Visual Flow on Eye-Activity and Application of Learning Techniques for Visual Fatigue Analysis

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Abstract. All Smartphones have become a necessity rather than a utility. Not a single person can deny that our mobile phones go wherever we go. Phones were created as a means for more accessible communication over distance. The purpose of a phone has dramatically changed over the years by the technology advancement and the arrival of smartphones which provides many applications and make us stick to it. This study understands the correlation between the activity of eyes and flow level of the eye. Also, how the visual activity parameters are calculated will be discussed. This study enhances the understanding of visual fatigue caused due to the digital medium. Examine the subject's eye flow level with smartphone and VDT utilisation. Besides, the application of learning algorithms, including machine learning/deep learning is massive with regards to analysing visual fatigue. The purpose of this study also going to discuss the application of both machine learning and deep learning on analysing visual fatigue caused by Digital Medium.

1. Introduction
Technology plays a massive role in our lives. It is used for communication, education, entertainment, interaction, and more. Most schools are insisting students have personal laptops, and education will surround the fact that everything students do is on their laptop. Now, because a lot of the new technological gadgets around, we will move away from paper and notebooks. Specifically, in the current lifestyle, many people misuse the opportunity they get to do nothing and sit home and play videogames all day. However, the other side of the spectrum has much room. People with creativity can use these new techniques to start a business, get people moving, or start something that lets more people do less to survive. Technology will be attached to everyone's lifestyle in these upcoming years, and it led to more innovative organisations to increase people's likely-hood for success. 

The computer is essential to compete in today's world. Having a computer does have many benefits, including access to comprehensive information, interact with others from anywhere on earth, online education, online shopping, the list goes on. Also, to get a job these days, it's becoming increasingly more expected that you have a home computer or necessary computer skills. In 2005 there are 16% of the total population utilises a computer but by 2019 it increased to 49.7%; similarly, the number of internet users in India are 525.3 million, whereas in the world are 4.39 billion [1, 2].

The prolonged utilisation of any digital medium won't damage physically but yes to an extent pretty much make you incapable of your sight or vision after a few years. Well! Using a computer for the long-time duration has considerable side effects on the eye such as eyestrain, difficulty focusing,

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blurred vision, changes in colour perception, dryness in eyes, itching, headaches, eye discomfort. Blinking of eyes circulates the tears in the eyes, which provides moisture to the eyes by the lubricant they secreted. A healthy human being blinks for every 4 seconds that is an average of 15 blinks for each minute, and each blink lasts for a period of 1/10th of second. Also, the blink rate varies from time-to-time and person-to-person. The blink rate was estimated at 8 to 21 blinks for each minute; however, it changes to an average of 10 to 32 blinks, when a subject is engaged in any work or conversation. It further reduces to 4 blinks while watching a video or reading in a Video Display Terminal (VDT). This reduction in blink-rate leads to computer vision syndrome or digital eye strain [3]. Even the sitting posture for longer duration in front of computer causes various musculoskeletal disorders [4]. It is very much needed to reduce strain on your eyes after using for 1–2 hours. Recommended to take an interval of 10–15 minutes if working for a continuous 8–9 hrs, use special eye-protective coating [5]. However, it's better to use the computer for a limited time so that it has not any adverse impact on Eyes.

2. Methodology
The literature review procedure consisted of exploring the scientific search engines namely PUBMED, Google Scholar, IEEE explorer, Science Direct to identify papers with keywords machine learning, digital eye strain, digital medium, computers, smartphones from the time between 1991 and 2019. Also, relevant conference proceedings are explored. After the initial articles were chosen, they were set to elimination assessment based on the topic relevance of the title, abstract and content. The most relevant papers were selected for a literature review.

3. Literature Survey
3.1. Computer Vision Syndrome
F. L. Filon, et al., [6] studied on subjects for psychosocial and visual symptoms and its factors of fatigue for ten years from 2000-2009 with frequent medical examinations to eyes. They identified the visual fatigue factors in the span of these ten years for VDT utilisers. Noticed, 64% of utilisers got effected with these visual fatigue symptoms. They experimented on 3054 subjects who are utilising any kind of computer or laptop for more than 20 hours per week. They conducted a subjective assessment in three sections where the initial one consists of 59 sociodemographic data, the second section consists of subject's health-related information, and the last section consists of eye-symptoms and the blink frequency with level discomfort of each symptom. For repeated measure ANOVA, they applied t-pair test and t-student test followed by a chi-square test. The correlation between visual fatigue and its symptoms with the other sociodemographic information is examined utilising univariate regression and Pearson correlation. They found that Visual fatigue is correlated with duration of digital medium utilisation, psychosocial factors, and it is not related with seniority of work, visual acuity, sex, age. Chao-Wen Lin, et al., [7] examined visual field lighting and reflected glare effect on digital eye strain. They experimented on 30 subjects of 20-35 years age group under three sections of visual field lightening experimentation, reflected glare experimentation and observing the pupil size before and after at different lightening conditions. They considered subjects with no retinal surgery, dry eye syndrome, any other ocular issues and visual acuity less than 6 in both myopia and hyperopia conditions. They evaluated near and distant heterophoria, critical fusion frequency utilising Handy flicker device. The reduced critical fusion frequency indicated workload and eye fatigue. The pen and paper-based questionnaire data were collected before the experiment of both visual field lightening and reflected glare lightening of two different sections of dark-colored text on a white background or environment and similarly white-colored text on dark background. They observed uneven or dim lightning conditions significantly affect the fatigue levels, which leads to variation in pupil diameter. Also, by utilising proper or uniform lightening conditions can prevent eye damage, reduce the fatigue levels and variation in pupil diameter. Seung-Nam Min, et al., [8] investigated on eye's flow level, eye activity and factors related to it with three different games in a smartphone. They examined on 25 subjects of 26-31 years old with no vision issues or surgeries in the past 6 months of the experimentation. They utilised FaceLab 5 device and FaceLab 5.0.2 software for eye tracking,
which measures the duration of blinking and pupil diameter. They utilised only one smartphone of a 4.3-inch display screen with the same brightness throughout the experimentation of all subjects and also taken questionnaire data which is based on a flow index of flow state scale. The eye data were collected for three types of games like coloring, dot-to-dot and puzzle with two levels like the initial and final stage, where the initial stage is for the first ten seconds of the gameplay, where the final stage is last ten seconds of the gameplay. The authors identified duration of blinking, blink rate and pupil diameter as the most influential factors of eye flow level. They collected both the subjective and objective data and performed ANOVA analysis. Observed that blink duration is not affected by either game type or play, blink rate is affected by game type but not game time, but pupil size is significantly affected by both gameplay and time. Also, dot-to-dot has the lowest flow level of eye and puzzle size has the highest flow level of an eye than the other two games. Sezen Akkaya, et al., [9] evaluated on eyes tear evaporation and tear production with long term usage of the computer. They experimented on 60 subjects with no eye-related issues of two different group each of 30 members, and the first group spend about eight hours on their computer. In contrast, another group spend only one hour on their smartphone. Every subject was tested twice, at morning 8 AM and evening 5 PM, the index of ocular surface disease and Schirmer test scores were taken. The ocular surface disease index is awarded based on the subjective data with dry eye-related functions and symptoms, whereas in Schirmer test on the lower lid of subject's eye a Schirmer strip was placed and the subject was asked to look and blink normally. Again, into the subject's eyes, a fluorescein solution was dropped, and the subject was asked to blink and look normal. The quantity of drops in both the conditions were recorded to test the dry eye condition. They found the tear stability was low in the first group who utilises computer for eight hours than another group. Also, observed a positive correlation between dry-eye symptoms and incomplete blinks of an eye, and a negative correlation between eye dryness and the number of blinks. F. Leccese, et al., [10] investigate how computer-aided design utilisers and their work are influenced by visual fatigue and its symptoms in normal conditions. They experimented on 150 university students of 72 females and 78 males of age group 20-30 years old with the subjective assessment. It contains the sociodemographic data, number of hours of computer or CAD software utilisation, lightening conditions, screen conditions, the brightness of the screen, the symptoms of visual fatigue, how visual fatigue influences their working conditions and level of visual fatigue experienced. They observed 31% utilises any sort of VDT for 3 to 5 hours, almost 40% of the subjects were utilising any sort of VDT between 6 and 8 hours and 26% utilise it for more than 8 hours. Also, 90% of the VDT users experience more fatigue levels when they utilise CAD application in their VDT than the normal VDT utilisation, which makes 87% of them feel difficult in reading activity on their VDT. They experienced headaches, double vision, blurred vision, red eyes, dryness, itching, watering, burning of their eyes. They concluded that maintaining good brightness levels like ambient lightening can reduce the level of visual fatigue and other symptoms. Maj Gen J.K.S. Parihar, et al., [11] reviewed on symptoms due to the computer vision display and its vision syndrome. They observed various factors of subjects causes more fatigue like myopia induced due to prolonged VDT utilisation like from 0.12D to 1.3D of 0.4D mean. The usage period plays a vital role which is the most influential factor of visual fatigue. The break period of 5 minutes for every 30 minutes has to be provided to reduce the damage of eyes. The authors noticed age and sex are also important factors where the exposure of VDT at an early age leads to more eye strain than people above 30 years old; also symptoms of eye strain and Musculoskeletal disorders are observed more in female than male. The factors of visual fatigue related to device are environmental factors like display type, screen resolution, text color, background and lightening are the major factors of 36.8% symptoms, also height and angle of VDT. The flicker frequency should be between 55 and 90 Hz. Also contact lens wearing VDT utilisers are more susceptible to visual fatigue than normal utilisers, where the symptoms of fatigue observed in contact lens utiliser are 95% and in normal utiliser are 57%. Also, the utilisation of PUFA supplements, lubricating eye drops and avoiding contact lens could reduce the level of risk to eyes. Eric N. Wiebe, et al., [12] examined on a psychometric tool named User Engagement Scale and compared this scale with existing scales for measuring the subject's engagement during gameplay.
They examined 413 subjects of 18 to 66 years old and tested with both scales: flow state scale and user engagement scale. Subjects played an online game named 'block walk' for a minimum period of 10 minutes or a maximum period of 90 minutes, and both flow state scale and user engagement scale subjective assessment were recorded. The user engagement scale consists of 31 items with 6 subscales with a 5-point Likert scale, on the other hand, the flow state scale consists of 36 items with 9 subscales with the same 5-point Likert scale. The authors observed satisfaction, aesthetics, perceived usability and attention as major factors which describe the engagement of the subject with the gameplay in user engagement scale. Also, the user engagement scale was more predictive than the flow state scale in terms of game performance. Simone Benedetto, et al., [13] studied how the luminance effect on visual fatigue during an extensive utilisation of computer for reading. They considered two kinds of luminance ambient illuminance and screen luminance of two levels each high and low. They experimented on 48 subjects of 20-34 years age group were divided into four different batches according to the luminance conditions. An infra-red based eye tracker was utilised to record the eye movements with a 250 Hz sampling rate. Also, the system was calibrated to 9-point before every recording for reliable results. The subjects read in the LCD screen of 22" for 1 hour at 60 cm distance. They measured reaction time, reading speed, saccades, fixations and eye blink duration, pupil diameter and blink rate. The results were analysed utilising ANOVA and noticed that visual fatigue is increased by reading or utilising the computer under high screen illuminances, which also leads to a reduction in blink rate. Also, the performance and alertness of the subject are increased under high luminance or illuminances. Adaptive brightness implementation is the best solution to avoid the damage to the eye and restore the digital reading arousal levels. Gauri Shankar Shrestha, et al., [14] to investigate the major symptoms, visual related problems associated with VDT utilisers in Nepal community. 76 subjects who work on a computer for a minimum of hours per day of both students and staff in a medical institute of different age groups are considered. The questionnaire assessment was recorded, visual acuity test was carried, and other ophthalmic examinations of Schirmer test, accommodative facility, the convergence of near point, positive fusional vergence, cover test, refraction were conducted on each subject. Now, each subject suffers from some of these symptoms, systemic symptom headache, back pain, neck pain, shoulder pain, the visual symptoms are double vision and blurred vision. Ocular symptoms are tired eyes, sore eyes, aching, pain behind eyes, itching, dryness and watery eyes. The authors concluded that all the VDT utilisers have a higher risk of systematic and ocular symptoms; the dryness in eyes is more correlated with the visual fatigue symptoms. Sunny Lin, et al., [15] examined on positive effect and flow experience of online game players. They classified the flow experience in four different classifications apathy, anxiety, boredom and flow. In apathy condition, both skills and challenges of the subject are lower than group mean; in anxiety condition, it requires only challenges but no skills, where boredom is a condition of both challenges and skill are above the group main. In flow condition, all the skill and challenge are in a balanced state. They experimented on 30 subjects of 19 female and 11 male of different age groups for 30 minutes of gameplay. By utilising questionnaire data and analysed utilising chi-square analysis and noticed 42.4% of subjects with flow condition, 28% subject's with boredom and 21% subjects with anxiety condition and remaining subjects in apathy condition. Philipp, et al., [16] developed a technique for detecting drowsiness utilising eye-blink parameters. The authors experimented a subjective assessment on 60 subjects of 16-64 years old before and after the experimentation, which includes sociodemographic data and drowsiness level. The subject was asked to look at a static picture of 25 cm x 35 cm dimensions at a distance of 2-meters for 20 minutes, and no further instructions regarding the eye movement are given. A portable measuring device which consists of an infra-red camera was attached at the side of the painting which is electronically connected to the laptop to identify various blink parameters of eye. The blink parameters include eye closure time, reopening time and blink duration. Arne Aaras, et al., [17] studied how different lightening conditions affect the level of computer vision syndrome or visual discomfort. The experiment was conducted on 50 male subjects and divided them into three different batches, two batches T and S were provided with the new working environment and lightning conditions like 25% light upwards and 75% light downwards with 600 lux and no glare,
whereas the third batch was kept under the same environment and lightening conditions for 2 years. The questionnaire data was recorded and observed batches T and S experience fewer fatigue levels than batch C. Joseph H. Goldberg, et al., [18] developed a technique for analysis of eye movement data with different eye-tracking systems of good and bad. They experimented on 12 subjects of age 20-27 years old on both the trackers. The trackers were adjusted, and the parameters like saccade duration, number of saccades, fixation duration, number of fixations, fixation to saccade ratio and other eye movement data are collected. S. Patel et al., [19] studied on tear stability and blink rate after the VDT utilisation. Experimented on 16 subjects of 17 to 31 years old with no contact lens and other vision-related issues. Here the blink-rate was collected manually by the investigators and noted down for 1-minute, where the tear stability was measured utilising Bausch and Lomb keratometer. The Authors observed while watching VDT the blink rate reduced by an average of 5-fold. However, there is no significant variation in tear stability while utilising VDT.

3.2. Machine Learning Techniques utilised to Identify State of Eye
Jon D. Elhai et al., [20] developed a model for addiction scale of problematic smartphone usage in university students of Chinese community by utilising supervised machine learning techniques. They examined 1097 subjects with age from 18 to 21 years old and 898 female subjects and 199 male subjects. They utilised anxiety and depression as their variables in developing the model, as they are more noticed symptoms in problematic smartphone utilisation. They conducted an online web-based subjective assessment as recorded their responses utilising four different scales, namely ruminative responses scale, fear of missing out scale, depression anxiety stress scale-21 and smartphone addiction scale-short version. With the respondent's data of psychological variables, age, sex, they trained the model by utilising R software with the caret package. They observed that out of all the other scales fear of missing out scale is more robust and reliable scale which responses are more relative in modelling problematic smartphone usage. Sree Sharmila, et al., [21] identified the blink rate of eyes after prolonged utilisation computer with Viola Jones algorithm and Kanade-Lucas-Tomasi algorithm by separating foreground and background with gradient detection technique. In this method, they locate the eyes and identify feature points with successive frames. The edges of the eye are detected utilising gradient detection and background subtraction. Later they fix up one point on the white part of the eye and set the threshold value for calculation of blink rate. They record with some number of frames per minute and observe the blink rate. They utilised inbuilt webcam in the laptop to identify the blink rate and experimented on 50 subjects of age 15-50 years old. Each subject must be experimented after 3 to 4 hours of computer utilisation under good lighting conditions for 30 seconds to 3 minutes. Rui Huang, et al., [22] designed a visual fatigue detection technique based on neural networks and developed a Fatigue detection neural network system. They calculated the fatigue levels of an eye based on blink frequency and PERCLOS. In this system, they capture the video of the eye and identify its fatigue levels. The blink frequency of the normal condition is about 15-30 blinks per minute if the number of blinks reduces to 8 per minute is considered as moderate fatigue and beyond if it reduces to 4 blinks per minute is considered as severe fatigue. Similarly, if PERCLOS is ~0.05 is normal fatigue level, if PERCLOS is ~0.24 is considered moderate fatigue level, and if PERCLOS is ~0.914 is considered as high fatigue levels. Naoto Nojiri, et al., [23] examined driver drowsiness by recognition of eye status with both machine learning and deep learning techniques. In the machine learning technique to extract key features, they utilise histogram of oriented gradients, and for classifying the eye status, they utilise support vector machine technique. The steps involved in machine learning-based recognition are pre-processing the subject image like gamma correction, converting an image to grey-scale and resize the image, then normalisation of an image, later histogram calculation for histogram feature creation. Similarly, in deep learning technique, they utilise Google-Net and AlexNet conventional networks for classifying the status of eyes. The data-sets under different combinations of open-eye, closed-eye, right-eye and left-eye are created. In deep learning there exist various convolutional layers and pooling layers with filters to recognise the state of the eye. Authors observed for open-eye and closed-eye recognition Google-Net technique is better than other available
techniques. For right-eye and left-eye recognition deep learning method is more suitable than other methods which help in identifying the driver drowsiness. Xiaoqing Ding, et al., [24] developed a novel eye extraction method by utilising a contour extraction of an eye. In this method, the eye status is located utilising 16 landmarks which also states the open or closure of eyes. Fat classifiers are utilised for training each landmark of the system, and YALE database was utilised of 2500 training data-set and 500 testing data-sets. Both eye localisation and face detection are performed in this work, where eye position is detected by detecting eye patches using Viola and Jones detector and active shape model of eye contour extraction. Degree of the eye close and open, blink frequency, duration of blinking are considered for eye blink estimation. Shinjiro Kawato, et al., [25] proposed an algorithm for tracking the eye position and extracting the eye status in the real-time video stream. The gaze camera was utilised for tracking eye status, which is placed at 50-100 cm away from the eyes. For tracking the position of the eye, they utilised 'between the eyes' template, which will be updated automatically with the slight movement of eyes with relating to the previous frame. The template 'between the eyes' can run up to 30 frames per second with low hardware requirements and accurate detecting results. Also, to reduce error due to head movement in eye position localisation, head movement cancellation algorithm was implemented, which makes the system more efficient.

4. Summary
As discussed earlier, extensive utilisation of any sort of digital medium leads to vision-related problems which are technically called computer vision syndrome or digital eye strain. The utilisation of VDT for more than one hour leads to various issues like burning, irritation, aching, tiredness of eyes increases and tear film break-up time and blink rate reduces. Also, the detection and prediction of visual fatigue with eye parameters like blink rate and duration utilising machine learning algorithms are more reliable. In machine learning techniques the system is trained with data-set with the convolutional layers and pooling layers which includes performing mathematical operations, reducing the size of the image and conversation from 3D to the 1D image where the specific value is assigned to each image, and the blink rate can be detected in the real-time video stream. Machine learning techniques are incorporated in eye trackers to predict the model of visual fatigue with eye parameters. The combined robust system of both machine learning techniques and biomedical instrumentation is expected as future scope for more validation and reliability of results.

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