static loads to the neck when texting. Participants walked with significantly less ($p < 0.05$) variation of the head flexion when texting (5.3°) than when browsing (6.8°), and it implies larger efforts of neck muscles to keep the head steadier for texting.

Study 3 was aimed to quantify the myoelectric activation (EMG) of neck extensor muscles, head/trunk movement and eye-smartphone position when using a smartphone while walking. Twenty-one asymptomatic young adults conducted three tasks (no smartphone, one-handed web-browsing, two-handed texting) in the laboratory. The mean normalized EMG (NEMG) of the splenius muscles and the cervical erector spinae muscles were 33.3% to 101.8% greater when web-browsing and texting while walking compared to walking without smartphone. Task effect was found in NEMG of splenius of dominant and non-dominant side, NEMG of cervical erector spinae of non-dominant side, head tilt angle, trunk tilt angle, horizontal viewing distance ($p<0.05$). Also, angular acceleration RMS of neck flexion when normal-walking was significantly higher than other two task conditions.

The findings of these three studies indicated that the smartphone use causes substantially flexed head/neck position of smartphone users, which demands the contraction of neck extensor muscles to maintain the head-down posture. The head-down posture and muscle activation during smartphone use may result in neck muscle fatigue or dynamic and static biomechanical loads on the cervical spine and surrounding tissues. Moreover, head-down position and dual-task cost of smartphone users when they are walking on the road may cause another kind of risks such as fall, collision, stability, and traffic safety. Overall conclusion of this thesis would promote awareness of risks of smartphone use to users and support further researches related to health of smartphone users.

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1. INTRODUCTION

1.1 Research background

<u>State of smartphone users and text-neck</u>

Smartphone is a mobile information technology (IT) device with operating system (OS), which is differentiated from previous cell phone. The advent of Smartphone has made a remarkable impact on people's lifestyle in the world.

The number of smartphone users in worldwide has increased explosively and reached approximately 3 billion in 2018 (NewZoo, 2018). The report published by New Zoo says that the number of active smartphone users will pass 3.8 billion by 2021. Other research center reported that median 76% of adults in advanced economies own their smartphone and 45% of adults in emerging economies own it (Pew Research Center, 2019). According to its report, the smartphone ownership rate of adults runs up to 95%, 88%, and 87% in South Korea, Israel, and Netherlands, respectively (Figure 1).

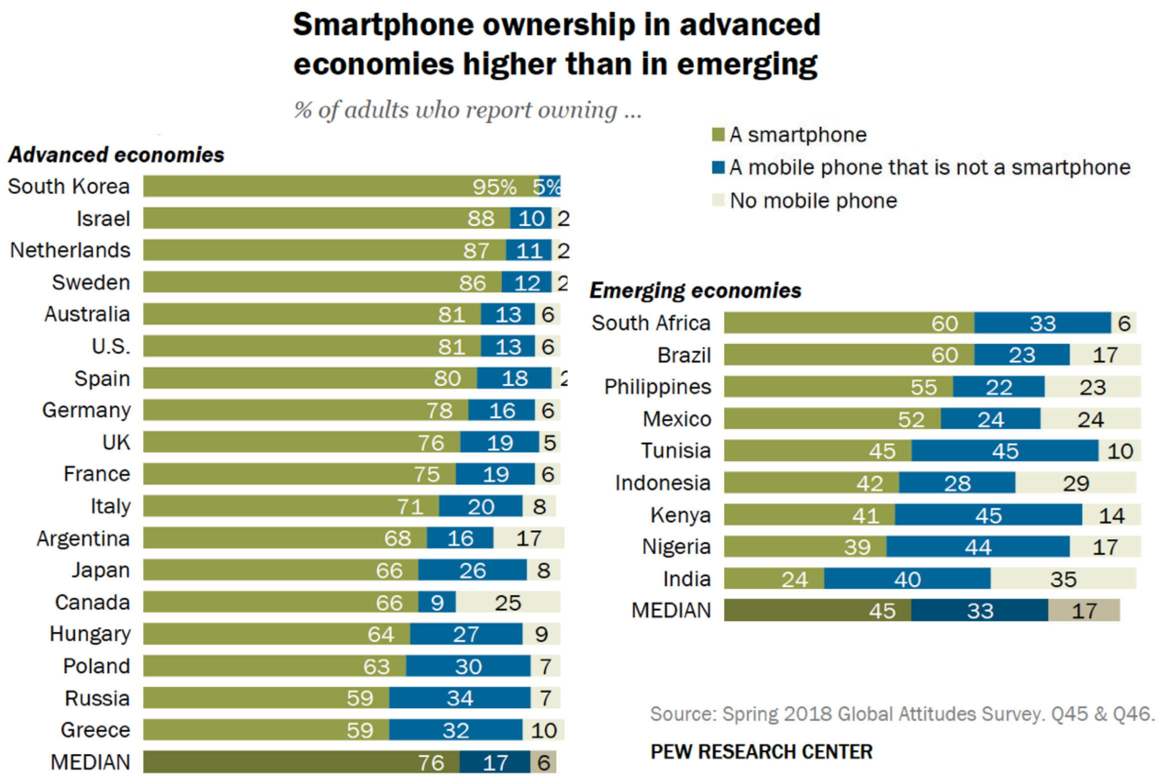


Figure 1. Smartphone ownership in advanced economies higher than in emerging (retrieved from Spring 2018 Global Attitudes survey, Pew Research Center)

The hours of smartphone use also have increased as application market has grown. According to some research centers, American adults usually spent 58 minutes to use their smartphone in 2013 (Simmons Connect, 2013), and it increased up to 3 hours per day in 2017 (comScore, 2017). More recently, it was reported that the Android phone users use their smartphone average 2.8 hours in US, 3.6 hours in South Korea, and 4.1 hours in Indonesia in 2018 (App Annie, 2019). The average hours of smartphone use assumption varied in research centers, but the macro trend of smartphone use implies that smartphone cannot be missing in our lives.

Moreover, it is not difficult to see people who use their smartphones on the street while walking. Recent surveys have reported the prevalent use of smartphone while walking, especially among young smartphone users. According to a nationwide survey in Korea in 2016, 93% of the respondents in twenties used to use their smartphone while walking (Korea Transportation Safety Authority, 2016). An online survey that we conducted by ourselves among university community in Korea, 44% of 383 participants responded 'frequently' and 11% responded 'always' to a question "How often do you use your smartphone while walking?". Only 5% responded 'never' to the question, which coincides with the results of the nationwide survey.

As the number of smartphone users and time of smartphone use has increased, some health and safety concerns about the influence of intensive use of smartphones has also increased. Text neck syndrome (text neck) which refers to pain symptoms of the neck and neighboring regions is one of the most noted issues because of its prevalence in hand-held device users including smartphone (Berolo, Wells, & Amick, 2011; Cuéllar & Lanman, 2017; Gustafsson, Thomée, Grimby-Ekman, & Hagberg, 2017; Kim & Kim, 2015). It has been supposed that the intensive use of smartphone might contribute to the prevalence of such symptoms since smartphone users frequently look down on the screen by tilting their head downward or bending their neck to use smartphone as other hand-held devices (Berolo et al., 2011; Gold, Driban, Yingling, & Komaroff, 2012). However, scientific evidence that supports such hypothesis is not enough yet, so it is necessary to quantify head-down posture of smartphone users.

The association of smartphone use and text-neck and its potential pathological path are schematized in figure 2 and figure 5. Figure 2 presents the risk factors of smartphone use in static posture such as standing and sitting, which are studied by many researchers.

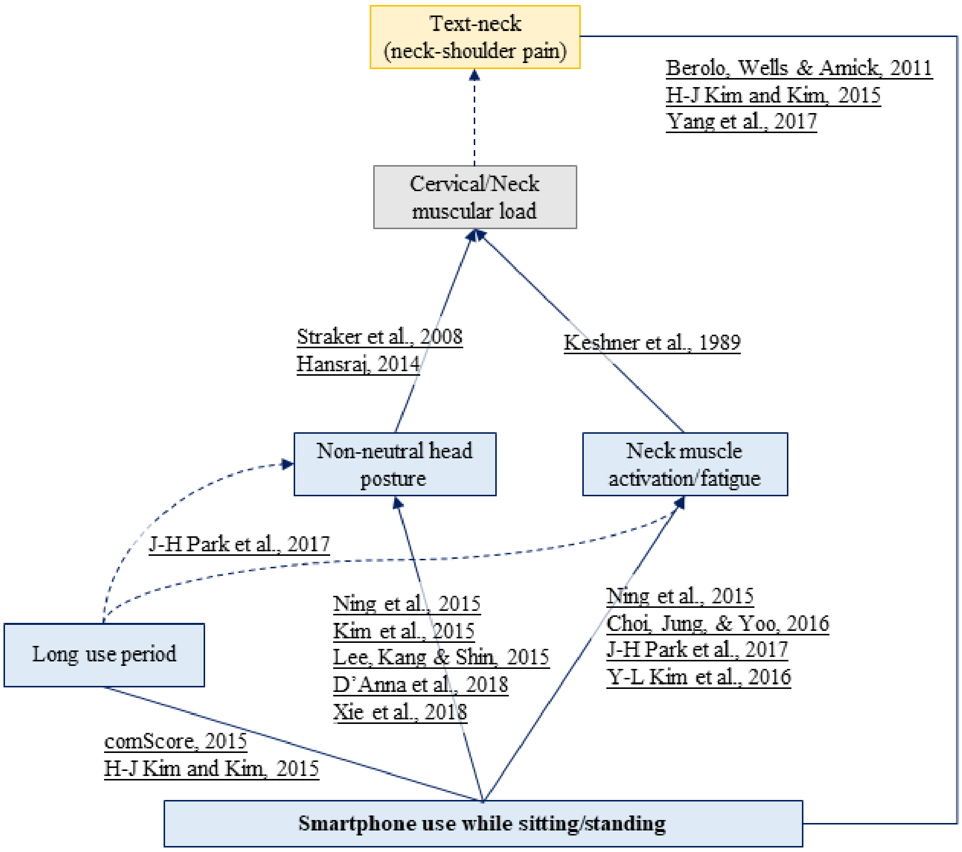
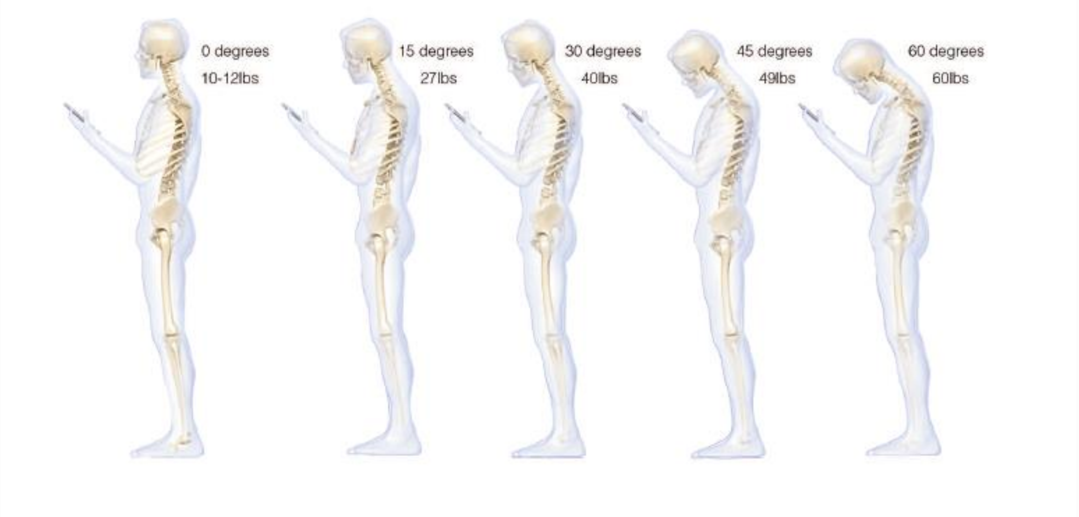


Figure 2. Potential risk factors of text-neck syndrome when using smartphone while sitting or standing. Dashed arrow indicates assumed path, solid arrow indicates possible path that supported by previous researches.

Evaluation of head-down tilt posture

One possible method to evaluate the head-down tilt posture is measuring neck flexion angle in the sagittal plane. Neck flexion posture leads to increase of the moment arm length of the head from its axis of rotation at the cervical joint, and this requires more contraction force of the neck extensor muscles to support the weight of the head (Straker et al., 2008). It was also reported that flexing neck increases mechanical load seen by the cervical spine dramatically, which may result in early wear, tear, or degeneration of cervical spine and adjacent tissues (Hansraj, 2014).

Neck flexion angle has been used to investigate risk factors related neck musculoskeletal symptoms in various researches. Some studies showed that the flexed neck posture when using computer was a predictor for neck pain for students(Brink, Louw, Grimmer, & Jordaan, 2015) or for office workers (Ariens et al., 2001). Others figured out the quantified neck flexion angle to evaluate muscular load of neck when using laptops(Moffet, Hagberg, Hansson-Risberg, & Karlqvist, 2002; Sommerich, Starr, Smith, & Shivers, 2002), tablet PC (Straker et al., 2008; Young, Trudeau, Odell, Marinelli, & Dennerlein, 2012), and recently using smartphone.



Position	Neutral	15 °	30°	45 °	60 °	90°
Force To Cervical Spine	10-12lbs.	27lbs.	40lbs.	49lbs.	60lbs.	Not Measurable

Figure 3. The weight seen by the spine according to the neck flexion angle. Retrieved from Hansraj, 2014.

In recent smartphone researches, head flexion angle of smartphone users was quantified when they were using different applications by holding smartphone in sitting and standing posture in the laboratory setting(D'Anna et al., 2018; S. Lee, Kang, & Shin, 2015). Another study evaluated the effect of duration on the neck flexion angle of smartphone users when they were using smartphone in sitting and standing posture(S.-Y. Lee, Lee, & Han, 2016). The difference of neck flexion angle between using smartphone on the table and by holding it was also found(Ning, Huang, Hu, & Nimbarte, 2015). However, these studies are conducted in specific static postures, during a limited time period (Douglas & Gallagher, 2017, 2018; S. Lee et al., 2015). Because smartphones could be used anywhere and at any time, it was necessary to evaluate the head posture in realistic conditions.

Figure 4. Postures and tasks previous researches evaluated: texting while sitting (left) and standing (right). Retrieved from Lee, Kang, and Shin 2015 and Lee, Lee, and Han 2016, respectively

Previous researches of smartphone use while walking

Meanwhile, using smartphone while walking is very common and concerned behavior these days. A new term 'smombie (smartphone + zombie)' which refers to people who don't look forward to use smartphone on the road, shows its severity. Despite the prevailing use of smartphone while walking, however, the neck muscular load of smartphone users associated with such usage scenario has not been investigated enough.

Safety issues associated with the use of a smartphone while walking have been studied. Previous researches have shown that the use of a smartphone on streets would interrupt situation awareness (Agostini, Lo Fermo, Massazza, & Knaflitz, 2015; Hyman Jr, Boss, Wise, McKenzie, & Caggiano, 2010; Lamberg & Muratori, 2012), impair dynamic balance capacity(Azab, Amin, Mohamed, & Sciences, 2017; Cho, Choi, & Goo, 2014; Hyong, 2015) and disrupt gait performance and stability(Caramia, Bernabucci, D'Anna, De Marchis, & Schmid, 2017; Russo, James, Aguilar, & Smaglik, 2018; Schabrun, van den Hoorn, Moorcroft, Greenland, & Hodges, 2014), alerting the risks for collision and/or fall accidents of pedestrians. However, little is known regarding potential risks of the walking with head down for the occurrence of neck musculoskeletal problems.

In Schabrun et al. (2014), kinematic data including head flexion angle of participants was collected when they were conducting reading and texting tasks while walking on an 8.5m walkway in the laboratory. They reported that the mean head flexion angle was 29.22° and 31.8° in reading and texting task respectively as well as range of motion of neck (head relative to thorax) was reduced in texting task more than reading task, compared to walking without smartphone. However, 8.5m walkway that was used in this study might not be long enough for participants to fully engaged with smartphone tasks or reach a stable walking speed(Macfarlane & Looney, 2008). Additional research is needed with a data collection environment where participants can be more engaged in using their phones, as they would do on streets (Plummer, Apple, Dowd, & Keith, 2015).

There is another problem in studies of smartphone use while walking. Some studies have measured head flexion angle while walking as a measure of neck muscular load, however, it is not likely that the amount of head flexion alone can represent the muscular load of smartphone users who conduct texting or browsing while walking. Human walking involves dynamic motions of body segments to produce the forward projection of the body while maintaining stability. The head also makes harmonic translational and angular motions with respect to the torso in a coordinated fashion to maintain the stability of walking posture and gaze (Cappozzo, 1981; Cromwell, Schurter, Shelton, & Vora, 2004; Menz, Lord, & Fitzpatrick, 2003).

The oscillating motions of the head during walking, if occurred when using a smartphone in a head down position, may pose dynamic muscular load to the neck, and it cannot be assessed by the measurement of head flexion alone. More reliable and valid assessment of the neck muscular load during the dynamic motions would require the evaluation of myoelectric activation level of the neck extensor muscles. The amplitude of the myoelectric signals of the neck muscles has been used as a direct indicator of neck muscular load in previous ergonomics research(Choi, Jung, & Yoo, 2016; Keshner, Campbell, Katz, & Peterson, 1989; Xie, Szeto, Dai, & Madeleine, 2016), and it can be a valid measure of neck muscular load during the smartphone use while walking.

The association between ergonomic issues and smartphone use while walking and its potential pathological path are also schematized in figure 5. While solid lines are in some path from smartphone use while walking to accidents, there is few solid lines from smartphone use while walking to text-neck issue.

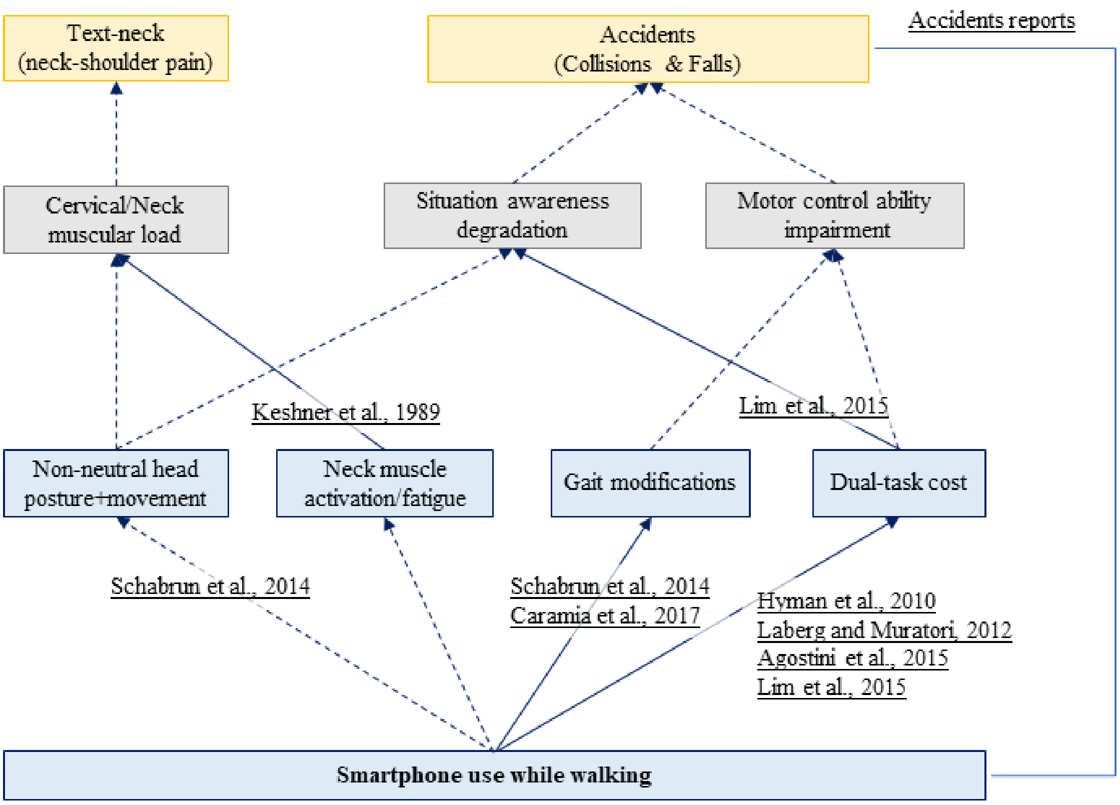


Figure 5. Potential risk factors of smartphone users when using smartphone while walking. Dashed arrow indicates assumed path, solid arrow indicates possible path that supported by previous researches, and solid line indicates proved association.

1.2 Research objective and Thesis organization

From such background, the goal of this research is to investigate the potential risk factors among young adults when they are using smartphone in daily life, especially when they are walking. To fulfill the research goal, three linked studies were conducted for distinct objectives. Research questions and hypothesis of each study is described below:

The aim of study #1 was to evaluate the association between smartphone use and head-down tilt posture in natural settings. The study was designed to objectively assess the angle and duration of head-down tilt posture during smartphone use by using Android application which was developed for collect smartphone-app usage data. The null hypothesis was that there would be no difference in participants' head-down tilt posture between when they were using their phones and when they were not using the phones during the 8-hour period.

The aim of study #2 was to determine how head posture would vary when browsing mobile web and texting messages with smartphone while walking. Head tilt angle and acceleration were measured by using IMU sensors when conducting one-handed web-browsing and two-handed texting while walking on a 60-meter outdoor walkway. The null hypothesis was the head tilt angle and range of vertical acceleration data when texting while walking and when web-browsing while walking would not be different.

The aim of study #3 was to evaluate the musculoskeletal risks of neck among smartphone users when they use smartphone while walking. Neck muscle activation and head kinematics data were collected by using EMG sensors and optical motion tracking system while participants conducting 3 tasks (without smartphone, one-handed web-browsing, two-handed texting) while walking in laboratory setting. The null hypothesis was the neck muscle activation and head kinematics of each task would not be different from each other.

I organized the thesis by integrating those three studies condignly. The first chapter, Introduction includes the general background of research, short literature reviews, global and local objectives of research. The second chapter, Methodology describes the detailed method of each study one by one and provides the overview of them. The third chapter, Results shows the whole results of three studies in regular sequence. The fourth chapter, Discussion explains the meaning of results by variables from all experiments. In that chapter, I would discuss the potential risks of smartphone users based on research findings, as well as some limitations of studies. The fifth chapter, Conclusion summarizes the thesis research and presents implication of thesis.

2. METHOD

2.1 Study 1: Naturalistic data collection of head posture of smartphone users

First study was a naturalistic data collection study with young adults of a university community. Head tilt angle was quantified by an inertial motor unit (IMU) sensor while participants were conducting their routine school activities with their own smartphones for 8 hours continuously. In this study, the term of "head tilt angle" refers to the angle of head flexion in sagittal plane, regardless of neck flexion. This study was published as "Naturalistic data collection of head posture of smartphone users" in 2019 *Ergonomics*.

<u>Participants</u>

Thirty-one healthy young adults (16 females and 15 males) who did not have any physical symptoms and medical history on their neck and neighboring body regions participated in this study. All participants were experienced smartphone users who had owned touch-screen smartphone at least one year (Table 1). Volunteers who are not full-time college students or had difficulty to attach sensor on their forehead were excluded. Participants provided informed consent on a protocol approved by the institutional review board (IRB) of the Ulsan National Institute of Science and Technology, prior to starting experiment.

Table 1. Descriptive statistics for participants of study 1 (mean, SD).

	#	Smartphone use period, yrs	Age, yrs	Height, cm	Weight, kg
All	31	2.6 (1.1)	20.6 (1.4)	167.2 (8.4)	60.6 (10.5)
Female	16	2.4 (0.9)	20.4 (1.0)	161.3 (4.8)	54.7 (6.3)
male	15	2.9 (1.3)	21.0 (1.8)	174.2 (6.0)	67.6 (10.3)

<u>Data collection</u>

Smartphone use data were collected by an Android application (app) which were developed in-house and installed to participants' own smartphone prior to data collection. The app tracked the status of smartphone (ON/OFF), active app name and time at a rate of 2 Hz for 8 hours continuously and store the data in device memory.

Figure 6. Sensor attachment on participant's middle of forehead

Head tilt angle data were collected by using a lightweight (22g) IMU sensor (I2M, Nexgen Ergonomics, Canada). The sensor was attached to participants' middle forehead by hypoallergenic adhesive tapes and set to record angular data at a rate of 20 Hz for 8 hours continuously in its embedded memory (Figure 6). A reference head tilt angle was recorded prior to the beginning of data collection while the participants was standing upright with their eyes looking straight forward for 10 seconds. Finally, head tilt angle was calculated by subtracting the angle of reference head posture from raw head tilt angle.

Each participant visited the laboratory in the morning (between 8:00 AM and 10:00 AM) to start data collection. The data collection app was installed to participants' own smartphone and the IMU sensor was attached to participants' middle forehead. After recording the reference head posture, participant left laboratory and started his/her typical school day. The participant was asked not to lie or take naps during recording period. Other specific instructions were not given. After 8 hours, the participant returned to the laboratory and sensor data were downloaded.

Data processing and analysis

Smartphone use data was synchronized with head tilt angle data from IMU sensor that were down-sampled to 2Hz by matching internal clocks between the two data sets. Apps that participants used during the data collection period were categorized into nine major groups: system and tool; email and text communication; social network service (SNS); voice communication (phone); game; web-browsing; video, photograph, and music; camera; and productivity. Then, the total time spent on each app category as well as its median head tilt angle were computed for each participant.

The moments when smartphone was turned on (ON) and turned off (OFF) were identified with synchronized data. The difference of distributions of head tilt angle between ON and OFF status was statistically tested at the 10^{th}, 50^{th}, and 90^{th} percentile levels using a paired t-test. Then, the effect size of them was calculated.

The head tilt angle data of the ON and OFF periods were also partitioned into seven intervals of angle range (0-10°; 10-20°; 20-30°; 30-40°; 40-50°; 50-60°; and >60°) and shares of time spend in the intervals were computed for each period. Pairs of each interval were compared using paired t-test to determine whether participants spend more or less share of time with their heads in a specific posture range during one period compared to the other. All t-tests were conducted after testing for normality assumption. A significance criterion of $p<.05$ was used for all statistical analyses.

2.2 Study 2: Quantifying head tilt posture while walking

Second study was an outdoor experiment to collecting head posture data of young adults when they were walking with and without smartphone use. The head tilt angle was defined same as study 1. This study was written in a paper and published online in 2019 *Applied Ergonomics*.

Participants

Twenty-eight young healthy adults (13 females and 15 males) who had no physical difficulties in using their smartphones while walking were recruited from the university community (Table 2). All participants had at least one year of experience of smartphone use and were accustomed to using a smartphone while walking. Participants provided written consent on a protocol approved by the institutional review board (IRB) of the Ulsan National Institute of Science and Technology. The sample size was determined to satisfy the minimum number of samples to achieve the statistical power of 0.80.

Table 2. Participant age and height: mean (standard deviation) by gender.

	N	Age (yrs)	Height (cm)
Female	13	21.8 (1.4)	159.9 (1.8)
Male	15	23.6 (2.0)	175.2 (6.1)
All	28	22.8 (1.9)	168.1 (9.0)

Data collection

The experiment was carried out at an isolated outdoor soccer field of a university campus in daytime. A 60-m straight walkway was marked as a data collection area. Average outdoor temperature during the experiment period ranged from 20℃ to 24℃. Pedestrians were not allowed to enter the data collection area to avoid collision and to minimize visual or auditory distractions during the experiment.

(a) (b) (c)

Figure 7. Participant posture in three tasks; (a) normal walking (b) web- browsing walking (c) texting-walking

Each participant was given either Samsung Galaxy S6 or Apple iPhone 6S according to his/her familiar operating system, and conducted three tasks: 1) upright normal walking without using a smartphone (normal walking); 2) one-handed web-browsing while walking (web-browsing walking); and, 3) two-handed texting while walking (texting walking) (Figure 7).

During ‘normal walking’ task, the participant was instructed to look forward and walk straight along the 60-m walkway at own preferred walking speed while swinging both arms naturally. No additional restrictions were imposed.

During ‘web-browsing walking’ task, the participant held given smartphone with one hand (preferred hand) in portrait orientation and browsed a specific new portal site while walking the same walkway at a preferred pace for the condition. The web-browsing task included cycles of ‘opening an article by tapping’, ‘reading the article with vertical scrolling’ and ‘returning to the home page of sit by tapping’. All touch gestures were made by the thumb of the hand that was holding the phone.

During the ‘texting walking’ task, the participant held the given smartphone in portrait orientation with both hands and typed given short sentences one by one through the messaging app installed in the participant’s smartphone. Participants were allowed to correct errors while typing. The texting task was continued during 60-meter walking and the participant was instructed not to raise his/her head until reach the goal of walkway.

Head tilt angle in the sagittal plane and linear accelerations of head data were collected from each participant by using an IMU sensor (I2M, Nexgen Ergonomics, Canada) when conducting tasks. An IMU sensor was attached on the middle of forehead by hypoallergic adhesive tape (Figure 6) and recorded angle and acceleration data at a sampling rate of 20Hz in its internal storage. The reference had posture was measured in upright standing posture before starting tasks.

Prior to data collection, all participants were briefed and trained for the task protocols and had adaptation time to data collection area and tasks. They also completed all the three tasks as practice trials before collecting data. Between consecutive walking tasks, participants were asked to walk around the data collection area without looking at the phone for at least 60 second to minimize potential carry-over effects.

Data processing and analysis

Probability distributions of the head tilt angle data were obtained to conduct statistical analysis. For each task, raw head tilt angle samples of the middle 50-meter were extracted among whole sample, and the 10^{th}, 50^{th} and 90^{th} percentile angle values were computed from the distribution. Reference head tilt angle was subtracted from computed angle.

For each variable, differences between the three walking tasks were tested by using a repeated measures ANOVA and Tukey's post-hoc analysis with a significance criterion of $p<0.05$. Effect size of smartphone use in head tilt angle was also calculated.

2.3 Study 3: Evaluation of neck muscle activation and head motions when using smartphone while walking

Third study was in-door, with-in subject experiment to quantify neck muscle activation and head/trunk kinematics as well as eye-smartphone position to evaluate biomechanical load of neck muscles. A paper including the results of study 3 was written and now under reviewing.

Participants

Twenty-one asymptomatic young smartphone owners (10 females and 11 males) were recruited from the university community (Table 3). All participants had at least one year of touch-screen smartphone use experience, no physical and cognitive difficulties in using a smartphone while walking. They participated in the study with their own smartphones and provided informed consent on a protocol approved by the institutional review board of Ulsan National Institute of Science and Technology.

Table 3. Participants information. Mean and standard deviation.

	#	Height, cm	Weight, kg	Left handed	Right handed
Female	10	161.3 (2.5)	55.0 (4.6)	1	9
Male	11	176.0 (2.6)	74.8 (11.6)	2	9
All	21	169.0 (7.8)	65.5 (13.4)	3	18

Data collection

The experiment was carried out in a laboratory by using participants' own smartphone. Participants conducted walking upright without smartphone (normal walking), one-handed web-browsing while walking (web-browsing walking) and two-handed texting while walking (texting walking) on a treadmill at a preferred walking speed (Figure 8).

During the web-browsing walking task, the participant held his/her phone with dominant hand in portrait orientation and browsed a news portal site with scrolling and tapping gestures. Switching hands and typing texting while web-browsing were not allowed. During the texting walking task, the participant his/her phone with both hands in portrait orientation and copy-typed text messages that were sent by the experimenter at own preferred pace. Participants were allowed to correct errors. Each task was continued for one minute and 1-min break was given between consecutive trials.

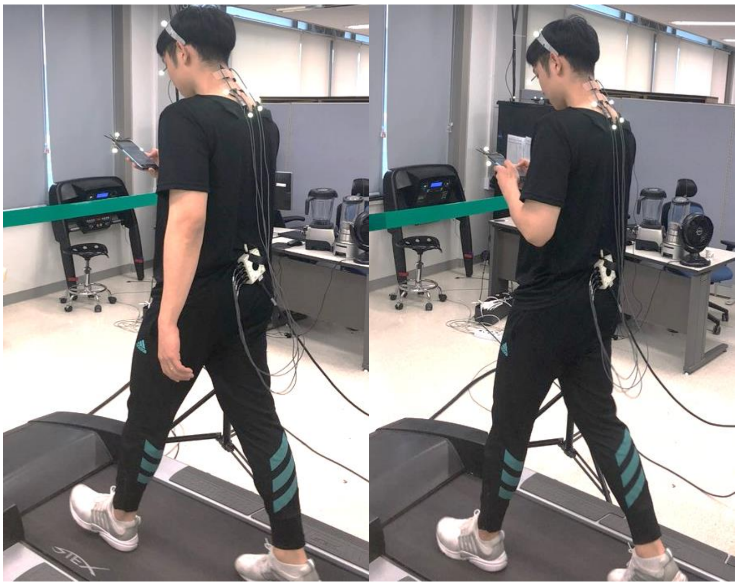


Figure 8. Web-browsing while walking task (left) and texting while walking task (right).

While conducting each task, the electromyographic signals (EMG) of four neck extensor muscles were collected by using a surface EMG system (Delsys Bagnoli system, Delsys, USA). 2cm*4cm sized Ag-Cl bipolar electrodes were placed bilaterally at the level of the 2nd cervical vertebra to capture the EMG signals from the splenius muscles and 2~3cm lateral from the midline at the level of the 3rd cervical vertebra for signals of the cervical erector spinae muscles (Schuldt & Harms-Ringdahl, 1988). The EMG signals were collected at 2,000 Hz, full-wave rectified.

Simultaneously, three-dimensional motions of the head, upper back and the phone was quantified by using an 18-camera motion capture system (OptiTrack, Naturepoint, Oregon, USA) at a sampling rate of 100 Hz. Rigid bodies were constructed from attached reflective markers, four on the head, three below the 7th cervical vertebra, and three markers on the upper edge of the phone, for head, upper back and smartphone respectively. The reference of kinematic variables were recorded while the participant was standing upright looking straight forward at the beginning of the experiment.

Data processing and analysis

Collected raw EMG signals were band-pass filtered between 10Hz and 500Hz and smoothed by the 2nd order Butterworth filter with a low-pass cut-off frequency of 6Hz. The linear enveloped EMG data of each muscle were normalized by the mean amplitude of EMG of normal walking task without smartphone as a reference voluntary contraction (RVC).

Raw kinematic data were smoothed by the 2nd order Butterworth filter with a low-pass cut-off frequency of 6Hz. Then a set of kinematics variables were defined from the sagittal plane coordinates and orientations of the three rigid bodies (Table 4).

Four NEMG data and ten kinematics data were tested by the one-way repeated measures ANOVA to evaluate the effect of the task. Normality and sphericity assumptions were confirmed by the Shapiro Wilk test and the Mauchly's sphericity test, respectively. A statistical package (Minitab v.18.1, Minitab Inc., PA, USA) was used with a significance criterion of $p<0.05$ for all statistical analyses. Effect size of smartphone use in head tilt angle was calculated.

Table 4. Dependent variables.

	Variables (unit)	Description
Kinematics variables	Median head tilt angle (deg)	Median angle of head tilt in the sagittal plane
	Median neck flexion angle (deg)	Median angle of 'head tilt – upper back tilt' in the sagittal plane
	Range of head tilt angle (deg)	'90^{th} percentile – 10^{th} percentile' of head tilt angle
	Range of neck flexion angle (deg)	'90^{th} percentile – 10^{th} percentile' of neck flexion angle
	Range of head vertical position (cm)	'90^{th} percentile – 10^{th} percentile' of head vertical coordinate
	Range of phone vertical position (cm)	'90^{th} percentile – 10^{th} percentile' of phone vertical coordinate
	Horizontal viewing distance (cm)	Median horizontal distance from the midpoint of the eyes and the center of the phone's screen
	Vertical viewing distance (cm)	Median vertical distance from the midpoint of the eyes and the center of the phone's screen
	RMS, Head angular acceleration (deg/s^2)	Root mean square of head angular acceleration
	RMS, Head vertical acceleration (cm/s^2)	Root mean square of head vertical acceleration
EMG variables	NEMG of dominant SP (%RVC)	Normalized EMG of splenius of dominant side
	NEMG of non-dominant SP (%RVC)	Normalized EMG of splenius of non-dominant side
	NEMG of dominant CES (%RVC)	Normalized EMG of cervical erector spinae of dominant side
	NEMG of non-dominant CES (%RVC)	Normalized EMG of cervical erector spinae of non-dominant side

2.4 Methodological overview

Table 5. Key features of methods of three studies.

	Study 1	Study 2	Study 3
Study type	Observational study	Experimental study	Experimental study
Point of study	Realistic data collection	Long outdoor experiment	Neck EMG measurement while walking
Study design	Non-intervention With-in subject	With-in subject	With-in subject
Study location	Not limited	Outdoor	Indoor
Sample	31 young adults	28 young adults	21 young adults
Focal body part	Head	Head	Head, neck and trunk
measures	Kinematics (IMU sensor) App use information (android app)	Kinematics (IMU sensor)	Kinematics (optical motion capture system) EMG (Delsys surface EMG system)
Conditions	Not controlled	Normal walking Web-browsing walking Texting walking	Normal walking Web-browsing walking Texting walking
Analysis	Descriptive statistics Paired t-test	Descriptive statistics ANOVA (Post-hoc)	Descriptive statistics ANOVA (Post-hoc)

3. RESULTS

3.1 Study 1

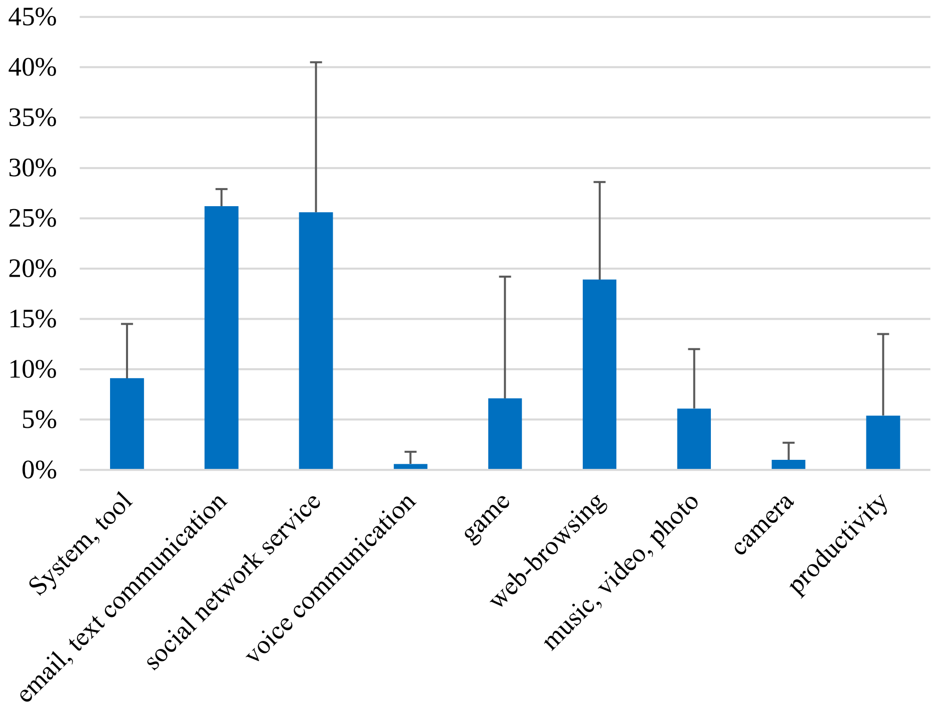
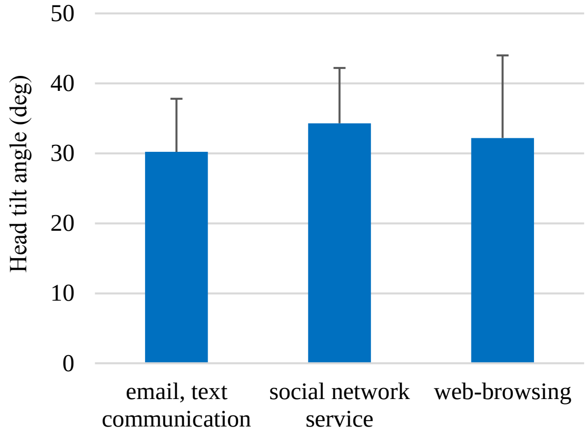


Figure 9. Share of time spent on apps. Error bars indicate one standard deviation.

Participants of study 1 spent average 145.2 minutes (Standard deviation, 77.9 mins) to use their smartphones during 8 hours of daily school activities. Median usage period was 125.9 minutes. The three most used app categories were email/text communication (26.2%), social network service (25.6%) and web-browsing (18.9%). Voice communication app registered the least share of usage time (0.6%) among the nine categories (Figure 9)



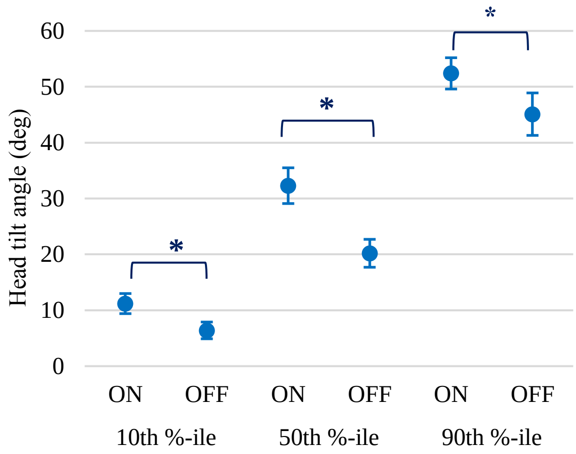


Figure 10 (left). Median head tilt angles of three most-used app categories

Figure 11 (right). Mean and 95% confidence interval of head tilt angle when the smartphone was turned on (ON) and turned off (OFF). * $p<0.05$

Head tilt angles of participants during 8 hours of daily activities ranged from 6.4° (10th percentile) to 49.3° (90th percentile) with the median tilt angle at 23.0°. Median head tilt angles of the three most-used app categories were 30.2°, 34.3° and 32.3°, respectively (Figure 10). In the comparison between ON and OFF periods, the head tilt angle was significantly greater for ON periods than OFF periods at all three levels, with the largest difference at the 50th percentile level (Figure 11). The median head tilt angle was 20.2° while conducting daily activities without using the phone and 32.3° while using the smartphone. The effect size of head tilt angle in 10th, 50th, 90th percentile between ON-OFF was 3.20, 4.84, and 1.92, respectively.

Table 6. Effect size of head tilt angle in study 1

	Effect size
	smartphone ON - OFF
10th percentile	3.20
50th percentile	4.84
90th percentile	1.92

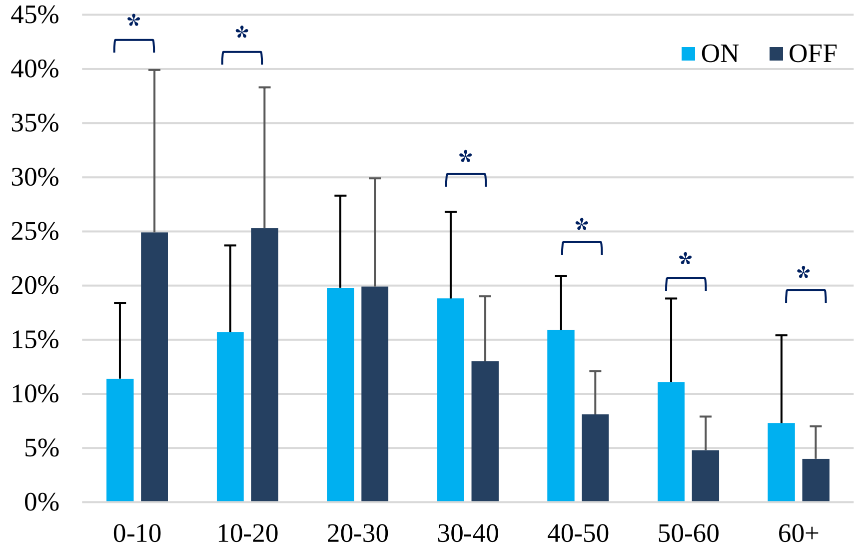


Figure 12. Shares of time spent in 7 intervals of head tilt angle when smartphone was turned on (ON) and turned off (OFF). Error bars indicate one standard deviation. *p<0.05

The shares of time spent in every 10° intervals of head tilt angle excluding 20-30 were significantly different between ON and OFF periods (Figure 12). Time shares of head-down posture less than 20° were significantly greater for OFF periods, while time shares of head-down posture than 30° were greater for ON periods. It indicates that participants spent longer time in greater tilt posture while using the smartphone, compared to when they were doing usual activities without smartphones.

3.2 Study 2

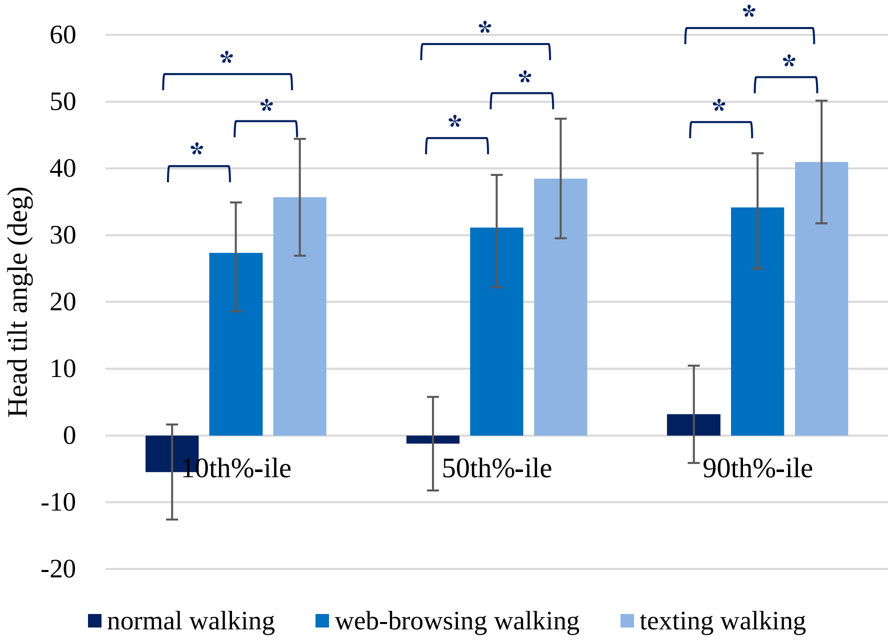


Figure 13. Head tilt angle while normal walking, web-browsing while walking, and texting while walking. Error bars indicate one standard deviation. *p<0.05

Head down tilt angle in sagittal plane ranged from 27.3° (10th percentile) to 34.2° (90th percentile) during one-handed web-browsing while walking, and from 35.7° (10th percentile) to 41.0° (90th percentile) during two-handed texting while walking, whereas varied between -5.5° (10th percentile) and 3.2° (90th percentile) while walking upright. Differences between the three walking tasks were significant at all three percentile levels (Figure 13). The effect size between two-handed texting and normal walking was larger than that between one-handed web browsing and normal walking (Table 7).

Both walking speed and range of head vertical acceleration were reduced in web-browsing walking and texting walking tasks compared to normal walking task (Table 8)

Table 7. Effect size of head tilt angle in study 2

	Effect size	
	web browsing - OFF	texting - OFF
10th percentile	4.61	5.78
50th percentile	4.62	5.67
90th percentile	4.25	5.19

Table 8. Descriptive statistics of dependent variables

Dependent variables	Walking	Web-browsing walking	Texting walking
10^{th} percentile of head tilt angle (deg)	-5.5 (7.1)	27.3 (7.6)	35.7 (8.7)
50^{th} percentile of head tilt angle (deg)	-1.2 (7.0)	31.1 (7.9)	38.5 (9.0)
90^{th} percentile of head tilt angle (deg)	3.2 (7.3)	34.2 (8.1)	41.0 (9.2)
Range of head vertical acceleration (m/s^2)	5.69 (1.05)	4.55 (0.82)	4.18 (0.71)
Walking speed (m/s)	1.27 (0.16)	1.08 (0.15)	0.99 (0.17)

3.3 Study 3

The NEMG amplitude of the splenius muscle ranged from 113%RVC to 253%RVC at dominant side and from 97%RVC to 263%RVC at non-dominant side when using smartphone while walking. Both dominant side and non-dominant side of splenius were more activated significantly in texting walking task than web-browsing task in all levels (Table 9). The NEMG amplitude of the cervical erector spinae ranged from 113%RVC to 215%RVC at dominant side, and from 97%RVC to 225%RVC at non-dominant side when using smartphone while walking. The cervical erector spinae at both sides also contracted more when texting walking task than web-browsing walking task, however, there was no significance of difference in 90^{th}-percentile level of cervical erector spinae activation at dominant side.

Table 9. ANOVA results of NEMG variables: Mean (standard deviation) and significance.

Dependent variables		Web-browsing walking	Texting walking	***p***
NEMG of splenius of dominant side (%RVC)				
	10^{th}-percentile	113 (25)	135 (45)	*
	50^{th}-percentile	160 (42)	184 (59)	*
	90^{th}-percentile	222 (64)	253 (85)	*
NEMG of splenius of non-dominant side (%RVC)				
	10^{th}-percentile	112 (29)	146 (62)	*
	50^{th}-percentile	159 (51)	198 (85)	*
	90^{th}-percentile	216 (176)	263 (107)	*
NEMG of cervical erector spinae of dominant side (%RVC)				
	10^{th}-percentile	113 (24)	123 (33)	*
	50^{th}-percentile	153 (36)	164 (4)	*
	90^{th}-percentile	205 (49)	215 (63)	
NEMG of cervical erector spinae of non-dominant side (%RVC)				
	10^{th}-percentile	97 (26)	127 (44)	*
	50^{th}-percentile	129 (34)	172 (75)	*
	90^{th}-percentile	176 (45)	225 (110)	*

The median head tilt angle of participants was 3.8°, 28.9°, and 36.8° for normal walking, web-browsing walking and texting walking, respectively. Range of head tilt angle was 5.8° for normal walking task, and decreased to 4.8° for web-browsing walking, and to 3.8° for texting walking. Differences of both median and range of head tilt angle in two tasks were found statistically significant in ANOVA and pairwise comparison of Tukey's post-hoc analysis (Table 10). The effect size of one-handed web browsing while walking was 5.46, and that of two-handed texting while walking was 7.17 (Table 11).

The neck flexion angle of participants was comparable with the head tilt angle. The median neck flexion angle was 1.3°, 23.1° and 30.5° for normal, web-browsing and texting walking, respectively. Range of neck flexion angle was 6.0° in normal walking, 3.7° in web-browsing walking, and 2.5 in text walking task. There was significant difference between the median neck flexion angle of three tasks, but not between the range of neck flexion angle of web-browsing and texting walking (Table 10).

Table 10. Summarized results of kinematics variables (Mean, standard deviation and results of ANOVA and post-hoc analysis)

Dependent variables	Normal walking	Web-browsing walking	Texting walking	***p***
Median head tilt angle (º)	3.8 (4.6)^{a}	28.9 (10.7)^{b}	36.8 (11.2)^{c}	*
Range of head tilt angle (º)	5.8 (2.2)^{a}	4.8 (1.6)^{b}	3.8 (1.5)^{c}	*
Median neck flexion angle (º)	1.3 (4.8)^{a}	23.1 (9.5)^{b}	30.5 (8.7)^{c}	*
Range of neck flexion angle (º)	6.0 (2.6)^{a}	3.7 (1.3)^{b}	2.5 (0.5)^{b}	*
Range of head vertical position (cm)	2.5 (0.5)	2.6 (0.8)	2.4 (0.6)	
Range of phone vertical position (cm)	-	5.4 (2.4)	3.3 (0.6)	
Median horizontal viewing distance (cm)	-	23.6 (4.4)	20.8 (4.1)	
Median vertical viewing distance (cm)	-	29.3 (4.7)	30.3 (4.1)	*
Head tilt angular acceleration RMS (deg/s2)	140.7 (48.4)^{a}	134.3 (46.2)^{ab}	114.3 (67.9)^{b}	*
Head vertical translation acceleration RMS (cm/s2)	75.9 (18.1)	76.7 (25)	70.7 (23.7)	

*Note. * indicates p<.05 and superscripts above values (a, b, c) indicate the grouping based on Tukey's Post-hoc analysis.*

The mean RMS of head tilt angular acceleration was largest in normal walking task (140.7°/s^2), and increased in web-browsing walking task (134.3°/s^2) and texting task (114.3°/s^2). There was significant difference between normal and web-browsing walking task, as well as between web-browsing and texting walking task (Table 8). Meanwhile, any statistical significance was not found in range of head vertical position, range of phone vertical position, median horizontal viewing distance, and head vertical translation acceleration RMS.

Table 11. Effect size of head tilt angle in study 3

	Effect size	
	web browsing - OFF	texting - OFF
Median value	5.46	7.17

4. DISCUSSION

The main objective of this research was to investigate neck muscular load among smartphone users when they using smartphone while walking by quantifying and evaluating head-down tilt posture. To achieve the research goal, three studies had own objectives: 1) to quantify head tilt posture of smartphone users in real life; 2) to quantify the amount of head tilt when conducting one-handed web-browsing and two-handed texting task while walking; and 3) to assess the muscular load of neck when conducting one-handed web-browsing and two-handed texting task while walking.

4.1 Head-down tilt posture of smartphone users

In study 1, participants flexed their head when using smartphones significantly more than when smartphone was turn off. The amount of head flexion was varied depending on application categories, and largest when using SNS apps (34.3°) and web-browsing apps (32.2°). Median head tilt angle of participants when smartphone was turned on was 32.3°, and it was 12.1° larger than that when smartphone was turned off. Also, the median head tilt angle of study 1 was smaller than that of previous laboratory study by Lee, Kang, and Shin (2015), which ranged from 34° to 40° and from 39° to 45° in standing and sitting posture, respectively. This might be because of measurement difference between two studies. Since the data of study 1 were collected continuously when screen of phone was turned on, moments of short head-up and head-down motions as well as sustained head-down might have been included. Also, some postures that participants could take during data collection might be allowed to support their arms or hands on desk and it could help them hold their phones with less head-down tilt as compared to when using the phones without any support. Moreover, the ‘SNS apps’ and ‘web-browsing apps’ group in the study 1 included more than five apps, whereas only one app was used for each task in previous research. So, different characteristics of apps might affect the posture of participants.

Median head tilt angle in study 2 averaged 31.1° and 38.5°, when one-handed web-browsing and two-handed texting while walking, respectively, while that is study 3 was 23.9° and 36.8°, when same tasks on a treadmill. Both studies found that the two-handed texting task while walking requires more tilted head posture than one-handed web-browsing task while walking. This result is consistent with the result of previous studies in which head tilt angle was larger in texting with both hands than web browsing with one hand in both standing and sitting posture(S. Lee et al., 2015), additionally while walking (Schabrun et al., 2014) . Holding a phone with both hands steady when conducting texting might have forced participants to hold the smartphone closer to their body, resulting in the larger head tilting as compared to holding the phone with one hand. This speculation could not be explained in previous researches, but the result of study 3 could do. Median horizontal viewing distance which represents the horizontal distance from the midpoint of the eyes and the center of the phone's screen of texting walking task was smaller than web-browsing walking task. It means the participants held their smartphone closer to their body when they were texting with both hands, even such difference was not statistically significant.

The effect size of head tilt angle in three studies showed similar tendency with minor difference. The effect size of two-handed texting task was larger than that of one-handed web browsing task in all levels. That means the different task affected head tilt down posture when smartphone user was walking regardless of the sample size.

However, the association between application type and head tilt angle was different in result of study 1 and study 2&3 in that SNS apps and Web-browsing apps have presented more tilted posture than text communication apps in study 1. The difference might come from the categorizing method of study 1. Apps in SNS group such as Facebook and Instagram include texting tasks as well as browsing tasks. For example, SNS users need to type text to upload post, to respond to others' post, and to reply to comments. Such texting tasks when using SNS apps might lead to large head tilt angle of participants.

To sum up, consistent results of three studies indicate that the use of smartphone in daily life including sitting, standing, and walking induces tilted head posture compared to daily activities without smartphone. Considering previous researches that reported the extensive head or neck flexion as the risk factor of cervical spine and neck muscles, the head posture when using smartphone could be regarded as a risk factor of text-neck, by increasing neck muscular load.

4.2 Dynamic head movement of smartphone users

In study 2, the range of head vertical acceleration which represents the variability of vertical head movement was widest in normal walking task (5.69 m/s^2) and decreased in web-browsing walking task (4.55 m/s^2) and texting walking task (4.15 m/s^2). However, in study 3, Head vertical translation acceleration RMS was lowest when texting while walking (70.7 cm/s^2) and highest when web-browsing while walking (76.7 cm/s^2). Even considering that the ways of measuring dynamic head movement were different in two studies, it is obvious that head vertical acceleration changes did not present the effect of task consistently.

Meanwhile, the head tilt angular acceleration RMS was largest in normal walking task (140.7°/s^2) and decreased to 134.3 °/s^2 and 114.3 °/s^2, in web-browsing while walking and texting while walking, respectively. The decrease of amount of head angular acceleration might be due to head stability strategy of participants to engage in texting task, or just due to decrease of walking speed (Hirasaki, Moore, Raphan, & Cohen, 1999). The speed of treadmill was adopted to each participant's preferred walking speed for walking and using smartphone and the differences between two walking speed were minor.

An association between the head flexion variation and biomechanical loads to the neck while is not yet clear. It is assumed that comparable oscillating head movement when using smartphone while walking generates dynamic flexion moment on the neck, which might require larger activation of the neck extensor muscles to maintain the head in flexed position compared to when simply holding the head in the position in sitting or standing. To validate it, more specific and elaborate evaluation of EMG of the neck muscles is needed.

4.3 Neck muscle activation of smartphone users

In study 3, it was found that conducting one-handed web-browsing task and two-handed texting task while walking required 12% to 163% more neck muscle activation compared to simply walking upright, except cervical erector spinae muscle at non-dominant side at 10th percentile level. Increased in NEMG of neck muscles indicates that neck muscle activated more as head tilt angle and neck flexion angle increased in two smartphone usage tasks. The positive association between the amount of head flexion and the amplitude of neck muscle EMG has been reported in previous research of personal computers (Seghers, Jochem, & Spaepen, 2003; Villanueva et al., 1997). Results of the study 3 showed that the same association would be valid for smartphone use involving finger touch gestures while holding the phone unsupported.

The difference in the way of holding the smartphone might also have affected the EMG results, specifically of the cervical erector spinae muscles. Participants used the dominant hand for both tasks, and it might result in the non-significant difference in the NEMG of the muscle of the same side. To the contrary, the non-dominant hand was not used for browsing and it could result in the significant difference in the NEMG of the muscle of the non-dominant side. Since the cervical erector spinae muscles were extended to the upper part of the shoulder and the back, the influence of arm posture might be more pronounced for the muscles than for the splenius muscles (Schüldt, Ekholm, Harms-Ringdahl, Arborelius, & Németh, 1987).

In summary, increased activation of neck muscles resulting from head-down tilt posture was observed in study, so the use of a smartphone while walking poses potential risks for the neck musculoskeletal problems due to muscular load of neck from muscle activation of the neck extensors to keep head down posture.

4.4 Gait stability and safety of smartphone users

Three studies quantified head tilt posture, neck flexion angle and neck muscle activation to investigate the risk factors of musculoskeletal symptoms related neck. However, using smartphone while walking has another risk factor related to gait stability and pedestrian safety of smartphone users. The importance of studying safety of smartphone users are well-known and the researches have been conducted like some previous studies introduced in early chapter.

Firstly, head tilt posture of smartphone users restricts vision to smartphone and extremely close points of walkway. They tend not to see forward frequently, which decreases visual situation awareness ability and increases the risk of accidents (Haga et al., 2015; Schwebel et al., 2012; Wang, 2015). This type of risk could be explained as dual-task effect, however, also explained with the effect of head tilt posture itself. It is difficult to separate the effect of cognitive and physical element in such situations. Therefore, it is necessary to study more advanced smartphone use situations.

Secondly, using smartphone while walking itself requires division of attention, resulting in dual-task effect or costs. They often appear in forms of gait performance decrease(Lamberg & Muratori, 2012; Russo et al., 2018), modification of gait parameter (Agostini et al., 2015; Caramia et al., 2017; Schabrun et al., 2014), and balance decrease (Azab et al., 2017; Hyong, 2015) which could lead to fall risks on the walkway.

To sum up, in addition to neck muscular loads, head tilt posture and cognitive demand resulting from using smartphone while walking are also potential risk factors of smartphone users in terms of gait stability and safety aspects.

4.5 Limitations

There were some limitations of this thesis research. First, the participants of all three studies were only asymptomatic college students. They do not represent the general population of smartphone users. In case of study 1, their 8-hour school activities during recording period were limited in campus and dormitory. If participants were recruited from other occupations or during other time frame, head tilt angle distributions of the ON and OFF periods might be different from those of the study.

Second, the study 2 was conducted at outdoor but isolated data collection are where potential risks of collision accidents were not present. If the data collection area was busy streets, the potential safety hazards could be considered as discussed in **4.4**.

Third, it was not clear whether more tilted head posture and larger NEMG amplitude when conducting two-handed texting task while walking compared to one-handed web-browsing while walking are due to physical demand or different characteristics of applications. This is open to doubt because it cannot be proved in both study 2 and study 3. To prove it, more specific and segmented study design is need. However, using one hand for web-browsing and both hands for texting is universal in our life. Therefore, the discussions for one-handed web-browsing and two-handed texting would be applied for most young smartphone users.

Finally, the measures of variables of three studies were not unified. Study 1 and 2 used same IMU sensor to collect head tilt angle data, however, study 3 used camera-based motion system. Also, the variables that were used to represent the head tilt posture or dynamic head movement (or oscillation) differed slightly throughout three studies. Therefore, it is necessary to standardize data collecting method and variables that could represent them, in unified form.

4.6 Applications

As the global smartphone market is still growing, though its change is getting slower, smartphone use while walking would be worth studying. Also, development of diverse applications and smart devices would extend the research field of smartphone use wiser, and deeper. For those future studies, this thesis research could give a guidance in terms of methods such as measuring criteria and organizing experiment protocol as well as reference values of resulting variables.

The findings of three studies indicates that the use of smartphone may cause neck muscular load, so this thesis could recommend not to use smartphone extensively or during too long period to avoid aggravation of neck muscular symptoms, especially for symptomatic users. Frequent and intensive neck muscular load may exacerbate neck pain, as introduced in the first chapter.

This research also could support for the authorities to devise and determine the policy for health and safety of smartphone users. For example, it could be recommended that smartphones for children or elders should have a risk-prevention application which alerts the awkward postures, gait modifications, or intensive use to users via sensors of smartphone or external devices. It is expected that this thesis research would contribute to reduce risks of musculoskeletal and accidents of smartphone users.

5. CONCLUSION

The aim of this thesis research was to investigate neck muscular load of smartphone users when they using smartphone while walking, by conducting three studies that has gradual objectives. The main findings of three studies were:

1) Young adult smartphone users more tilted their head when using smartphone compared to not-smartphone use period during their 8-hours daily activities;

2) Head tilt posture when using smartphone were found while walking at outdoor and tilt angle was larger when two-handed texting while walking than one-handed web browsing while walking;

3) Head tilt posture and increased neck EMG amplitude were found when one-handed web browsing and two-handed texting while walking, and this indicates the association of smartphone use and neck muscular load.

From those findings, we could conclude that the use of smartphone while walking poses potential risks for the neck musculoskeletal problems due to neck muscular load supported by large head tilt, neck flexion, and muscle activation of the neck extensors. Users tilted the head as much as they did when using a smartphone in standing, and the walking would add dynamic biomechanical loads to the static load from the head tilt. In addition to the neck musculoskeletal problems, smartphone use could lead to gait stability and safety issues. Although there were some limitations in studies and vague explanation, the findings of this thesis research would contribute to give a guidance for future studies and deciding policies for health and safety of smartphone users.

In conclusion, this research advanced our understanding of smartphone use and potential risks of smartphone users' neck muscular load, especially when they were walking. The scope of this research focused on dashed arrow to cervical/neck muscular load from smartphone use while walking in the potential risk factors model (Figure 5), which is boxed area of Figure 14. I hope that future researches would prove the assumed path and change dashed line to solid line, and completion of model would advance deeper understanding of potential risks of smartphone users, contributing health of smartphone users.

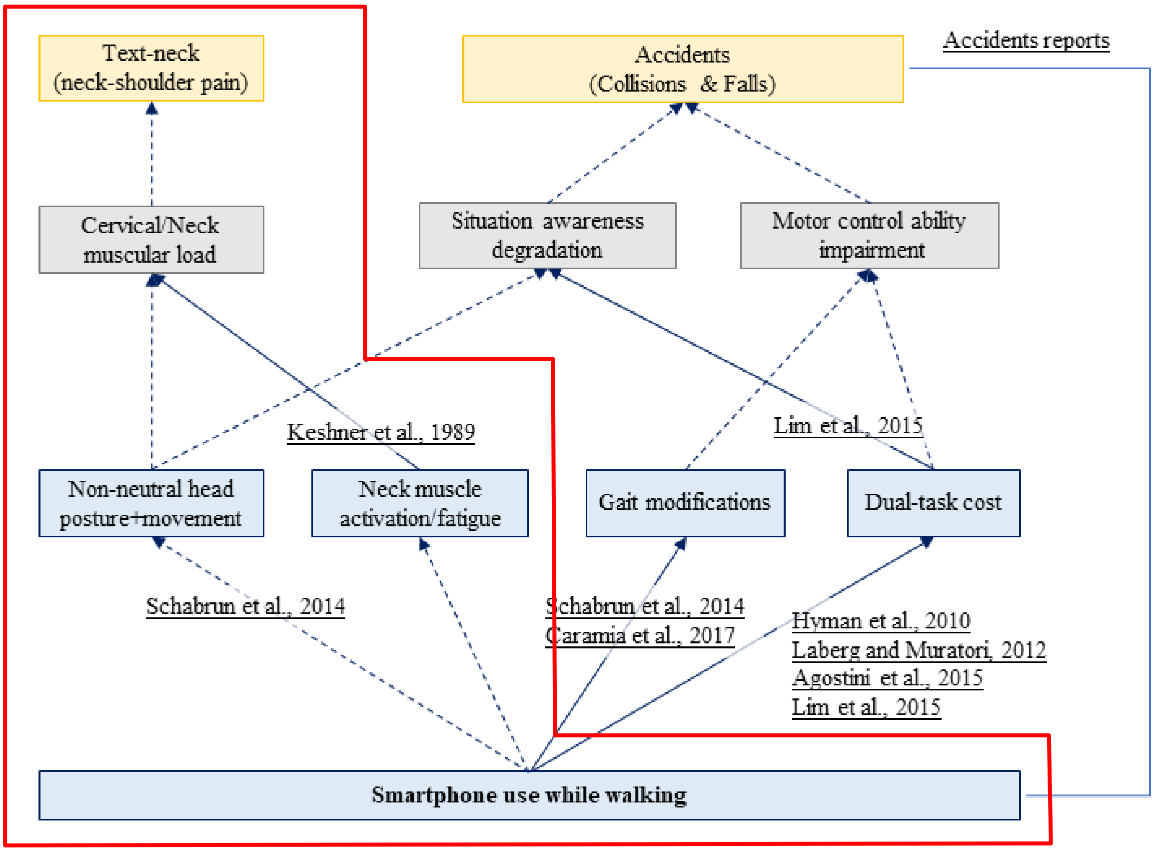


Figure 14. Scope of thesis research among potential risk factors model. Revised from Figure 5.

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APPENDICES

APPENDIX A : Results of study 1

a. Mean, CI and effect size of head tilt angle when smartphone was turned on and off

Variable		Mean	CI	Effect size
10th percentile	ON	11.2	1.8	3.2
	OFF	6.4	1.5	
50th percentile	ON	32.3	3.2	4.84
	OFF	20.2	2.5	
90th percentile	ON	52.4	2.8	1.92
	OFF	45.1	3.8	

APPENDIX B : ANOVA results of study 2

a. Head tilt angle

10th percentile					
Source	DF	SS	MS	F-value	P-value
task	2	26494.9	13247.4	385.11	<0.001
subject	27	3126	115.8	3.37	<0.001
Error	54	1857.6	34.4		
Total	83	31478.5			

50th percentile					
Source	DF	SS	MS	F-value	P-value
task	2	25010.27	12505.13	371.71	<0.001
subject	27	3348.01	124	3.69	<0.001
Error	54	1816.67	33.64		
Total	83	30174.94			

90th percentile					
Source	DF	SS	MS	F-value	P-value
task	2	22723.03	11361.51	355.49	<0.001
subject	27	3764.17	139.41	4.36	<0.001
Error	54	1725.86	31.96		
Total	83	28213.06			

b. Head vertical range

Source	DF	SS	MS	F-value	P-value
task	2	34.5801	17.29	48.05	<0.001
subject	27	41.904	1.552	4.31	<0.001
Error	54	19.4297	0.3598		
Total	83	95.9138			

APPENDIX C : ANOVA results of study 3

a. NEMG of Splenius at dominant side

10th percentile					
Source	DF	Adj SS	Adj MS	F-Value	P-Value
Subject	20	4.9464	0.24732	6.06	<0.001
Task	1	0.5087	0.50868	12.47	0.002
Error	20	0.8161	0.0408		
Total	41	6.2711			
50th percentile					
Source	DF	Adj SS	Adj MS	F-Value	P-Value
Subject	20	10.1245	0.50623	10.77	<0.001
Task	1	0.5796	0.57965	12.33	0.002
Error	20	0.9402	0.04701		
Total	41	11.6444			
90th percentile					
Source	DF	Adj SS	Adj MS	F-Value	P-Value
Subject	20	20.9785	1.0489	7.36	<0.001
Task	1	0.9827	0.9827	6.9	0.016
Error	20	2.8488	0.1424		
Total	41	24.81			

b. NEMG of cervical erecter spinae at dominant side

10th percentile					
Source	DF	Adj SS	Adj MS	F-Value	P-Value
Subject	20	3.1105	0.15552	11.04	<0.001
Task	1	0.1127	0.11271	8	0.01
Error	20	0.2818	0.01409		
Total	41	3.505			

50th percentile					
Source	DF	Adj SS	Adj MS	F-Value	P-Value
Subject	20	6.9597	0.34799	14.79	<0.001
Task	1	0.125	0.12505	5.32	0.032
Error	20	0.4704	0.02352		
Total	41	7.5552			

90th percentile					
Source	DF	Adj SS	Adj MS	F-Value	P-Value
Subject	20	12.2953	0.61477	9.74	<0.001
Task	1	0.1131	0.11312	1.79	0.196
Error	20	1.2618	0.06309		
Total	41	13.6703			

c. NEMG of Splenius at non-dominant side

10th percentile					
Source	DF	Adj SS	Adj MS	F-Value	P-Value
Subject	20	8.083	0.40415	4.54	0.001
Task	1	1.179	1.17946	13.24	0.002
Error	20	1.781	0.08906		
Total	41	11.044			

50th percentile					
Source	DF	Adj SS	Adj MS	F-Value	P-Value
Subject	20	6.9597	0.34799	14.79	<0.001
Task	1	0.125	0.12505	5.32	0.032
Error	20	0.4704	0.02352		
Total	41	7.5552			

90th percentile					
Source	DF	Adj SS	Adj MS	F-Value	P-Value
Subject	20	35.033	1.7516	16.34	<0.001
Task	1	2.264	2.264	21.12	<0.001
Error	20	2.144	0.1072		
Total	41	39.441			

d. NEMG of cervical erecter spinae at non-dominant side

10th percentile					
Source	DF	Adj SS	Adj MS	F-Value	P-Value
Subject	20	3.661	0.18305	1.9	0.08
Task	1	0.985	0.98499	10.22	0.005
Error	20	1.927	0.09635		
Total	41	6.573			
50th percentile					
Source	DF	Adj SS	Adj MS	F-Value	P-Value
Subject	20	8.361	0.418	1.39	0.232
Task	1	1.918	1.9183	6.39	0.02
Error	20	6.001	0.3		
Total	41	16.28			
90th percentile					
Source	DF	Adj SS	Adj MS	F-Value	P-Value
Subject	20	19.686	0.9843	1.97	0.069
Task	1	2.604	2.6045	5.22	0.033
Error	20	9.979	0.4989		
Total	41	32.269			

e. Mean head tilt angle

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Subject	16	3216	200.99	4.42	<0.001
Task	2	9581	4790.41	105.33	<0.001
Error	32	1455	45.48		
Total	50	14252			

f. Head-phone horizontal distance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Subject	16	0.057672	0.003605	12.96	0
Task	2	0.007123	0.007123	25.62	0
Error	32	0.004449	0.000278		
Total	50	0.069245			

g. Head-phone vertical distance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Subject	16	0.06208	0.00388	14.94	0
Task	2	0.001009	0.001009	3.89	0.066
Error	32	0.004155	0.00026		
Total	50	0.067244			

APPENDIX D : Effect sizes

a. Effect size of head tilt angle in three studies

	Study 1	
	smartphone ON - OFF	
10th percentile	3.20	
50th percentile	4.84	
90th percentile	1.92	
	Study 2	
	web browsing - OFF	texting - OFF
10th percentile	4.61	5.78
50th percentile	4.62	5.67
90th percentile	4.25	5.19
	Study 3	
	web browsing - OFF	texting - OFF
Median value	5.46	7.17

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