Muscle Fatigue and Head Flexion Angle Analysis while using Smartphone

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Abstract. With the introduction of smartphones, the frequency of usage gradually increased when compared with keypad phones. The statistics show that the number of smartphone users in India alone increased from 200 million to 400 million in 2015 – 2019. In general, most of the young adults spend an average of 3 to 4 hours daily. The extensive usage of a smartphone causes various disorders, including cervical/neck pain, shoulder pain. The objective is to measure and correlate the relationship between muscle fatigue and the head flexion angle. Also, to analyze the posture using RULA analysis. By utilizing both subjective evaluations through web-based survey and objective evaluation by using both mechanical sensors such as Gyroscope for neck angle measurement and biomedical sensors such as EMG sensor for muscle activity for 14 subjects of age 17 to 26. Head posture, including flexion angle, will be measured, and muscle activity will be observed while using a smartphone in a sitting posture for 1 hour. Expected to understand the correlation between head angle and muscle fatigue while using a smartphone.

1. Introduction
The Introduction of the smartphone is a breakthrough in human history. Smartphones are one which can do much work like a computer. A smartphone can access the internet quickly and can be used for many applications like to watch videos, listen to music, social media, and gaming. In the past two decades, the development of technology is very high, which led to the invention of the smartphone in the year 1992 by a company called IBM. Then the Blackberry Company started the production of the first generation of smartphone, later the companies like Apple, Samsung, Nokia came into the smartphone manufacturing business, where the sales and usage of smartphones increased exponentially. In general, nearly 2.7 billion people of the total world population are estimated to use smartphones. Statistics show that in India alone, the number of smartphone users increased in 2015-2019 from 200 million to 400 million users [1]. The major cause for the increase in the number of smartphone users is because of various features in the smartphone, easy accessibility, user-friendly interface, which also provides excellent security for the user.

Despite having more advantages, smartphones have their disadvantages. Smartphones affect our physical and mental health which causes visual, muscle and mental fatigue [2-4]. Blue light which is emitted by smartphone affects the human eye causes a reduction in blink rate, dry eyes, and it also reduces the sleeping time of an individual [5]. The extensive usage of smartphones leads to discomfort or pain in the neck, shoulder, wrist and fingers, which causes various medical conditions such as Text
neck, Cubital tunnel syndrome [6]. Utilizing a smartphone while walking causes more flexion angles of the head, which leads to more load acting on the head and neck [7]. Smartphone and social-media addiction cause stress, anxiety, and depression which affects social behaviour by reducing the interaction with other individuals [8]. It is necessary to study on fatigue caused by a prolonged period of smartphone usage to minimize the adverse effects caused.

H. Han and G. Shin [7] studied smart phone users head flexion angle under three different walking conditions. They have measured the angle using Inertial Measurement Unit sensor (IMU). They concluded that the head flexion angle is significantly larger while texting with both the hands also more significant load acts on the neck while using mobile with both the hands. H. Han et al. [9] aimed to associate head tilt angle and duration of the posture while using a smartphone. The IMU sensor was attached to the forehead for 31 college students; their head posture recorded for 8 hours on a typical working day. They found there was a significant increase in head tilt angle while using smartphones. This study provides there is an association between smartphone usage duration and intensity of head tilt down. Yan Fei Xie et al. [10] conducted the study to compare three types of texting in smartphone users with chronic neck-shoulder pain. The users with and without chronic neck pain-shoulder pain performed texting with one hand, with both hands and typing on a computer. IMU sensor used to examine the three-dimensional spinal kinematics. The study shows that cervical flexion increase with two-handed texting and asymmetric neck posture correlated with one-handed texting. J. W. Machangpa and T. S. Chingtham [11] designed a wheelchair that can be controlled by the head movement for Quadriplegic patients. Ultrasonic, Gyroscope and Accelerometer sensors used for navigating, detecting obstacles, operated by the head gesture. The Head movement sensed by using Accelerometer and gyroscope, which enables the movement of the wheelchair.

M. Smulders et al. [12] studied on neck posture and muscle activity of the passenger in a reclined aircraft seat with and without headrest. Muscle activity monitored using Surface Electromyogram (SEMG), the participants subjected to three conditions, and there was no significant variation found between with and without head support. There was a significant variation in comfort rating. P. Areeudomwong et al. [13] conducted a study to measure the effects of shoulder taping on neck discomfort while using a smartphone on a numerical rating scale. Twenty-five participants were subjected to two conditions, texting with single and both hands for 30 minutes, tapping across shoulder muscle and no taping. The muscle activity monitored using SEMG. The results show that taping reduced discomfort.

S. Lee et al. [14] studied the head flexion angle while texting using a smartphone. The study conducted on 18 students, they were asked to use a smartphone in sitting and standing posture. The head flexion was measured by attaching markers to forehead and neck, were tracked using motion capture cameras. The study shows that there was significantly larger head flexion while sitting than standing. Longyin Wen et al., [15] conducted a study to understand the effect of Multi-Object Detection Influence in Multi-Object Tracking. They took 100 real-time videos recorded by Canon EOS 550D camera, and the videos recorded in 25 frames per second. They ran their Detection and Tracking algorithm (UA-DETRAC dataset). They analyzed and concluded that Multi-Object Detection affects Multi-Object Tracing performance. They suggested designing an algorithm to combine both MOD and MOT, which can perform simultaneously.

The algorithm which the authors developed has an average accuracy of 54.32 percentage. They concluded the paper by suggesting to improve training for the machine to increase the accuracy. S. Dockrell et al. [16] conducted a study on the reliability of RULA for the assessment of children's computer-related posture. The video recording of 24 school children using the computer on the usual working condition collected. The RULA scores were given based on the video. The study shows that RULA was more reliable for assessing older children than younger children. Kenneth K. Hanraj [17] conducted a study on the spine and concluded that the force was acting on spine increases when the head flexed. The force calculated by taking average head weight as 10-12lbs. The calculations made at 15, 30, 45, 60, respectively. At 15 force acting on the cervical spine is 27lbs, at 30 it is 40lbs, at 45 it is 49lbs, and at 60 the force acting was 60lbs. The author concluded the paper by showing the force
acting on cervical spine increases during head flexion; thus, it causes more stress. These stress may lead to a new tear, degeneration, wear and surgeries.

G. M. Damasceno et al. [18] performed a subjective analysis to find the relation between smartphone usage and neck pain. The participants are of age 18-21. They have developed a questionnaire to analyze the relationship between smartphone usage and neck pain. Akoi k and Edward Downes [19] surveyed college students on how mobile phone influences than in psychological and behavioural changes. For a group of 32 students, four focus group interview was carried out. Based on the interview session, a questionnaire was developed, and 137 students completed the questionnaire. Questionnaire consist of behavioural questions like their frequency of call and time spent on the mobile phone. The answers were analyzed. The authors concluded the paper by recommending to increase the target population for better analysis.

Many research has been carried out throughout the world; however, with the author’s knowledge, the studies related to smartphone and muscle fatigue is virtually zero in India. Hence, this paper mainly concerned with analysis the muscle fatigue and head flexion angle while using a smartphone for a prolonged period. Hence, in this paper, an extensive literature survey was conducted to understand the effects caused by extensive smartphone usage. Also, this study analyzes the methods available to measure head posture and neck-muscle fatigue. This study proposes a portable and low-cost experimental setup to measure head flexion angle and muscle fatigue. The paper organized as follows, in Section 2, we have a methodology. Experimental setup and procedure will be described in Section 3. Finally, we present some experimental results and conclusion in Section 4 and 5, respectively.

2. Methodology
In this experimental study, the head flexion and muscle fatigue were analyzed based on subjective and objective evaluation. The methodology of this study explained in Fig 1. With the help of subjective analysis, the parameters were fixed, measuring techniques, the sensors and the other equipment to be used are decided. A gyroscope sensor and EMG sensor values are obtained through Arduino, the head flexion angle found using a camera, and the values are obtained using python. The angle and EMG values obtained in Arduino and the angle values from python are stored in excel with the help of python codes. The RULA scores are provided concerning angle data.

2.1. Subjective Evaluation
The subjective evaluation was conducted through Google form among students aged between 17 to 26 years. The questionnaire includes sociodemographic data, their medical conditions, visual problems, musculoskeletal disorders. Also, questions about their smartphone usage, average time spent on smartphones and maximum usage content, body posture maintained, single or both hands, uneasiness felt while using a smartphone. Based on the responses from 95 students, the parameters were sorted for the experiment. Some of the responses from students are shown in Figure 2 - 4. From the responses, the parameters for the experiment were finalized like age of subjects from 17 to 26 years, playing a game with two hands in sitting posture for 1 hour duration.
Figure 1. Study Methodology.

Figure 2. Average time spent on mobile per day (95 responses).
2.2. Objective Evaluation

The objective evaluation parameters were concluded from the subjective analysis. The experiment was conducted for 14 subjects of 17-26 years of age. The subjects demographics details presented in Table 1. Electromyogram (EMG) sensor attached (Fig. 5) in the neck extensors muscle to observe the neck muscle activity. Gyroscope sensor is placed at the top of the head with the help of a cap to measure the head flexion angle. A camera placed 1 meter away from the subject. The Open CV method used to measure the head flexion angle, which is an extra validation for the gyroscope. Posture analysis is done with the help of RULA, and it was used to assign a score for head flexion angle. Higher the RULA score higher the stress acting in the neck region. Lower the RULA score denotes less amount of stress acts in the neck region.

Table 1. Subjects Demographics Details.

| Details          | Age in years | Height in cm (Avg±SD) | Weight in kg (Avg±SD) |
|------------------|--------------|-----------------------|-----------------------|
| Number of subjects = 14 | 22.36 ± 1.74 | 174 ± 5.29 | 72.86 ± 14.75 |

Figure 3. Neck/Shoulder Pain experienced while using a smartphone (95 responses).

Figure 4. Pain level while using a smartphone (95 responses).
2.2.1. **Sensors.** EMG Sensor (Muscle sensor AT-04-001) was used for measuring muscle activity. This sensor detects the electrical signal generated whenever there is muscle movement. It helps to analyze the biomechanics of the human or the animal movement. Gyroscope Sensor (MPU-6050) used to monitor and measure the orientation. It can measure the tilt and lateral orientation of the object. This sensor combines a 3-axis gyroscope and a 3-axis accelerometer with an onboard Digital Motion Processor. The dimensions are 4 mm x 4 mm x 0.9 mm. Arduino UNO is a type of open-source electronic microcontroller board which used for building electronic gadgets. It consists of both the physical programmable circuit board and software that runs on a computer. The board equipped with sets of analogue and digital input & output (I/O) pins which interfaced to various expansion boards and other circuits. The camera used to capture the real-time video and process it in OpenCV. It is an open-source computer vision (OpenCV) and machine learning software library. It is used for image processing, and identify the tilt angle between head and neck.

2.2.2. **RULA.** The Rapid Upper Limb Assessment (RULA) method is an ergonomics assessment tool used to calculate the postural risks loading within the upper limbs and neck. This analysis used to lower work-related injuries. It has a simple scoring method with an action level output that identifies an indication of urgency. The RULA score table presented in Figure 6. Nevertheless, it does not consider the duration of the task, available recovery time, or hand-arm vibration.

![Fine Wire Sites: Surface Sites:](image)

**Figure 5.** Surface site for SEMG placement, Picture credit [20].

**Figure 6.** RULA score chart, Picture credit [21].
3. Experimental Setup

![Experimental Setup Diagram]

The Gyroscope sensor and EMG sensor are connected to Arduino UNO microcontroller, which gives the head flexion angle data and muscle activity data of the neck, respectively. The camera used to monitor the real-time head flexion angle with the help of image processing techniques OpenCV. These data are recorded in an excel sheet using python codes. Data from the excel sheet are then analyzed. Posture analysis for different angles is done with the help of RULA. The outlook of the overall experimental setup presented in Fig 7.

![Measurement Environment/Scene Diagram]

Figure 7. Experimental Setup.

Figure 8. Measurement environment/scene.
The participants were asked to sit in an office chair with hands rested in their comfortable position. The white background arranged for precise observation of head tilting. The camera was placed at a distance of 1 meter from the subject (refer Figure 8). The head movements were recorded using a camera with image processing techniques like OpenCV. Also, the EMG electrodes for measuring the muscle fatigue are attached to neck muscle, and the gyroscope is attached over the head to measure head flexion angle. An Arduino board was utilized to record data from the sensors and process through python and store the data in an excel sheet. Also, the RULA scores were taken accordingly for those angles.

3.1 Procedure
The experimental study was conducted on 14 healthy individuals in an office environment. The experimental procedure explained briefly to the subjects. The participants were asked to sit in the chair with their comfortable posture and wearing the given cap attached with the Gyroscope sensor. Then the area of electrode placement was cleaned by removing oils, lotions and other pollutions. The two measuring electrodes were attached to the neck muscle belly, and a reference electrode was placed in a bony area, the EMG sensor was attached to the electrodes. The muscle location for attaching the EMG electrode, shown in Fig 5. Both the sensors were connected to a laptop through cable for power supply and data transfer. The markers were attached to the cap and the neck of the participant for angle measurement using a camera, image processing through OpenCV. The camera was placed in a distance of one meter and 0.8 meter height. Next, the subjects neck muscles maximum voluntary contraction (MVC) measured for normalization. During the MVC measurement, the participants need to apply the maximum possible force (head forward movement) against the opposing force. The opposing force created by a band attached to the right support. The MVC measurement carried for 10 sec. After the MVC measurement, the participants were rested for 15 min. Then, the participants were provided with a smartphone of 5 inches display and instructed to use the smartphone using both the hands for one hour with pre-decided gaming content. The python program was initiated, and the neck posture was monitored using OpenCV. The outputs from both sensors and the image processing technique were collected and stored in an excel sheet. The experiment was done for one hour.

The output from the EMG is rectified and filtered with some high pass filters. The acquired signal was filtered in such a way that the average value will not be equal to zero, then it is rectified from noise and error signals. The rectified and filtered signal is then normalized using the MVC normalization calculation (Eqn. 1) [22]. After the experiment, the participants were subjected to answer some questionnaire regarding their experience.

\[
\text{EMG} \% = \left( \frac{\text{Task EMG} - \text{Rest EMG}}{\text{MVC EMG} - \text{Rest EMG}} \right) \times 100
\]  

4. Results & Discussion
The present work is to analysis muscle fatigue caused due to prolonged period of smartphone usage among younger adults. Various parameters have been measured and analyzed for all the subjects. For this paper, we are presenting the sample results of a subject.

4.1. Raw muscle activity (RMS) during a prolonged period of smartphone usage
The variation in Muscle Activity for 1 hour is plotted in the graph (Fig.9). Here, the muscle activity denotes RMS value. From Figure 9, we can understand that as time increases the muscle activity also gradually increases. The increase in muscle activity of the neck is from 150 µV to nearly 480 µV. From the literature, we could understand that increased RMS leads to muscle fatigue [13]. Hence, we could understand how prolonged usage of a smartphone causes fatigue in neck muscles.
Figure 9. Raw muscle activity (EMG) during one-hour smartphone usage.

4.2. Normalized muscle activity (RMS) during a prolonged period of smartphone usage

The Raw EMG data is normalized using Equation 1. The purpose of normalization to compare the muscle activity between subjects. Because the muscle thickness, volume varies between individuals. Hence, the normalization of muscle activity allows us to compare between subjects. It makes the muscle activity in terms of the percentage of that particular subject. With the help of Normalized EMG-Time graph (Refer Figure 10) we can observe the gradual increase in muscle activity of neck muscles. From 3 percentage the muscle activity reaches nearly 63% after 1-hour smartphone usage while the head is in the flexed position.

Figure 10. Normalized RMS EMG during one-hour smartphone usage.
4.3. Flexion angle during a prolonged period of smartphone usage

From the Angle-Time graph, change in head flexion angle is visible. The variation in head flexion angle for 1 hour is plotted in the graph (refer Figure 11). Angle above 0° denotes Head Flexion & Angle below 0° denotes Head Extension. The increase in head flexion angle increases the muscle activity in the neck region, and it leads to muscle fatigue after long term usage of the smartphone. Prolonged smartphone usage with increased head flexion angle causes muscle fatigue in neck muscles, which can be understood with the help of Angle-Time graph (refer Figure 11) and EMG-Time graph (refer Figure 10).

The force acting on the neck (C7) is a critical parameter to study fatigue and discomfort. Hence, we have calculated the force acting on C7 when subjects using the smartphone for a prolonged period as well as flexed posture. The calculation based on the literature [17]. From Figure 12, we can observe that the load/force acting on head increases, when head flexion angle increases. The load/force acting on neck is 6.32 kg, 13.09 kg, 19.45kg, 23.83 kg and 89.19 kg at 0°, 15°,30°, 45° and 60° respectively. If the individual maintains increased head flexion while using smartphone causes a large amount of load/force to act on the neck. So, the individuals are recommended to maintain a reduced head flexion angle while using a smartphone to reduce the load/force. The increased load due to the change in centre of gravity/mass.

![Figure 11. Head flexion angle during one-hour smartphone usage.](image1)

4.4. Force acting on neck (C7) while using a smartphone for a prolonged period

![Figure 12. Load acting on the neck (C7) at different flexion angle.](image2)
4.5. **Subjective analysis using RULA**

The Posture analysis was done with the help of RULA assessment (refer Figure 11). The scores are mapped according to the RULA chart for the neck. If the head flexion angle is between 0° and 10°, the RULA score is 1. If the angle is in between 10° and 20° the RULA score is two and if the angle is greater than 20° the score is 3. From Figure 13, we can observe that the subject is maintaining an angle above 20° for nearly 1 hour, which means the posture is wrong/high risk according to the RULA chart.

![RULA assessment graph](image)

**Figure 13.** RULA assessment graph.

5. **Conclusion**

This study mainly concerned with analysis the muscle fatigue and head flexion angle while using a smartphone for a prolonged period. An extensive literature survey was conducted to understand the effects caused by extensive smartphone usage. Also, this study analyzes the methods available to measure head posture and neck-muscle fatigue. This study proposed a portable and low-cost experimental setup to measure head flexion angle and muscle fatigue. This study only considered one muscle and a particular smartphone. Also, consider using two-hand, sitting posture for one hour. However, in real-time, users may follow different body postures and movements, including single-hand usage, different smartphone size, various content and time duration. So future study, with this methodology considering many subjects and experiment to get a clear idea about muscle fatigue and head flexion angle while using a smartphone.

6. **References**

[1] Madhumitha J 2019) Number of Smartphone users in India 2015-2022 [https://www.statista.com/statistics/467163/forecast-of-smartphone-users-in-india/](https://www.statista.com/statistics/467163/forecast-of-smartphone-users-in-india/) Accessed 04-06-2020

[2] Lee JH and Song JK 2012 Individual variation in 3D visual fatigue caused by stereoscopic images *IEEE transactions on consumer electronics* **58** 500-4

[3] Xie Y, Szeto G and Dai J 2017 Prevalence and risk factors associated with musculoskeletal complaints among users of mobile handheld devices A systematic review *Applied ergonomics* **59** 132-42
[4] Bodin T, Berglund K and Forsman M 2019 Activity in neck-shoulder and lower arm muscles during computer and smartphone work International Journal of Industrial Ergonomics 74

[5] Oner M 2018 Measure of Visual Fatigue as a Link Between Visual Environment and Visual and Non-Visual Functions of VDT Users a Review on What We have and What We Need In 2018 IEEE International Conference on Environment and Electrical Engineering and 2018 IEEE Industrial and Commercial Power Systems Europe 1-6 IEEE

[6] Toh SH, Coenen P, Howie EK and Straker LM 2017 The associations of mobile touch screen device use with musculoskeletal symptoms and exposures A systematic review 12

[7] Han H and Shin G 2019 Head flexion angle when web-browsing and texting using a smartphone while walking Applied ergonomics 81

[8] Park S, Yi J, Choi D, Lee S, Kyung G, Choi B, Lee JE and Lee S 2016 Effects of display curvature and task duration on proofreading task performance, visual fatigue, visual discomfort, and display satisfaction In Proceedings of the Human Factors and Ergonomics Society Annual Meeting 60 790-794

[9] Han H, Lee S and Shin G 2019 Naturalistic data collection of head posture during smartphone use Ergonomics 62 444-8

[10] Xie Y, Szeto GP, Dai J and Madeleine P 2016 A comparison of muscle activity in using touchscreen smartphone among young people with and without chronic neck–shoulder pain Ergonomics 59 61-72

[11] Machangpa JW and Chingtham TS 2018 Head Gesture Controlled Wheelchair for Quadriplegic Patients Procedia computer science 132 342-51

[12] Smulders M, Naddeo A, Cappetti N, van Grondelle ED, Schultheis U and Vink P 2019 Neck posture and muscle activity in a reclined business class aircraft seat watching IFE with and without head support Applied ergonomics 79 25-37

[13] Areeudomwong P, Oapdunsalam K, Havicha Y, Tantai S and Buttagat V 2018 Effects of shoulder taping on discomfort and electromyographic responses of the neck while texting on a touchscreen smartphone Safety and Health at Work 9 319-25

[14] Lee S, Kang H and Shin G 2015 Head flexion angle while using a smartphone Ergonomics 58 220-6

[15] Wen L, Du D, Cai Z, Lei Z, Chang MC, Qi H, Lim J, Yang MH and Lyu S 2015 UA-DETRAC: A new benchmark and protocol for multi-object detection and tracking arXiv preprint arXiv:1511.04136

[16] Dockrell S, O’grady E, Bennett K, Mularkey C Mc connell R., Ruddy R and Twomey S Flannery C 2012 An investigation of reliability of Rapid Upper Limb Assessment (RULA) as a method of children’s computing posture Appl Ergon 43 632-6

[17] Hansraj KK 2014 Assessment of stresses in the cervical spine caused by posture and position of the head Surg Technol Int 25 277-9

[18] Damasceno GM, Ferreira AS, Nogueira LA, Reis FJ, Andrade IC and Meziat-Filho N 2018 Text neck and neck pain in 18–21-year-old young adults European Spine Journal 27 1249-54

[19] Aoki K and Downes E 2002 Cell phone usage An analysis of users' subjective responses in the adoption In IEEE 2002 International Symposium on Technology and Society Social Implications of Information and Communication Technology Proceedings171-177 IEEE

[20] Konrad P The ABC of EMG: A practical introduction to kinesiological electromyography
[21] https://ergo-plus.com/wp-content/uploads/RULA-A-Step-by-Step-Guide1.pdf Accessed 04-06-2020

[22] Subramaniyam M, Min SN, Park SJ and Park S 2015 Muscle activity and spinal loading in lifting symmetrical loads beside the body compared to in front of the body *Journal of Mechanical Science and Technology* **29** 5075-81