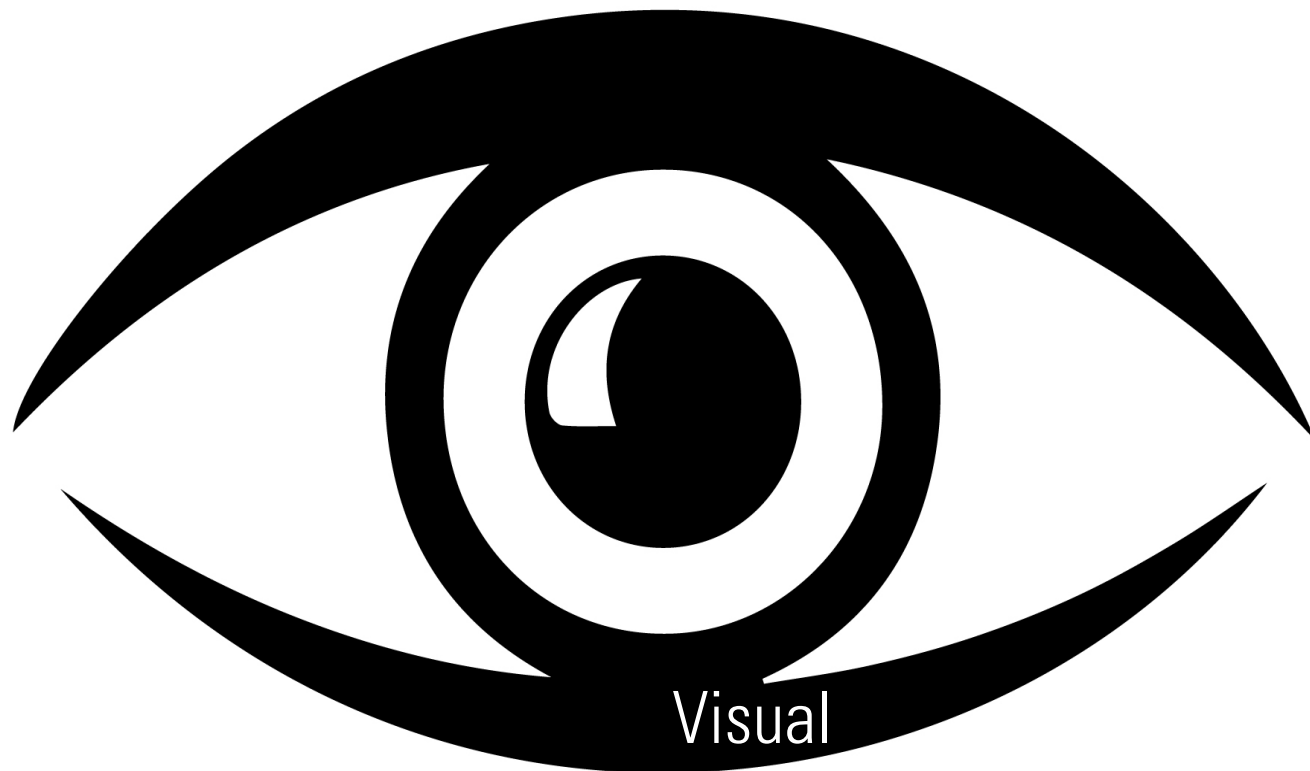




Visual
fatigue
among
computer
users

a literature review by
Rahul kumar Dhanuk



Visual fatigue among computer users, a literature review.

Communication Design
Design Research Seminar

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Industrial Design Centre
Indian Institute of Technology, Bombay
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Declaration

I have adequately cited and referenced the original sources. I declare that I have adhered to all the principles of academic honesty and integrity and have not misrepresented or fabricated or falsified any idea/ data/ fact/ source in my submission.

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Approval sheet

This Design research seminar titled “ Visual fatigue among computer users” by Rahul kumar Dhanuk, is approved for partial fulfilment of the requirement for the degree of Masters of Design in Communication Design.

Guide



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Abstract

This report presents a survey of the available literature related to the present scenario of technical devices and method to quantify visual fatigue, its long term effects on eye due to computer related work, along with psychological and physiological aspects.

Introduction of computer during 1970's gave rise to a lot of stormy controversial debate. Controversies were wide ranging from workplace ergonomics, lighting to health and work stress. The over usage of computers makes adults and children both susceptible to computer related vision symptoms. Performing both important and enjoyable tasks without breaks until near exhaustion may increase eye focussing problems and eye irritations. This calls for Computer Vision syndrome which is a widely spreading but largely unknown epidemic among computer users. It is considered as the top official health related problems. In ancient times human beings used to live in forests and primary occupation was hunting and visual need was to look at distance but now the distance dominant world has suddenly changed to near point world as most jobs are now confined to tables and chairs working on computers and small office boundaries.

Accommodation is the process by which the vertebrate eye changes optical power to maintain a clear image or focus on an object as its distance varies. Accommodation acts like a reflex, but can also be consciously controlled.

Visual acuity (VA) commonly refers to the clarity of vision. It is dependent on optical and neural factors, i.e. (i) the sharpness of the retinal focus within the eye, (ii) the health and functioning of the retina, and (iii) the sensitivity of the interpretative faculty of the brain.

Adaptation in ocular physiology is the ability of the eye to adjust to various levels of darkness and light.

Anaglyph is a stereoscopic photograph with the two images superimposed and printed in different colours, usually red and green, producing a stereo effect when viewed with appropriate filters over each eye.

Aperture is the pupil in the human eye, the. The pupil is a hole located in the centre of the iris of the eye that allows

light to strike the retina. It appears black because light rays entering the pupil are either absorbed by the tissues inside the eye directly, or absorbed after diffuse reflections within the eye that mostly miss exiting the narrow pupil.

Aqueous humor: In medicine, humor refers to a fluid (or semi-fluid) substance. Thus, the aqueous humor is the fluid normally present in the front and rear chambers of the eye. It is a clear, watery fluid that flows between and nourishes the lens and the cornea; it is secreted by the ciliary processes.

Asthenopia is an eye condition that manifests itself through nonspecific symptoms such as fatigue, pain in or around the eyes, blurred vision, headache, and occasional double vision. Giving the eyes a chance to focus on a distant object at least once an hour usually alleviates the problem.

Astigmatism is a common vision condition that causes blurred vision. It occurs when the cornea (the clear front cover of the eye) is irregularly shaped or

sometimes because of the curvature of the lens inside the eye.

Bifocals are eyeglasses with two distinct optical powers. Bifocals are commonly prescribed to people with presbyopia who also require a correction for myopia, hyperopia, and/or astigmatism.

Binocular vision is vision in which creatures having two eyes use them together. The word binocular comes from two latin roots, bini for double, and oculus for eye.

Carpal tunnel syndrome is a chronic pain, numbness, or tingling in the hand, caused by compression of the median nerve in the wrist. It can be caused by repetitive bending and extension of the wrist, as in keyboarding, or by medical conditions such as rheumatoid arthritis and diabetes.

Cataract is a clouding of the lens in the eye which leads to a decrease in vision. Cataracts often develop slowly and can affect one or both eyes. Symptoms may include faded colors, blurry vision, halos

around light, trouble with bright lights, and trouble seeing at night.

Candela per square metre (cd/m²) is the derived SI unit of luminance. The unit is based on the candela, the SI unit of luminous intensity, and the square metre, the SI unit of area. As a measure of light emitted per unit area, this unit is frequently used to specify the brightness of a display device.

Critical flicker fusion(CFF) threshold (or flicker fusion rate) is a concept in the psychophysics of vision. It is defined as the frequency at which an intermittent light stimulus appears to be completely steady to the average human observer.

Ciliary muscle is a ring of smooth muscle fibers that is responsible for changing the shape of the lens in the eye to achieve accommodation. Suspensory ligaments connect the ciliary muscle to the lens.

Conjunctiva is the mucous membrane that covers the front of the eye and lines the inside of the eyelids.

Convergence insufficiency is the inability to maintain binocular function (keeping the two eyes working together) while working at a near distance. Typically, one eye will turn outward (intermittent exotropia) when focusing on a word or object at near.

Cornea is the transparent layer forming the front of the eye.

Correlation coefficient is a number between +1 and -1 calculated so as to represent the linear interdependence of two variables or sets of data.

Cortical is an anatomical term relating to the outer layer of the cerebrum, which is the principal and most anterior part of the brain in vertebrates, located in the front area of the skull and consisting of two hemispheres, left and right, separated by a fissure. It is responsible for the integration of complex sensory and neural functions and the initiation and coordination of voluntary activity in the body.

Cycloplegia is paralysis of the ciliary

muscle of the eye, resulting in a loss of accommodation.

Diathesis is a constitutional predisposition toward a particular state or condition and especially one that is abnormal or diseased.

Diplopia is a disorder of vision in which two images of a single object are seen (as from unequal action of the eye muscles) and is called also double vision.

Edema is an abnormal infiltration and excess accumulation of serous fluid in connective tissue or in a serous cavity which is also called dropsy.

Electroencephalography (EEG) is an electrophysiological monitoring method to record electrical activity of the brain. It is typically non-invasive, with the electrodes placed along the scalp, although invasive electrodes are sometimes used in specific applications.

Electrooculography (EOG/E.O.G.) is a technique for measuring the corneo-retinal standing potential that

exists between the front and the back of the human eye. The resulting signal is called the electrooculogram. Primary applications are in ophthalmological diagnosis and in recording eye movements.

Epidemiological relating to the branch of medicine which deals with the incidence, distribution, and control of diseases.

Epileptic seizure also known as an epileptic fit, is a brief episode of signs or symptoms due to abnormal excessive or synchronous neuronal activity in the brain. The outward effect can vary from uncontrolled jerking movement (tonic-clonic seizure) to as subtle as a momentary loss of awareness (absence seizure).

Epiphora is watering of the eyes due to excessive secretion of tears or to obstruction of the lacrimal passages.

Esophoria is a condition characterised by inward deviation of the eye, usually due to extra-ocular muscle imbalance. If not fixed early, it can lead to blindness later

on in life.

Extraocular muscle (EOM) is any of the six small voluntary muscles that pass between the eyeball and the orbit and control the movement and stabilization of the eyeball in relation to the orbit.

HDTV (High definition television) is a digital TV broadcasting format where the broadcast transmits widescreen pictures with more detail and quality than found in a standard analog television, or other digital television formats. HDTV is a type of Digital Television (DTV) broadcast, and is considered to be the best quality DTV format available.

Hypofunction is decreased or insufficient function especially of an endocrine gland (relating to or denoting glands which secrete hormones or other products directly into the blood).

Keratoconus is a slow, progressive eye disease in which the normally round, dome shaped cornea (the clear outer front portion of the eye) thins and begins to bulge into a cone-like shape. This cone shape is irregular, bending light as it

enters the eye.

Lacrimation is the secretion of tears especially when abnormal or excessive.

Luminance is the luminous (emitting or reflecting usually steady, suffused, or glowing light) intensity of a surface in a given direction per unit of projected area.

Macula is a small yellowish area lying slightly lateral to the center of the retina that is made up mostly of cones and it plays a key role in visual acuity, and has the fovea at its center —called also macula lutea or yellow spot.

Migraine is a condition marked by recurring moderate to severe headache with throbbing pain that usually lasts from four hours to three days, typically begins on one side of the head but may spread to both sides, is often accompanied by nausea, vomiting, and sensitivity to light or sound, and is sometimes preceded by an aura and is often followed by fatigue.

Mucus is a viscid slippery secretion that is usually rich in mucins and is produced

by mucous membranes which it moistens and protects.

Multifocus is an intraocular lens inserted into the eye during cataract surgery that gives the wearer clear vision at near, intermediate, and far focal points.

Musculoskeletal is of, relating to, or involving both musculature (the muscles of all or a part of the animal body) and skeleton.

Ocular is term related with the eyes or vision. It is another term for eyepiece (the lens or group of lenses that is closest to the eye in a microscope, telescope, or other optical instrument). Oculomotor relates to the motion of the eye.

Ophthalmic is a term relating to the eye and its diseases.

Ophthalmologists is a specialist in the branch of medicine concerned with the study and treatment of disorders and diseases of the eye.

Optometer is an instrument for measuring the power and range of vision.

Palpebral is a term relating to the eyelids.

Parallax is the effect whereby the position or direction of an object appears to differ when viewed from different positions, e.g. through the viewfinder and the lens of a camera.

Phoria is the resting position that ones eyes go to when covered or when fusion is broken by repetitively and alternately covering each eye.

Photosensitive is being sensitive to the action of radiant energy being or caused by an abnormal reaction to sunlight.

Physiological is of or relating to physiology which is a branch of biology that deals with the functions and activities of life or of living matter (as organs, tissues, or cells) and of the physical and chemical.

Potentiometer is an instrument for measuring an electromotive force by balancing it against the potential difference produced by passing a known current through a known variable

resistance.

Presbyopia is long-sightedness caused by loss of elasticity of the lens of the eye, occurring typically in middle and old age.

Pupillary hippus, also known as pupillary athetosis, is spasmodic, rhythmic, but regular dilating and contracting pupillary movements between the sphincter and dilator muscles. It is particularly noticeable when pupil function is tested with a light, but is independent of eye movements or changes in illumination.

Refractive error: These are the vision problems that happen when the shape of the eye keeps you from focusing well. The cause could be the length of the eyeball (longer or shorter), changes in the shape of the cornea, or aging of the lens.

Stereoscopic acuity, also stereoacuity, is the smallest detectable depth difference that can be seen in binocular vision.

Stereogram is a diagram or computer generated image giving a 3 dimensional representation of a solid object

or surface.

Stereoscopic is a term relating to or denoting a process by which two photographs of the same object taken at slightly different angles are viewed together, creating an impression of depth and solidity.

Strabismus is abnormal alignment of the eyes, also defined as the condition of having a squint.

Vestibulo-ocular reflex is the reflex by which the direction of the eyes remains constant when the head is moved.

Tsuneto Iwasaki and Shinji kurimoto said Visual fatigue is the fatigue of eye muscles, a sense of pressure in the forehead, headache, blurring, diplopia, dizziness, nausea and vomiting.

(Eye strain and changes in accommodation of the eye and in visual evoked potential following quantified visual load, 1988)

Azmeh Shahid, Jianhua Shen, Colin M. Shapiro stated that fatigue is a feeling of strain or exhaustion; it includes physiological fatigue and pathological fatigue. Physiological fatigue, or normal fatigue, is induced by daily activities which lasts for a short period and is usually relived by rest. Pathological fatigue is usually caused by a medical or emotional disorder and is more chronic in nature. Sleepiness and fatigue are terms commonly used in both clinical practice and research literature. Both sleepiness and fatigue are ubiquitous phenomena. Sleepiness and fatigue negatively effect daily functioning, and patients who have these feelings are distressed. Sleepiness and fatigue are two different and distinct entities, many patients and unfortunately many medical practitioners are unaware

of the complexity and heterogeneity of these symptoms. This may be because that some patients use the terms tired, sleepy and fatigued interchangeably and it is difficult to tease apart whether the primary issue is fatigue or sleepiness. *(Measurements of sleepiness and fatigue 2010 Journal of Psychosomatic research)*

J. Kuze, K. Ukai decribed Visual fatigue is defined as eye-strain or asthenopia, caused by both two-dimensional (2-D) and stereoscopic (3-D) motion images which has a wide range of visual symptoms, including tiredness, headaches and soreness of the eyes. "Simulator sickness", "Cinema or Cinerama sickness", "Visually induced motion sickness" and "Vehicle-induced sickness" shows the same symptoms as visual fatigue. But the above definition is not exactly the same as the "Visual fatigue" of Computer Vision Syndrome (CVS), where eye complaints are caused by using Visual DisplayTerminals (VDT) or Visual Display Units (VDU). Difficulty in focusing, hazy, gritty, near vision difficulty and far vision difficulty which are all symptoms of eye-strain or asthenopia.

The motion sickness symptoms contains includes vomiting, vertigo, nausea, dizzy and sleepiness; whereas the ocular surface-related symptom are watery eyes, sting and eye-ache.

(Subjective evaluation of visual fatigue caused by motion images)

A.J. Dittner, S.C. Wessely, R.G. Brown discussed that although fatigue often identified as a sign or symptom of a disease or side effects of a treatment, fatigue is essentially a subjective experience. It has largely defied efforts to conceptualise or define it in a way that separates it from normal experiences such as tiredness or sleepiness. Emphasis is usually given to the degree and persistence of such experiences in the absence of any excessive expenditure of energy or effort as fatigue is typically defined as extreme and persistent tiredness, weakness or exhaustion mental, physical or both.

(The assessment of fatigue- A practical guide for clinicians and researchers)

Kazuhiko Ukai, Peter A. Howarth

discussed that visual fatigue as a topic of study came to the fore after the 1970s with the introduction of visual display units. They mentioned that visual fatigue or asthenopia is sometimes referred to as eyestrain. Generally "strain" indicates the elastic distortion caused by "stress". If the stress is too high, or if the stress continues for a long time, irreversible changes may result. They discussed that a number of studies on myopia has suggested that similar to mental strain, eyestrain is also a warning of possible irreversible health damage by VDUs in the office environment. They discussed that visual fatigue caused by stereoscopic images is a safety issue. Fatigue is possible caused by the discrepancy between accommodative and convergence stimuli that are included in the image. Their studies on accommodation and convergence are surveyed and an explanation regarding the characteristics of these functions is offered. They said that visual fatigue has a wide range of visual symptoms, including tiredness, headaches, and soreness of the eyes. Visual fatigue

can be caused by demands on early visual functions such as focusing and converging the eyes on a near object and may also involve central cortical structures, of those involved in viewing a wide-field, high-contrast, geometric pattern. They mentioned that most visual tasks in everyday life can contribute in some way to visual fatigue, especially when the eyes are used for long period of time. Visual fatigue may occur while doing fine work, while reading poorly printed texts and low-quality computer images, and when reading in inadequate or intense lighting, and when exposed to flickering lights or to geometric patterns, as well as when a person has uncorrected hypermetropia. Visual fatigue can also arise when people are viewing stereoscopic motion images. They discussed that stereoscopic images used for entertainment must be particularly free of visual fatigue because they are not essential for our lives and very little is known about the mechanisms of fatigue, this is partly attributed to the fact that fatigue, and its symptoms are generally assessed subjectively. They mentioned about Wilkins who has published a book on visual stress. He has proposed that

when a person looks at a specific pattern (such as fine stripes), a part of the brain is strongly stimulated, resulting in migraine and/or fatigue. Wilkins has suggested that people who easily develop migraine also tend to be affected by eyestrain. It was mentioned that symptoms of visual fatigue generally include eyestrain, dried mucus or tears around the eyelids, feeling of pressure in the eyes, ache around the eyes, discomfort when the eyes are open, hot eyes, difficulty in focusing or blurred vision, stiff shoulders, and headaches.

(Visual fatigue caused by viewing stereoscopic motion images: Background, theories, and observations)

Ajay kumar Bhootra in his book "Basics of computer vision syndrome" discussed that most eye care professionals agree that computer users demonstrate unique eye and vision problems, and the sources for such problems are not only individual visual system but also the ergonomics of the work environment. The list of change starts with the difference in letter types with which they need to work. The letter types that are printed with solid black colour on a white background paper shows well defined edges with good contrast between its background and the letters. On the other hand, electronically generated letter types that are displayed on computer screens which are made of small dots or pixels. These pixilated letters have poorly defined edges. They are brightest in the center and diminish in contrast at the edges. Human eyes and brain react very well to the most printed materials that have good contrast, whereas it react differently to those pixilated characters. They are optically imperfect characters and sometimes even the perfectly functioning eyes have difficulties maintaining accurate focus on such imperfect characters. The

second major difference is because of the illuminated letters and the background. The light emitted by computer monitor when it interacts with the lights of visual environment causes glare in the visual field. Glare creates veiling effect and reduces contrast. It also adds to the visual stress. The result is noticed in the form of reduced ability to sustain the focus on the plane of computer screen. Another important difference is the viewing distance at which they work. The computer monitor is usually placed at a distance of 50-60 cm which is slightly more than usual reading distance and significantly less than long viewing distance. Meaning thereby the accommodative mechanism of the visual system is always active. Besides different occupations on computer have different visual demands. Those who are primarily on computer designing or net surfing or any other job that needs constant viewing demonstrate different visual demands than those who are mostly engaged in data feeding from a source document to the system. Each occupational need on computer has to be evaluated separately before deciding upon the management. The change in viewing angle while

working on computer monitor also has its own effect. Moreover, most computer related tasks are repetitive and can become stressful both mentally and physically after an extended period of continuous work. The eyes end up being overworked and this can result in eyestrain. Most computer related tasks are repetitive and can become stressful both mentally and physically after an extended period of computer work. The eyes end up being overworked and this can result in eye-strain. In such a highly visually demanding task where there is always a possibility that the visual demands for an individual concerned may exceed his visual ability it is very critical to look at eyes and the visual system as a total system where each element may contribute to symptoms. The common elements of the visual system that must be addressed as follows:

- Visual acuity
- Contrast
- Accommodative system
- Binocular vision
- Oculomotor skills
- Depth perception
- Colour perception

Visual acuity:

More than 90% information received is through the vision. Good vision is the most important attribute that involves the ability to use the eyes for an extended period of time without any discomfort. Vision is the function of visual acuity. Vision can be improved by optimizing the visual acuity in a clinical set up with specific test chart placed at specific test distance. Good refraction is the primary requirement in achieving the optimal visual acuity. Unless visual acuity is maximized during the refraction, all other aspects of eye examination have no meaning. And this becomes more critical when there is a pressure of excess visual demands on the visual system. Traditional eye examination for near vision is for reading distance at 40 cm, but most computer screens are placed at a distance which is always more than normal reading distance. Besides, printed texts are used for near vision eye examination, not the pixilated text of computer monitors. Our eyes react differently to the stimulus of a computer letters. Therefore, improving visual acuity at the specific computer monitor

distance with computer simulated targets is very critical for improving visual acuity for computer tasks. An improved acuity will aid to aiming and focusing at the computer monitor for comfortable working. Uncorrected or under corrected refractive error can be major contributing factors to computers related eye stress. Sometimes, even a small amount of astigmatism can also result in symptoms because of acuity demands of the task. This would translate to loss of employee's productivity because of increase in employee's fatigue. The problem becomes more critical in presbyopia when the normal glasses that meet their visual needs for most other tasks usually do not properly correct their vision for computer display.

Contrast:

Good contrast makes characters more legible. Contrast is typically limited by the darkness of "black" on the display. Better contrast is attained with darker black. Contrast is the function of corrected visual acuity. It is also affected because of media opacities that results in light scattering. Reflection from the display

and glare in the visual environment also result in the reduced contrast of text presented on the screen. The decreased contrast makes it more difficult for the eyes to fixate and focus, maintain binocularity, and move over the text quickly and efficiently. Working under these conditions increases the demand on the visual system.

Accommodative system:

Most computers tasks are either at near or extended near viewing distance. The computer workers have to accommodate to look at the keyboard and then to look up at the screen, again to the written text and back to the screen. It implies that the visual system is always in a state of accommodative stress. This cycle continues for several hours. Allowance for efficient accommodative system is therefore, very critical to prolonged comfortable computer viewing. An improper functioning of accommodative system is normally the cause of intermittent blurring of near objects, such as the computer screen or reference document, and is also responsible for temporary blurring of distance objects

after working at near distance for an extended period of time.

Binocular vision:

The very nature of most computer tasks implies that the person is either looking at near or extended near viewing distance. Eye alignment at near viewing distance is more complex than at distance because of ocular convergence required to view near objects. Convergence is also associated with accommodation. Computer users with poor convergence ability results in symptoms of eye-strain and eye fatigue. Convergence insufficiency is quite common in the population as a whole. People who do not perform demanding visual task do not develop symptoms from it. Therefore, even a small amount of vertical or horizontal phorias need to be corrected to ease the symptoms.

Oculomotor skills:

It is controlled by extraocular muscles outside the eye and networked with the brain. It is an important skill to maintain binocular vision. It is the ability of moving our eyes quickly and accurately so that

we can direct and maintain a steady fixation on an object of regard. The two oculomotor skills are very important, i.e. saccades and pursuits. Saccade moves the eyes from one point to another point as it is observed while reading, whereas pursuit is efficient tracking of a moving object. Oculomotor skill is an important element of binocular vision system.

Depth perception:

Depth perception or stereoacuity is an important aspect of normal and healthy vision. It is being considered as the barometer of binocular vision. The quality of binocular vision is higher with finer stereoacuity. Any anomalies in the stereoacuity suggest that the binocular vision system is not working efficiently or in other words, suppression and excessive fixation disparity may lead to reduction in stereoacuity. Stereoacuity is more critical at close viewing distance than far distance. The computer worker works predominantly at close viewing distance. Good stereoacuity is needed to see the figures in their three-dimensional structures, locate the relative position of the supplementary hardware and

materials for smooth functioning, and also follow the text on the screen and source document.

Colour perception:

It is very important consideration while developing websites and other designing tasks. Missing colour information can be as much of a problem as missing words in written text. If a colour is primary carrier of information and is confused or not seen, transfer of information is reduced. Colour Vision may be altered because of many reasons. Colour vision defect may be inherited or it may be acquired. Sometimes, it may alter because of drugs, medications or toxic effects of chemicals. The status of colour vision examination forms an important part of overall eye examination and it may also help in differential diagnosis.

Sumio Yano, Shinji Ide, Tetsuo

Mitsubishi and Hal Thwaites jointly stated that the mechanism between convergence eye movement and the accommodation function in the depth of focus and in addition to conflict of convergence eye movement and accommodation function appears to affect visual fatigue.

(A study of visual fatigue and visual comfort for 3D HDTV/HDTV images, 2001)

Atsushi uetake, Atsuo murata, Miho

Otsuka and Yosuke Takasawa study shows that visual fatigue induced during a VDT task is caused by not only one factor but multiple factors. Pupil diameter reflects the function of the autonomic nervous system, focal accommodation reflects the activity of the visual system itself such as the ciliary muscle, refraction force, and depth of focus of the eye.

(Evaluation of Visual Fatigue during VDT tasks)

Tsuneto Iwasaki and Shinji kurimoto's confirmed that not only peripheral hypofunction but also the decrease of centrecephalic activity level may be responsible for the development of

eye-strain caused by visual tasks. VEP (Visually evoked potential, measured by Gulmann et al 1979) and accommodation are physiological functions closely related to eye-strain.

(Eye strain and changes in accommodation of the eye and in visual evoked potential following quantified visual load, 1988)

Chia-Fen Chi and Fang-Tsan Lin

mentioned about Taptagaporn and Saito (1990) conclusion that for all lighting conditions, a positive display caused less adaptive strain on the eye than a negative display because there were smaller pupil diameter differences among viewing a positive CRT display, a manuscript, and a keyboard. However, the relationship between pupil diameter and feelings of visual comfort has not been confirmed. Chia-Fen Chia and Fang Tsan Lin also mentioned about Kanaya (1990) who stated that one of the causes of eye related complaints was the high density of office work created by the introduction of the VDT. For example, VDT workers keep pace by the processing speed of the VDT; they have to input commands and continuously react to

the information consequently displayed on the screen, forcing them to engage in very intense and stressful work as the processing speed of the VDT increases. Beside lighting and screen parameters, both information processing load and eye movement velocity can create an increase in the pupil diameter that adversely affects the depth of focus. Thus visual fatigue could be partially induced by the action of the eyeball and eye muscles, in particular when the operation of internal and external muscles of the eye is in excess of that required for normal levels of eye movement. Participants in their study reported a significantly greater degree of visual fatigue during tracking than during reading. It was observed that eye movement velocity was sensitive only to changes in target velocity for dynamic visual tasks. In the study the differences in accommodation power found by manipulating viewing distance and target velocity suggested that a short viewing distance and a fast-moving target were harmful to the oculomotor mechanisms of accommodation. They have also found that differences in visual acuity by manipulating luminance contrast and tracking speed indicated that

low luminance contrast and a fast moving target can lead to an overall decrease in visual function. They reported that decrease in visual acuity, accommodation power, and CFF all could have been caused by a general decrease in eye function.

(A Comparison of Seven Visual Fatigue assessment techniques in three data acquisition VDT Tasks)

Agnieszka Wolska & Marcin Switula confirms that the sources of visual fatigue are probably the weakening of the oculomotor system, perception, neuronal transmission, and processing of visual stimuli. They have also cited that non-uniform light distribution, which requires continuous retinal adjustments as well as frequent pupillary reactions could be a cause of asthenopic disturbances (Piccoli, 1993) *(Luminance of the Surround and Visual Fatigue of VDT Operators)*

F Mocci, A Serra, G A Corrias found that improper illumination and glare, work demands, computer screen design, and task characteristics can contribute to

visual discomfort.

(Psychological factors and visual fatigue in working with Video display terminals)

Donghyun Kim, Sunghwan Choi, Sangil Park and Kwanghoon Sohn found that the problem in viewing 3DTV is visual fatigue. They said that visual fatigue is induced by the conflict between accommodation and convergence of the eye. Even if a user is able to perceive a constant 3D view, the effort required to resolve the visual conflicts may lead to serious fatigue, eyestrain and headaches. Visual fatigue is also caused by a number of other factors which include camera configuration, viewing conditions and image characteristics of the magnitude of parallax, parallax distribution, parallax variation, vertical parallax, crosstalk, noise, motion and asymmetries. They have also mentioned that many researchers have reported that vertical parallax causes visual fatigue and eyestrain. Vertical parallax occurs when using a converged camera configuration, which induces keystone distortion. It has been discussed that the fusional limit is related to the disparity, which

is contained in 3D videos because disparity over the fusional limit causes Visual fatigue. In addition to that it was mentioned that fusional response is related to the motion of the 3D videos, which implies a 3D object with fast motion and it can lead to the visual fatigue because of lack of time for fusing and tracking the object in the limited time. They verified that susceptibility to visual fatigue was related to both the fusional limit and response. It was concluded by them that while watching a 3D video, the viewer who has slow fusional response and low fusional limit were more sensitive to visual fatigue. *(Stereoscopic visual fatigue measurement based on fusional response curve and eye-blinks)*

J. Kuze, K. Ukai explained that some kinds of projectors and shaky cameras causes motion sickness. They said that flickering images was the reason behind Pokemon incident in 1997 where 685 people were hospitalized because of uncomfortable symptoms and photosensitive seizures after watching the TV animation program. Severe camera motion contributed to

the Matsue movie sickness incident in 2003. They have also found that when the eyes rapidly move while watching a colour sequential image, the colour image, especially the white colour part surrounded by a dark field, is seen as separated into its component colours. This phenomenon causes visual fatigue, especially in people with congenital nystagmus.

(Subjective evaluation of visual fatigue caused by motion images)

Sumio Yano, Masaki Emoto, Tetsuo

Mitsuhashi stated that the causes of visual fatigue which results from viewing stereoscopic images, which are perceived based on the binocular fusion of parallax, are not well understood, even though much research has been done. They mentioned that the causes of visual fatigue from viewing stereoscopic images are thought to be: (1) geometrical distortions between the left and right images, (2) differences between the electrical characteristics of the left and right images, (3) conflict between convergence eye movement and the accommodation function and

(4) excessive binocular parallax. It was concluded that items (1) and (2) depend on the performance of electrical equipment used for stereoscopic images and so the error of the image signals should thus be under the threshold of the corresponding characteristics of the human visual system in terms of visual comfort for the displayed stereoscopic images. Then they mentioned that items (3) and (4) relate to a basic problem in the case of viewing stereoscopic images by utilizing binocular fusion. It is presumed that visual fatigue from viewing stereoscopic images is not serious based on the other experimental results when stereoscopic images are displayed within the depth of focus. However, they said that the results of many evaluation experiments indicated that viewing stereoscopic images does indeed cause visual fatigue. They referred that results of one experiment indicated that visual fatigue occurred when viewing stereoscopic images under the condition of a 4.5 m viewing distance. The cause of visual fatigue based on the conflict between the convergence eye movement and the accommodation function is not correct because visual

fatigue is caused even if the stereoscopic images are displayed within the range of the depth of field. They said that viewer felt visual comfort from watching still stereoscopic images in spite of a large degree of binocular parallax, and that one felt visual discomfort from stereoscopic images which were composed of rapidly changing scenes from the result of a single stimulus continuous quality evaluation in the same experiment.

(Two factors in visual fatigue caused by stereoscopic HDTV images)

Kazuhiko Ukai, Peter A. Howarth found that accommodation and convergence responses are closely related, but they can also differ depending on the stimuli. If the discrepancy is small, the two functions respond correctly, i.e. differently. They mentioned that it is often said that, this is unnatural, which results in visual stress and causes visual fatigue. They discussed that quality of images on the display is continuously improving and this is enhancing many aspects of image reality, which is a desirable development, however, according to Okada et al and Torii et improvement of

image quality, when stereoscopic system is derived, increases the discrepancy of accommodation and convergence and that may cause increased visual fatigue. It was also found that stereoscopic HDTV images when moved in depth according to a step pulse function, visual fatigue was induced. They explained that visual fatigue which is caused by watching stereoscopic HDTV images, that were displayed within the corresponding range of depth of focus, and which remained motionless in the depth direction, was similar to fatigue induced by watching images displayed at screen depth, however, when images were displayed outside the corresponding range of depth of focus, visual fatigue also occurred.

(Visual fatigue caused by viewing stereoscopic motion images: Background, theories, and observations)

Ajay kumar Bhootra in his book "Basics of computer vision syndrome" discussed that dry eye is a disorder of the ocular surface of the eye and broadly speaking there are two reasons for dry eye symptoms:

- Aqueous deficiency
- Tear evaporations

Dry eye because of computer use is mostly attributed to evaporation of tears. He mentioned that computer users experience dry eye symptoms because of unique visual posture that features higher viewing angle, larger palpebral aperture and lower workplace humidity together with decreased blink rate. Dry eye disturbs the natural function and protective mechanisms of the external eye that leads to an unstable tear film during the open eye state. Sometimes, the condition worsens and disturbs the quality of life.

Decreased blink rate:

The computer user while working on computer hardly blinks more than 4-6 times per minute. This is much less than the normal blink rate of 15 blinks per minute. This is a clear indication to support the facts that blink rate decreases during the computer use. Possible explanation for the decreased blink rate may include concentration on the task or a relatively limited range of eye movement. Regular blinking is necessary

to properly reform the tear layer on a regular basis. The decreased blink rate coupled with increased rate of tear evaporation occurs with most computer workers and they experience ocular drying while working at the computer. Blinking helps spread tears across and removes irritants from the surface of the cornea and conjunctiva. At normal individual in normal circumstances blinks 15 times per minute. During relaxed be increased to 21-23 blinks per minute during relaxed condition and may be reduced to 7 blinks per minute while viewing text on computer display and 4 blinks per minute during extensive computer use. The reason for decreased rate of blink may be attributed to concentration needed for computer task and/ or a relatively limited range of eye movement. Although book reading and other intensive near tasks also result in significantly decreased blink rates, computer work usually requires a higher gaze angle, resulting in most incomplete blinks. Incomplete blink is like no blink. Reduced blink rate coupled with larger size of the ocular aperture is the primary cause of tear elimination through evaporation which makes them

experience ocular drying and foreign body sensation.

Higher viewing angle:

Computer work usually requires a higher gaze angle. Higher gaze angle results in a greater percentage of blinks that are incomplete and incomplete blinks don't count. The reasons are simple. The tear lipids normally pool along the lower lid margin, and during a full blink the upper eyelids grab the lipids and spread them over the aqueous tear layer to form oily layer of the tears. An incomplete blink does not allow this to occur, therefore, the evaporation of tears is more that results in loss of tear aqueous.

Larger palpebral aperture:

The size of ocular aperture is related to the gaze elevation-as we gaze higher, our eyes are wider open. Studies have shown an average exposed ocular surface is nearer to double while working on computer than most other tasks. This cause tears elimination through evaporation.

Lower workplace humidity:

The office air environment is often

low in humidity and may also contain contaminants. Relatively low humidity may cause drying of the skin, mucous membranes, and conjunctiva. Dryness of eye may lead to tearing and pain, especially in those wearing contact lenses and who work on computers. The symptoms increase in severity with time.

Ajay kumar Bhootra also mentioned in his book "Basics of computer vision syndrome" that

Glare is a visual sensation that occurs because of excessive and uncontrolled lights or brightness. Not all people are equally sensitive to glare. Some are more sensitive and some are less sensitive. Age also affects glare sensitivity. In general older people are more sensitive than younger people. The most common condition for glare is driving in the night when the illumination in one part of the visual field is much greater than the illumination to which retina is adapted. While working on computers, glare occurs when the level of illumination of the screen exceeds the level of illumination of the background. Glare forms a veil of luminance which reduces

the contrast and thus visibility of a target is decreased. There are two types of glare:

- Discomfort Glare
- Disability Glare

Discomfort glare

It refers to the sensation one experiences when overall illumination is too bright or illumination level varies in one part than other within the visual field. A person is at greater risk for experiencing discomfort glare when the light source is closer to the fixation point. Computer users usually suffer from discomfort glare because horizontal gaze brings the light source closer to eyes and illuminated target creates difference in illumination level in the visual field.

Disability Glare

It refers to the reduced visibility of a target due to light scatter within the globe by the ocular media. This scattered light forms a veil of luminance which reduces the contrast and thus the visibility of the target is reduced. It is basically caused by cataract, keratoconus, corneal

edema, vitreous opacities, etc. While it is true that our visual performance improves with light level, it is also not always true that more light is better. Computers are self-illuminating and require a different lighting arrangement. While the illumination produced by one lighting system may be ideal for paper tasks, it could create conditions that are absolutely dreadful for computer-based tasks. With paper tasks and typing we look downward whereas while working on computers, we tend to look straight ahead at the screen. This leads to increase in glare caused by overhead lighting in our field of view either directly or in the periphery. Looking straight at our task, we also tend to see light that bounces off highly polished objects, such as picture frames, furnishings, mirrors, glass and high reflective wall surfaces.

The largest single enemy today in the workplace is the glare that maybe defined as 'light pollution' and the effect of which increases with time spent. Following are the effects of glare on visual performance of computer worker:

- Contrast discrimination is an

important ability to read and work faster and more accurately. Overhead lights or lights from window when they strike the illuminated objects on the computer monitor, they create light pollution in the viewing zone of the user which ultimately conflict with the displays on the screen and thereby reducing the contrast.

- Colour discrimination is an important attribute to work more efficiently on computers. The excessive luminance level creates a veiling effect on the computer display and thus creates a washed out effect. This results in more difficulties to discriminate the colours. This is because of the adverse effect of washed out image on the retina.
- Discomfort glare also causes light sensitivity. The computer worker is horizontally looking in the room, as the screen is most of the time at the eye level. Bright open windows also pose the same risk as overhead light fixtures. A person is at a greater risk of experiencing discomfort glare when the source of light has a higher luminance and when it is closer to

the point of attention. Some of the common symptoms of light sensitivity is rapid blinking poor concentration, lowering of chin to shield the eyes, narrowing of the palpebral aperture, epiphora.

- Light dark adaptation is another problem that occurs because of glare present in the viewing field. This is because of large disparities in the brightness of objects in the field of view that occurs when viewing from brighter objects to darker objects or vice versa. The eye takes a brief period of time after the eye movement to adapt to the new brightness level. This is similar to what is noticed while entering or leaving a dark movie theatre. The similar effect occurs on a smaller scale when the eye needs to fixate back and forth from bright to dark objects in an office environment. When the eye is not properly adapted to the brightness level in which it is working, the vision is not good. This is a particular problem when constantly looking back and forth from a dark background computer display to a bright white reference document. If

this process recurs day by day, you are on road to first step towards macular degeneration.

He also discussed that the first consideration for all patients with vision related complain is to correct refractive error. He said that an uncorrected refractive error will lead to deficiency in visual skills and any deficiency in visual skills will lead to symptoms of CVS. This in turn will affect occupational performance. The straight forward meaning is uncorrected refractive error of any magnitude is very critical for people working on computer. He explained that the reasons are simple. Computer tasks are highly visually demanding task requiring focused concentration with reduced blink rate and widening of the eyelids. The condition is exacerbated by low humidity and drying atmosphere of the working station. The cumulative effect is on the visual function of the computer workers because of its effect on various elements of Visual system:

- It influences accommodative function of the eyes.
- It influences vergence function of

the eyes.

- It creates an imbalance between the two eyes, leading to sensory fusion disturbances.

He mentioned that the common types of refractive error includes Hypermetropia, Myopia, Astigmatism, Presbyopia.

Hypermetropia:

Hypermetropia is far-sightedness. The patient can accommodate and can correct his error. A young individual who has large accommodative amplitude can correct even a large amount of hypermetropia. But he cannot manage to see at near as the entire accommodative ability is spent while distance viewing. However, amplitude of accommodation decreases with age and compensating for hypermetropia error with accommodation becomes difficult even for distance. The straight forward understanding is uncorrected hypermetropia. It is a very important cause of eyestrain. Latent hypermetropia can be uncovered with cycloplegic refraction, in which one's accommodative power is eliminated with eye drops. Without cycloplegic refraction, they may be mistakenly prescribed

bifocals when the reading problem is reported. Proper hypermetropic correction in these cases will make the patient more comfortable at all times and also may postpone the need for bifocal glasses.

Myopia:

Myopia are short-sighted. They can see at near working distance even without correction. Thus, myopia, by itself, does not usually cause symptoms for a computer user. Low to moderate myopic individuals can read comfortably without their correction at normal viewing distance. A myopia with 2.50D can read at 40 cm without using his accommodation. However, he may experience difficulties while viewing at computer monitor because computer monitor is located farther away than normal reading distance. In order to compensate for the same, they may assume an awkward posture to obtain a shorter distance to the computer screen and thus may show the symptoms of CVS.

Astigmatism:

Astigmatism creates blur vision at all working distances. A small amount

of astigmatism may not be noticed in normal life. But when the visual demands increase as occurs while working on computers, playing sports at higher levels, etc. it may affect visual performance. Sometimes, the individual may feel headache or eye-strain. Studies have shown that uncorrected astigmatic error of 0.50D is significantly associated with visual discomfort for work at computer displays. Therefore, astigmatism of 0.50D or greater, should always be considered as a potential problem for a computer user and should be corrected.

Presbyopia:

Presbyopia is the condition that results when the normal age related loss of accommodation prevents from comfortably maintaining focus on near objects. The usual treatment for presbyopia is to prescribe Separate reading glasses or multifocal lenses.

Sumio Yano, Shinji Ide, Tetsuo

Mitsubishi and Hal Thwaites discussed that in a stereoscopic image, the viewer watches two images corresponding to the right and left eyes with convergence eye movement, allowing the two pieces of the image to fuse. As a result, conflict occurs between convergence or divergence eye movement and the accommodation function which causes visual fatigue.

Although image hardware has progressed, image presentation for the human visual system remains inadequate. They mentioned that there has not been enough effort on reducing visual fatigue and strain for the viewer, especially in the case of stereoscopic image systems. When stereoscopic HDTV images were displayed within the corresponding range of depth of focus, and remained still in the depth direction, the degree of visual fatigue was almost the same as that induced by watching images displayed at the depth of the screen. However, when images were displayed outside the corresponding range of depth of focus, visual fatigue was clearly induced. Moreover, they found that even if images were displayed

within the corresponding range of depth of focus, visual fatigue was induced if the images were moved in depth according to a step pulse function. (Depth of Focus : the distance between the nearest and the furthest objects giving a focused image) The results suggest that the scenes causing visual discomfort are composed of a main object that is located in the front of the screen and moves rapidly.

(A study of visual fatigue and visual comfort for 3D HDTV/HDTV images)

Susumu Saito said visual fatigue is the most representative phenomenon in an increasing number of VDT workers in various occupations. He mentioned that ergonomic problems and occupational fatigue related to VDT operation were pointed out in the latter half of the 1970s (Matula 1981), and many research papers have been published (Grandjean and Vigliani 1980, Cakiretat. 1980). He stated that physiological studies also revealed that VDT work may induce temporal decrease in lens accommodative function. He suggested that considering the utilization of the eye movement system as an indicator of fatigue. He

discussed that effects of fatigue on the eye movement control system are insignificant compared with temporal phenomenon. Therefore, these vague characteristics lead to the conclusion based on the quantitative and statistical analysis that there is no fatigue in the eye movement system. He found that subjective complaints of visual fatigue after accomplishing all tracking experiments were very strong in all the subjects. It was also mentioned that saccadic frequency was not affected by heavy eye tracking tasks. Accuracy of saccades, frequency of tracking tasks and correct percentage of character discrimination were not significantly changed after eye tracking in spite of the strong complaints of subjective visual fatigue. He tried to show absence of fatigue in eye movements from the quantitative analysis. After the appearance of the blunt saccades, he observed that the subject often complained of monotony and drowsiness during at tracking task. In spite of a large number of subjective complaints of visual fatigue, he found that quantitatively measured characteristics of eye movements were independent of the

intensive load and its control system. He explained that physiological distinctive features of the extraocular muscles such as abundant blood supply were reconfirmed. He claimed that abnormal saccades were rarely observed during the experiments, and even when they appeared, there was an immediate recovery back to the normal saccades in the next sequence of eye tracking.

(Does fatigue exist in a quantitative measurement of eye movements, 2007)

Masaru miyao, Selim S. Hacisalihzade, John S. Allen & Lawrence W. Stark mentioned that it is known that it is difficult to measure visual or oculomotor fatigue (Stirk and Johnston 1984). They have argued that measurements under bad reading conditions, such as high glare or flicker rate, or lack of contrast, would be more effective in the measurement of visual fatigue. But they also mentioned that these stressors would be outside of normal task variation and therefore less relevant to the general problem. They said that there experimental subjects did complain of eye strain, irrespective of display type

which was worth some consideration. They mentioned that it has been proposed that blink rate is not a measure of fatigue but that it correlates with effort (Kim et al. 1984, Wu et al. 1986), especially if performance remains constant. They found that with the H type display, subjects read slightly (but not significantly) faster than with the S type; therefore, they might have been able to devote more effort to the reading task, which resulted in significantly lower blink rate. Reading aloud takes about twice as long as reading silently, thus filtering out any possible changes in silent reading speed. They have also pointed out that these are saccadic, as opposed to smooth pursuit eye movements. A significant difference was found between the two displays for mean eye fixation duration while reading mini-sized characters. The slowing down of the reading speed may be indicative of a perceptual delay. The number of lines read during the same time span varied significantly for mini-sized characters on the S type display. This can be explained as an increase in the number of fixations per line due to difficulty in reading mini characters on the S type VDT. The

interindividual and intra individual variabilities in eye fixation while reading different sizes characters on both types of VDTs are small, with the exception of mini-sized characters on the S type display. They proposed a hypothesis to account for this is which stated that there can be two reasons for fixations: to see better, or to understand better. They found that an increase in mean fixation duration (over some predetermined baseline) could be the result of difficulty in comprehension, difficulty in visual processing (readability), or both. They mentioned that as indicated by the relatively constant fixation durations exhibited by our subjects under the majority of experimental configurations, comprehension of the contemporary novel used for text display was not a problem for the well-educated subjects in their experiment. Therefore they said any increase in fixation is much more likely to be the result of difficulty in early visual processing (Hacisalihzade and Miyao, in preparation). So they found that the increase in fixation duration for the S type display with mini characters cannot be due to comprehension difficulties which are not a function of readability.

They said from this, it follows that the fixation pattern differences observed in subjects reading from the standard VDT with mini characters must be due to lower readability.

(Effects of VDT resolution on visual fatigue and readability: an eye movement approach, 1989)

Atsushi Uetake, Atsuo Murata, Miho

Otsuka and Yosuke Takasawa confirmed that most VDT tasks are classified as mental tasks. In such a task, the symptom of visual fatigue also induces symptoms of general fatigue, particularly mental fatigue. It is more reasonable to evaluate visual fatigue from the viewpoints of decreases in both focal accommodation and the autonomic nervous system. They mentioned about an attempt that was made to assess visual fatigue from physiological, psychological, and performance aspects. In their study, which required the subjects to perform a VDT task lasting for 1 hour, the effect of visual fatigue on performance seemed to be, at most, very weak. On the other hand, signs of visual fatigue appeared clearly in

both physiological and psychological measures. The psychological feeling (rating) of visual fatigue was strongly related to physiological measures that reflected the functions of the autonomic nervous system and focal accommodation.

(Evaluation of Visual Fatigue during VDT Tasks)

Chia-Fen Chi and Fang-Tsan Lin stated that visual display terminals (VDTs) can be used to store and convey static and dynamic visual information, and thus they have inevitably become interfaces in both the office and the industrial workplace. However, VDTs have brought with them numerous complaints of visual fatigue, mental load, and musculoskeletal pains. Of these complaints, visual fatigue is the most pronounced and prevalent.

(A comparison of seven visual fatigue assessment techniques in three data acquisition VDT Tasks)

Agnieszka Wolska & Marcin Switula

in their objective evaluation of visual fatigue demonstrated a tendency towards bigger changes in visual

functions with an increase of surrounding luminance for both screens. They said lighting requirements are determined by the satisfaction of three basic human needs safety, visual performance (i.e. workers are able to perform their visual tasks even under difficult circumstances and during longer periods), visual comfort (i.e. workers have a feeling of well-being). The way of establishing appropriate lighting parameters, especially for new and complex types of visual work, is through modelling different lighting conditions and investigating both the subjective evaluation of lighting and the objective measurements of visual performance or visual fatigue up to 40% of VDT users suffer daily from asthenopic symptoms (Bergqvist, 1984). If the luminance ratios are too high, they could cause fatigue, discomfort glare. They have also mentioned that non-unified lighting requirements seem to be a substantial problem for proper lighting designing and the assessment of lighting conditions on VDT workstations. The interpretation of some specific results of luminance distribution, like

luminance ratio between the screen and its surrounds of 1:15, could be quite different, depending on the source. They concluded that luminance distribution in the participants' field of view was defined by luminance ratios of area mean luminances of task areas that are frequently viewed in sequence (e.g., document-screen, keyboard screen) and between the task area and its surrounds (e.g. Document-table, keyboard-table, screen the wall behind the display). They established that work with VDT affected (in most cases) changes of phoria for near in the direction of esophoria (a minus sign before the mean value) irrespective of the type of screen or the surrounding luminance value. The biggest changes of distance phoria were obtained for the biggest value of surrounding luminance for both screens. They found that there was a tendency towards bigger changes in distance phoria with an increase of the surrounding luminance value, and in the case of absolute values of changes in accommodation, distant phoria, and visual acuity indicated a tendency of visual fatigue to increase

with the growing value of surrounding luminance not significant except for a near point of accommodation. They found accommodation seems to be a visual function most sensitive to changes of luminance distribution. Surrounding luminances values of less than 200 cd/m² (luminance ratio of less than 1:60) did not affect the growth of visual fatigue and drop in visual performance.

(Luminance of the Surround and Visual Fatigue of VDT Operators)

Kimiko Kawashima, Jun Okamoto, Kazuo Ishikawa and Kazuno Negishi stated that image safety (e.g. visual fatigue and visually induced motion sickness) as well as image quality that concerns with conventional 2D video services must also be considered for quality of 3D video services. Although 3D movies have become popular, concerns for image safety still exist. They mentioned that The National Consumer Affairs Centre of Japan received inquiries and complaints from people regarding visual fatigue after watching 3D movies. They found that visual fatigue is caused by a number

of factors such as content production, video compression and delivery, and viewing environment. They have also said that even if safe 3D content is delivered, video compression and delivery factors may bring about visual fatigue. Their study have also suggested that video compression and delivery factors are critical for safe 3D video services and they also found that subjective quality assessment of "visual fatigue" showed that the greater the difference between the left and right frame quality in the 3D videos, the lower the grade of subjective quality assessment of "visual fatigue", which means the stronger their feelings of visual fatigue.

(Parameter comparison of assessing visual fatigue induced by stereoscopic video services)

F Mocchi, A Serra, G A Corrias confirmed that many jobs that require heavy daily computer use have been found to be stressful. They mentioned that with the spread of this type of work and the associated appearance of health complaints in workers, a vast amount of research has been aimed at

identifying the possible causes of the health problems associated with VDT work. Their study found no correlation between asthenopia and number of hours of work a day at the VDT or number of years spent performing the same work duties. They found that asthenopia was correlated with age, sex, and environmental discomfort. They have also said that mental workload was particularly correlated with work at VDTs and asthenopia.

(Psychological factors and visual fatigue in working with video display terminals)

Donghyun Kim, Sunghwan Choi, Sangil Park and Kwanghoon Sohn assessed fusional response curve and eye-blink rate to measure visual fatigue induced by stereoscopic videos. They utilized a random dot stereogram to measure the reliable fusional limit and response curve acquired by determining the direction of Landolt C. The results were analyzed by them to discriminate the individual ability of 3D fusion and compared with the results of subjective evaluation and descriptive self-report. Their study showed that while watching 3D video,

viewers who have slow fusional response and low fusional limits are more sensitive to visual fatigue.

(Stereoscopic visual fatigue measurement based on fusional response curve and eye-blinks)

Sumio Yano, Masaki Emoto, and Tetsuo Mitsuhashi said that generally when a viewer watches stereoscopic images, the viewer gazes at one position in the images using convergence eye movement, and the area surrounding the gaze position mentioned by Panum's fusional area which is perceived by using retinal fusion characteristics. They said that as a result, the viewer can get a sense of distance and depth from the stereoscopic images. They have also mentioned that binocular single images are perceived by utilizing convergence fusion based on convergence eye movement and retinal fusion based on detector cells in the cortex. But the said display condition of stereoscopic images is the state without any depth information in Panum's fusional area. In their study the target was only located on the horizontal and vertical

horopter, regardless of whether the gaze point determined using convergence eye movement and the focus point determined using accommodation. They concluded that this display condition means that the stereoscopic images are perceived by only convergence fusion. According to them this display condition is well known as the stereoscopic images perceived using a prism test. They stated that the relationship between the magnitude of binocular parallax and visual fatigue was investigated by using HDTV stereoscopic images that were perceived by wearing prism glasses. There have also found that there are some differences between stereoscopic images using a prism and stereoscopic images based on television technology. One key difference is that the whole visual field is changed by setting the prism. On the other hand they have found, stereoscopic TV images are only changed within the TV image screen. They mentioned that another difference is prism adaptation. This adaptation seems to be related to the change of the whole visual field, and they said that the degree of adaptation must be examined, especially in the case of still images.

These mentioned that these experiments were based on the figure of Percival's Visual comfort. They discussed that visual fatigue was not a serious problem when still stereoscopic images, which were only perceived by convergence eye movement, were displayed within the corresponding range of the depth of focus. They have also found that visual fatigue occurred when the stereoscopic images involved the depth motion component even if they were displayed within the range of the depth of field.
(Two factors in visual fatigue caused by stereoscopic HDTV images)

Kazuhiko Ukai, Peter A. Howarth said that International and domestic organizations such as ISO (International Organization for Standardizing) published recommendations for working environments using VDU, in order to reduce fatigue symptom. In spite of these measures, many people suffer from visual fatigue even today, although it is often said that the number of people reporting visual fatigue in the office environment has decreased since the recommendations were implemented.

In their study they reported that a stereoscopic image is produced by presenting one image to the left eye, and another to the right eye and the presentation of these two images may be realized by several methods. They mentioned that Binocular head mounted displays (HMDs) give rise to certain health problems even when they are used in a non-stereoscopic (bi-ocular) mode. They warned that axes, magnification factor and image distortion of the binocular optical system must be precisely controlled in the manufacturing process otherwise, viewers will experience similar to the prismatic effect caused by wrong centering of spectacle lenses resulting in a phoria on the eye muscles which in turn causes persistent eyestrain. They discussed that images on HMDs are not fixed to actual space coordinates, but to the head. They said that when we move our head, reflex eye movements that are known as vestibulo-ocular reflexes, or VOR, are evoked. If the visual input is fixed to the head, VORs are suppressed. The visual suppression of torsional eye movement to head roll motion is small compared to the horizontal and vertical movements. Thus

they found that images on HMDs are complex and unnatural, and as a result, cause modifications of the vestibular system. They mentioned that long-term effects of VOR suppression on health are yet unknown and image sickness is more easily induced when using HMDs in comparison to conventional displays, possible because of the characteristics of HMDs. They accepted that the actual setting up of stereoscopic imaging systems, such as the appropriate shift of the binocular images on the screen, is a controversial issue.
(Visual fatigue caused by viewing stereoscopic motion images: Background, theories, and observations)

Masaru miyao, Selim s. Hacisalihzade, John s. Allen & Lawrence w. Stark found in their study that reading speed remained relatively constant for both H-type and S-type displays but blink rates were significantly lower when reading from the H type VDT, and they increased insignificantly over the 1h reading period for both the H type and the S type displays. Subjective fatigue was described by all of their subjects and they complained of considerable eye strain, including dry or watery eyes. Two of their subjects also reported having headaches, one after reading from the H type display and the other after reading from the S type. Half of their ten subjects felt that the H type was less fatiguing and the other half felt that the S type was less fatiguing. Several of their subjects also mentioned that they initially preferred the H type VDT, because the characters appeared to be 'crisper', but after reading for 1 h, they felt that the S type display was less fatiguing.

(Effects of VDT resolution on visual fatigue and readability: an eye movement approach)

Chia-Fen Chi and Fang-Tsan Lin reported

in their study that one reason for reports of visual fatigue from VDT workers is that the viewing distance is usually less than their dark-focus point. During performance of a VDT task, which is typically near work, a person's ciliary accommodation muscle changes the optical power of the lens to form a sharp image on the retina, and the horizontal extraocular muscles converge the axes of the eyes to fuse the two retinal images. These oculomotor mechanisms of accommodation and convergence are increasingly strained as the viewing distance shortens. They mentioned about JaschinskiKruza (1988) who showed that visual strain was greater at a viewing distance of 50 cm than at 100 cm, irrespective of the individual's dark focus point.

(A Comparison of Seven Visual Fatigue assessment techniques In three data acquisition VDT Tasks)

Agnieszka Wolska & Marcin Switula mentioned in their study that the symptoms of asthenopia are (North, 1993) Ocular: Sore, tired, tender, itchy, heavy, dry, burning, or aching

eyes; Visual: Blurred or double vision, focusing problems; Systemic: Headache and general fatigue. They mentioned that ocular symptoms of asthenopia (irritation, pain, redness, etc.) may be more linked to workroom lighting, whereas for visual symptoms (blurring, flickering, double vision, etc.) display characteristics may be more important (Bergqvist, 1984). Their MANOVA analysis revealed that there was a statistically significant influence of the screen type on the intensity of the following complaints: redness, lacrimation, piercing, sensitivity to light, and burning. It also revealed that there was a statistically significant influence of the surrounding luminance value on the accommodation changes. *(Luminance of the Surround and Visual Fatigue of VDT Operators)*

Atsuo Murata , Atsushi Uetake , Miho Otsuka & Yosuke Takasawa have shown in their studies that the characteristics of visual display terminal (VDT) work are related directly to eye discomfort and psychological symptoms. The most frequent symptom of fatigue in a VDT

task is eyestrain. VDT tasks manifests itself as (a) painful irritation (burning), accompanied by lacrimation, reddening of the eyes, and conjunctivitis; (b) double vision; (c) headaches; (d) reduced power of accommodation and convergence; and (e) reduced visual activity, sensitivity to contrast, and speed of perception (Grandjean, 1990). They said all of these symptoms of visual fatigue contribute to general fatigue. The more rapid and precise eye movements a task calls for, the heavier the demand on perception, concentration, and motor control. They mentioned that when the eyes are overstressed in VDT tasks for long periods, symptoms of visual fatigue will be added to these symptoms which is a crucial problem in VDT tasks because such phenomena induce loss of efficiency, productivity, and accuracy. A few studies have revealed significant relations among the photometric characteristics of VDTs, such as screen flicker, excessive luminance, the contrast ratio between screen and environment, and reflected glare. However they stated that at present, there is no definite method to evaluate visual fatigue in individuals working with VDTs. They

mentioned in their study that many researchers have said that pupillary response reflects the activity of the autonomic nervous system (Bucks & Walrath, 1992; Beatty, 1982; Beatty & Kahneman, 1966; Geacintov & Peavler, 1974; Hess & Polt, 1964; Kahneman & Beatty, 1967; Libby, Lacy, & Lacy, 1973; Lowenstein, Feinberg, & Lowenfeld, 1963; Marek & Noworol, 1986; Murata, 1997; Pooch, 1973). They found that pupillary response is, under controlled conditions, a rather sensitive indicator of mental activity, as indicated by a number of studies. They mentioned that Hess and Polt (1964) reported that changes in pupil size during the solving of simple multiplication problems could be used as a measure of mental activity. It was also mentioned that Beatty and Kahneman (1966) showed that the pupil diameter increased with the difficulty of a memory task. Also Bucks and Walrath (1992) demonstrated that pupillary response measures were sensitive to the information-processing demands of a search task, not merely to the physical parameters of a display, and Murata (1997) showed that pupil diameter was suitable for the assessment of fatigue.

They discussed that Geacintov and Peavler (1974) tried to use the pupil constriction as a reflection of fatigue in an industrial environment. Also Marek and Norworol (1986) showed that pupil diameter was indicative of mental fatigue. They concluded that most VDT tasks are classified as mental tasks and in such a task, the symptom of visual fatigue also induces symptoms of general fatigue, particularly mental fatigue.

(Proposal of an index to evaluate visual fatigue induced during visual display terminal tasks, 2001)

F Mocci, A Serra, G A Corrias said that social support, group conflict, self esteem, work satisfaction, and underuse of skills were found to be predictors of visual complaints; they mentioned that social support played a part also as a moderating factor in the stress and strain model; this model accounted for 30% of the variance. They concluded that subjective environmental factors, although in some cases significantly correlated with asthenopia, were not found to be strong predictors of the symptoms. They said that asthenopia

(visual discomfort) was measured by a questionnaire which queried the presence of blurred vision, ocular soreness, itching of the eyes, blinking, heaviness of the eyes, and double vision. They instructed their subjects to respond affirmatively only if a given symptom was felt during or soon after working time. They solicited responses on a three point scale (0=never or rarely, 1= at least 3 days a week, 2 = every day). The final score for the scale of asthenopia was calculated by adding the scores obtained for every ocular symptom. Among the psychological factors they said, physical workload was the only factor not significantly correlated with asthenopia. They identified asthenopia, has more or less striking presence of any of several different disturbances including a sensation of heaviness of the eyes, conjunctival redness, a subjective perception of tiredness, dry eyes due to insufficient production of tears, and sudden phenomena of double vision or clouding of vision.

(Psychological factors and visual fatigue in working with video display terminals)

Donghyun Kim, Sunghwan Choi, Sangil Park and Kwanghoon Sohn said subjective quality evaluation methods can be used to measure visual fatigue. They mentioned that symptoms of visual fatigue are measured subjectively by assessing eyestrain, difficulty in focusing or blurred vision, stiff shoulders, and headaches. They mentioned that psychological researchers reported that higher eye blink rates were related to higher eyestrain.

(Stereoscopic visual fatigue measurement based on fusional response curve and eye-blinks)

J. Kuze, K. Ukai mentioned that in 1997, approximately 685 people were hospitalized because of uncomfortable symptoms and photosensitive seizures after watching a TV animation program called "Pokemon". They discussed that as new technology arrives, it brings with it new effects of light and sound, dynamic movement of quasi-images and so forth and it was effects such as these that are thought to have accidentally caused the Pokemon incident in 1997. They pointed out four symptoms when comparing

visual fatigue of VDT or VDU workers, i.e., ocular symptoms, visual symptoms, systemic symptoms and behavioural symptoms. Ocular symptoms refer to discomfort of the eye and tense, heavy, dry eyes, whereas visual symptoms refer to perceptual difficulties, which do not actually cause pain, such as fixation and focusing problems. They mentioned that Ocular symptoms are associated with eye strain factor while visual symptoms are related to focusing difficulty factor. They have also discussed that systemetic symptoms refer to headaches which may be dull and difficult to localize or which may appear to reside in the forehead, and general aches in the neck and arms. Systemic symptoms are seen as a combination of general discomfort factor and headache factor. Behavioural symptoms consist of a variety of voluntary and involuntary actions, which all stem from visual fatigue. They mentioned about a recent review on CVS, Blehm which describes four symptoms such as asthenopic symptoms, ocular surface-related symptoms, visual symptoms and extraocular symptoms. Asthenopic symptoms refer to symptoms such as eyestrain, tired eyes, sore eyes

and dry eyes, while ocular surface related symptoms refer to symptoms like watery eyes, irritated eyes and contact lens problems. Visual symptoms refer to blurred vision, slowness of focus change, double vision and presbyopia; whereas extraocular symptoms refer to neck, back and shoulder pain. They said that the main visual symptoms of VDT or VDU are eyestrain, tired eyes, blurred vision and double vision; which means that the greater symptoms of focusing difficulty and eye strain after viewing with a TV monitor use is quite understandable. Symptoms of eye strain and focusing difficulty were also greater when watching TV images compared to HMD images. Therefore they said visual fatigue associated with the anaglyph method may have similar causes as from viewing TV monitors; thus it is suggested in their study that one should avoid using the anaglyph method for viewing motion images for long periods of time.

(Subjective evaluation of visual fatigue caused by motion images, 2007)

Kazuhiko Ukai, Peter A. Howarth have mentioned about studies which have

investigated ocular-motor imbalance and visual fatigue when viewing non-stereoscopic images. After 4 h of VDU tasks, they have observed decreases in amplitude and the velocity of accommodation, delay and increase of the pupillary light reflex, and decrease in pupil size. They found a weak correlation between the decrease in pupil size and accommodation function. Changes in various visual and oculomotor functions, such as refraction and visual acuity, tonic accommodation and accommodative velocity of step responses, distance and near heterophoria, AC/A ratio, following 2 h of viewing a movie using bi-ocular HMDs have been reported in their studies. They said that irreversible change of accommodative functions such as onset of myopia, or its progression, cannot be examined without epidemiological study. They mentioned that one of such works did not support any increased occurrence of myopia in the VDU workers compared with other near-vision workers while another described increased myopic progression in the VDU workers. Viewing stereoscopic images is not so popular to carry out epidemiological study. They mentioned

that some ophthalmologists remain concerned that viewing stereoscopic images may cause strabismus, an abnormality in binocular alignment, in young children. It is influenced by accommodation, vergence, and binocular vision. There concluded that there is no evidence for or against the hypothesis that viewing stereoscopic images causes strabismus except for a report by Tsukuda and Murai. It was stated that many ophthalmologists may not be aware that stereoscopic images are a cause of acute onset strabismus, and therefore, will not ask patients about such experiences because acute strabismus is often a sign of central nervous system abnormality such as brain tumor, or thyroid-associated ophthalmopathy, the exclusion of these causes should be a priory. The increased occurrence of pupillary hippus following to near vision load has been reported in VDU workers. They said hippus is a slow (about once in 5 s), large-amplitude, cyclic changes of the pupil with strong constriction, induced by sleepiness in normal subjects and sometimes after near vision load. They mentioned that Nakamura also reported that subjects suffering eyestrain

had smaller pupil size and a slow change of size. They said intermittent light of CRT monitors reduced accommodative amplitude, increased eye blink interval made the pupil smaller. It was reported that a disparity was a strong enough stimulus for pupillary change to occur, regardless of convergence or accommodation. They have stated that myopia may progress with near work as accommodation adapts to a closer point in space. They found that if this is the case, the question arises whether accommodating to a point further than the screen would be good for preventing the progress of myopia and the answer depends on whether stimuli discrepancy or strong accommodation is related to fatigue and myopia. If have cited that if fatigue were caused by a discrepancy in accommodation and convergence stimuli, discrepancy would exist regardless of divergent stereoscopic stimuli. They said that if accommodation did play a role in fatigue, accommodating to a point further in space would be good for preventing myopia. They mentioned that symptoms of visual fatigue generally include eyestrain, dried mucus or tears around the eyelids, feeling of pressure in the

eyes, ache around the eyes, discomfort when the eyes are open, hot eyes, difficulty in focusing or blurred vision, stiff shoulders, and headaches.

(Visual fatigue caused by viewing stereoscopic motion images: Background, theories, and observations)

Ajay kumar Bhootra in his book "Basics of computer vision syndrome"

discussed that most of the visual symptoms of the computer worker are related to the blurred vision and symptoms arising because of blurred vision. They complain that they find it difficult to maintain clear and steady focus for a significant amount of time and sometimes refocusing is slow. Often they find themselves lost while reading text documents. Squinting the eyes enables them to read clearly. All of these symptoms usually point to the presence of refractive error. Blurred vision may be of different types:

- Constant blurred vision
- Postwork distance blur
- Intermittent blurred vision at near

Constant blurred vision is an indication

of an uncorrected or undercorrected myopia, hypermetropia, astigmatism or presbyopia, depending upon the viewing distance at which the blur occurs. The person complaining of blurred vision often squints his eyes to overcome the symptoms.

Delay in focusing at distance after working for a long period of time for near work is mostly the characteristic feature of an accommodation being locked at near viewing distance or general accommodative dysfunction. This kind of blurred vision may be momentary when the person looks up from his near work or it may last for several hours after near work.

Intermittent blurred vision at near viewing distance may also be caused by dry eyes. A careful history taking by asking the patient whether his vision clears just after he blinks may help diagnose it.

In extreme cases, symptoms related to double vision may be reported which straight away points towards binocular vision dysfunction. It often gets worse

as the day passes or reading extends beyond a few minutes. However, double vision complaining people are so sensitive that either they close their one eye or try to change their visual posture to overcome it. The occasional color perception problems may be because of poor display quality of the screen. Poor contrast and the presence of glare may also affect color perception temporarily.

Ocular symptoms:

Poor blinking rate, incomplete blinking, horizontal visual gaze and wide open palpebral aperture during computer tasks leads to dry and irritated eyes. The person often complains of itching eyes burning eyes, foreign body sensation and or sore eyes. At times the condition manifests in the form of excessive tears and excessive blinks. Wide open eyes with horizontal visual gaze angle at the screen causes tear evaporation that results in loss of tears. The condition aggravates because of low humidity of the office air that also adds to dryness. Dry eyes results in reflex tears and foreign body sensation. A complain of watery eyes is often the result of reflex tearing secondary to irritation caused by dry eyes. Irritated or

burning eyes in the absence of dry eyes may indicate presence of toxic elements in the office atmosphere which may be continued if the other employees also have similar symptoms.

Asthenopic symptoms:

Asthenopic symptoms most commonly include eyestrain, headache eye fatigue, tired eyes. They usually start after working for sometime on computers and increases as the day passes. The person complaining of asthenopic symptoms often reports that they are more comfortable when the illumination level is reduced. In many cases, these symptoms remain undiagnosed. Uncorrected or uncorrected refractive error, onset of presbyopia, a disorder of accommodative mechanism, binocular vision disorder all may lead to asthenopic symptoms. The condition may aggravate because of poor ergonomics such as glare and reflections around the working environment.

Light sensitivity symptoms:

It can result from several conditions. The following conditions can be noticed while working on computers:

- The horizontal gaze angle that is quite commonly seen during computer task is always higher than gaze angle needed for reading or other table task. The result is bright light sources of the office which are closer to central fixation.
- The computer worker is constantly gazing at the illuminated target which is absolutely in contrast with reading printed targets.
- Glare and reflections are present in the office atmosphere due to fluorescent light or reflections because of screen and other surfaces may create light pollution in and around computer working station.

Moreover, in some cases a binocular vision disorder may also result in light sensitivity. The person may report flickering sensation and light sensitivity. In extreme cases, the patient may report pain in the eyes.

Musculoskeletal symptoms:

The typical posture of the computer worker while working on computer can be explained as under: 'He sits on a chair that fits to his body size or slightly larger,

keeps his wrists on the keyboard with elbow at an angle between keyboard top and the chair handle top, neck upright with eyes gazing straight ahead on the display monitor with overall stiff body posture. The working station does not allow for much body movement and he maintains similar postures for hours together: Human body is not suitable to work for extended period of time in the same posture. He also mentioned that experience has shown that an individual who maintains the same posture for a longer period of time most commonly reports: neckaches, shoulder pain, backaches, wrist pain, pain in arms and waist.

O. Ostberg mentioned that trade unions have argued that VDU viewing tasks impose undue strain on operator's eyes, but employers naturally have been reluctant in signing agreements granting the operators rest-time allowances. They advised that it would help such workers very much if besides wearing spectacles they would give up the habit of keeping the head constantly bent and the eyes fixed on what they are making; They have also advised that if they would now and then drop their work and turn their eyes elsewhere or snatch a respite from several hours from their task and rest the eyes by looking at a number of different things it would help minimize visual fatigue.

(Accommodation and visual fatigue in display work)

Sumio Yano, Shinji Ide, Tetsuo Mitsuhashi, Hal Thwaites Sumio Yano, Shinji Ide, Tetsuo Mitsuhashi, said that it is considered that screen brightness must be increased and viewing distance must be extended for the reduction of visual fatigue because conflict between

convergence eye movement and accommodation function is one cause of visual fatigue.

(A study of visual fatigue and visual comfort for 3D HDTV/HDTV images)

Kazuhiko Ukai, Peter A. Howarth mentioned that hardware/software manufacturer should avoid unnatural image presentations, such as images that diverge further than infinity, large binocular disparity in the central visual field or around the objects that are the centre of the viewer's attention, difference of size and colour, unequal distortion between binocular images since they may cause fusion difficulty. They also mentioned that viewers should be careful to avoid viewing stereoscopic images for extended durations because visual fatigue might be accumulated. They should be ready to stop immediately if fusion difficulties are experienced. They mentioned that inter-individual differences in susceptibility are unclear and fatigue may be a warning of serious damage to the human body by continuous exposure. Thus they have warned that, severe damage may

occur suddenly in those with lower susceptibility. They have found one of the many causes of differences in susceptibility is perhaps migraine and it is known that repetitive periodic spatial patterns are a cause of visual fatigue and migraine, which may also cause epileptic seizures in viewers with a diathesis. They have said that children should be cautioned about stereoscopic images because they may not subjectively perceived a problem even if an eye is deviated.

(Visual fatigue caused by viewing stereoscopic motion images: Background, theories, and observations)

Ajay kumar Bhootra in his book "**Basics of computer vision syndrome**" discussed that visual abilities determine visual postures which will also be influenced by visual environment. This is based on the assumption that human eyes take the lead in deciding the bodily posture. Nature has designed our visual system to be so dominant that we alter our bodily posture to accommodate any deficiency in the way we see. If the task is visually demanding, the body locates the eyes

at a position where they can perform the visual task comfortably but assumes an awkward posture that results in musculoskeletal problems. Unhygienic visual environment adds to it. The straight forward meaning is that we need to be aware of how the design of office and the arrangement of the equipment in our computer workstation can affect our comfort, health and productivity. This is very important to minimize the work related musculoskeletal difficulties, such as carpal tunnel syndrome, back pain and neck pain that are commonly seen with computer workers. Another important issue that needs to be kept in mind while designing furniture and fixture is the fact that human body is designed for movement. The position that does not allow any body movement while working leads to more fatigue than the position that allows moderate movement. When the body is still, circulation is slowed and as a result fewer nutrients are delivered to the muscles. The result can be musculoskeletal discomfort and pain.

He discussed about issues related to body posture:

- A down ocular gaze angle of 15-20° relative to straight ahead gaze is more ideal for optimal performance as the effect on near triad function is relatively insignificant. When we look down, our eyes converge, accommodate to focus and pupil constrict that alters depth of focus. The condition is just opposite when we look straight ahead or upwards. In such a position, it is harder to focus for close objects. There are some accommodative advantages to having down ocular gaze in the form of accommodative convergence which is mainly a reflex convergence. This is also supported when we study the optical corrections available for presbyopia. All the bifocal and multifocal lenses have near viewing zones located in lower portion so that the near viewing angle is 20-25° below horizontal line of sight. This location has been empirically determined to be comfortable for the presbyopic patients.
- Resting of feet on the floor while working on computers for a long period of time allows support for legs that reduces pressure on the lower back and prevents leg swelling. In case the height of the chair does not allow for the same, a separate footrest may be used.
- It is also important to have support for the forearm while working with a mouse or keyboard in order to reduce tension mainly in the neck and shoulder muscles as well as localized pressure on the wrist. Together with the arm rest, a soft wrist rest in front of keyboard or mouse is helpful to prevent carpal tunnel syndrome.
- While sitting vertically straight on chair, our back has to be fully supported with backrest. This is important to reduce stress and strain on the muscles, tendons, and skeletal system and to reduce the risk of developing a musculoskeletal problem.
- Body posture as a whole is very important while seating for a longer duration of time in one position. Having just one part of our body out of neutral posture can affect the rest of

the posture. It is, therefore, essential that a comfortable working posture in which all our joints are naturally aligned has to be maintained to reduce the musculoskeletal disorder.

- Regardless of how good our posture may be, sitting still for long period of time is not healthy. Small changes in the posture at about every 15 minutes flex the body muscles. Larger changes in posture are also important. It may be a good idea to stand up, stretch or walk around for one or two minutes at regular interval.

He discussed issues related to furniture and fixture:

The designing and arrangement of furniture and fixture influence the visual comfort, visual efficiency and body posture. The following factors are important as far as issues related to furniture and fixtures are concerned.

- The distance between the eyes and the computer monitor determines the working viewing distance. There are several factors to be considered while

deciding onto the viewing distant. Most researchers support the longer viewing distance because of the least visual demand on visual system. But this is limited by availability of space and operational case. It may also put stress on torso because of forward leaning. At closer distance our eyes are at constant accommodative state that result in early fatigue and other symptoms. Some researchers are of opinion that greatest visual comfort is achieved when working at resting point of accommodation or resting point of vergence. However, they vary with different persons and also with age. This may not be possible because of availability of space in the office the most commonly accepted distance where the computer display should be placed is 50-70 cm from eyes. However, screen size and font size used while working should be taken into consideration while deciding onto it.

- The height of computer monitor determines the working viewing height. Several factors influence this decision. The objects lying at distance

are generally placed higher in the field of view and the objects lying at the near distance are placed lower. This is well accepted by the ophthalmic lens designers when they designed all the optical correction for the presbyopia providing distance correction at the top of the lens and near correction at the bottom of the lens. But since the advent of computers in the close work, the viewing height has become an important issue as it exposes the user to a different ergonomic world. The optimal height of the screen depends on several factors and also people adapt to the vertical location of their task by changing their gaze angle or by changing neck position or both. If the computer display is kept higher, it forces the user to keep his eyes wide open and exposes him to more discomfort glare. Higher gaze angle results in a greater exposed ocular surface, resulting in increased amount of tear evaporation and adding to dry eye problem. There are some accommodative advantages to having down gaze as against straight ahead gaze. It has been studied that the amplitude of accommodation

is greater with downward viewing position compared to upward viewing position. Also while looking down, your eyes have natural tendency to turn inwards and focus for near objects. The opposite is true for looking straight ahead or upwards your eyes tend to turn outwards and focus at a distance, and you will have to work harder to focus for close objects with your head in this position. All these indicate better performance and comfort with down gaze compared to up gaze. It justifies keeping the computer display slightly below the horizontal visual line of the user so that user has a down gaze angle of 15-20° relative to straight ahead gaze.

- A comfortable chair is most important for the computer user as he spends almost entire day sitting on it. It must be designed to his body with easily adjustable and reachable controls. The chair should have five legs with lockable casters to prevent tipping and allow easy roll on the floor. It should have large, wide and soft padded two armrests to support the forearm. The

backrest should be large enough to support the entire back and should contour to the curve of the lower back.

- Computer desk should provide adequate space to place both the feet together with footrest if needed. The top of the desk should be laminated with matte surface to minimize the glare. It should be large enough to accommodate all the parts of computer system with all attachments needed to work efficiently. It should also have two accessory drawers, pull-out keyboard tray with safety stop, and elevated shelf to accommodate the printer.

A good lighting is very critical for computer working station. A good lighting is the situation when all the visual objects in the field of view are uniformly or near uniformly illuminated. Working on computers is different than working with paper and writing materials. Computers are self-illuminated, whereas papers need illumination from different sources. This is one of the reasons for discomfort glare. The other glare sources are bright open windows, horizontal

fixation point, and white paper on desk, any glossy surface in the field of view, white table tops, and shiny finish walls. There are basically two types of lighting arrangements-overall lighting and task specific lighting. Task specific lighting can put directly on the specific object in such a way that it illuminates the object of interest uniformly and adequately and is not hitting the eyes directly. While installing overall lighting care should be taken to ensure at least 300-500 lux illumination. There are different types of lights available. Some of the examples are fluorescent lamps, tungsten halogen, incandescent lamps and mercury and metal halide lamps. Tubular fluorescent lamps are one of the most common sources of commercial lighting and also are among the most efficient. Light fittings should be installed in such a way so as to ensure uniform light distribution to prevent discomfort glare. In large office where a series of overhead lights are installed, it is always better if the workers look along the rows of lights while viewing computer display rather than across the rows.

He also discussed about issues related to hardware and attachment:

Computer Monitor: A correct placement of monitor is very important to minimize the symptoms of computer vision syndrome.

Monitor Distance: Place the monitor at a distance of 50-70 cm from the eyes. If you are presbyopic, set the distance to your refractive correction.

Monitor Height: Adjust the height of the monitor screen to allow gazing slightly down to view the center of the screen.

Monitor angle: Tilt the monitor screen slightly to accommodate your line of sight. If you are using bifocal glasses, monitor position might be shifted lower.

Monitor Size: Monitor should be large enough to display sizeable amount of information.

He also discussed about ideal sitting posture while working on computer:

- Head slightly tilted downward
- Shoulders relaxed, not elevated, hunched or rotated forward
- Elbow close to your sides and bent at about 90° angle
- Use the Chair's backrest to support your lower back or lumbar curve.
- Sit with your entire body upright or leaning slightly back
- Keep your wrists straight while you work, not bent up, down or to the sides.
- Place your feet slightly out in front of your knees and make sure they are comfortably supported, either by the floor or by a foot rest.

He also gave some suggestion about what can be an ideal computer workstation:

- Work area should be large enough to provide some body movement in addition to be enough for equipment and other accessories.
- Place those items in your nearest reach which are used more frequently.
- Avoid overcrowding.
- Do not direct the warm airflow from CPU towards you.

- Monitor placed at correct distance and height.
- Copyholder and other accessories are at appropriate position.
- Adequate overall light arranged as explained earlier.
- Provision for task specific light.
- Comfortable chair.
- Large size monitor with good pixel setting.

He also discussed about some solutions related to discomfort glare. He said that

- A good lighting arrangement illuminates all of the visual objects in the field of view with nearly equal brightness. Over-illumination, unequal distribution of illumination, improper light fitting, auxiliary light fitting-all may cause discomfort glare. When you find out the source of discomfort glare, simply turn off the offending light source, Many times, it is one single offending fixture in the ceiling that is creating nuisance.
- In the second step, check the screen brightness, the brightness of the screen should be adjusted to match the brightness of the visual objects

letters on white background are better option than white letters on black background.

- Tinted lenses per se do not help controlling the glare. The reasons are simple. Tinted lenses reduce light transmission and thereby reduce the overall effect of illumination. There are certain additional advantages of using tinted lenses as they increase contrast, reading comfort and provide relieves to light sensitive patients.
- Use blinds and drapes may be advised if the window view is considerably brighter than objects in the room, then it is wise to use blinds or drapes on windows. Using visor at times is also a very efficient way to eliminate the brightness of overhead fixtures.
- Reorientation of workstation may not be possible in many cases hence it is advised at the last. It is aimed to eliminate the sources of bright light from the field of view. Sometimes by just rotating the working desk by 90° so that light sources and bright window are not in the field of view works wonderfully. Idea is to control the brightness ratio

between the screen and the window or light source. Windows are not the source of discomfort glare in large offices. In large modern offices polished floorings, glass partitions and polished table tops may be the common sources of glare.

He also discussed about reflection and computer display. He said that the old CRT screen had lot of reflection issues, that has been mitigated to a great extent with the introduction of LCD and LED screens. Screen reflections are more noticeable when the person is using a dark background display, i.e. white characters on a black background. The reduction of contrast is noticed more with this polarity because of darker background compared to surrounding luminance. Switching over from dark background polarity to light background polarity may significantly reduce the reflection problem. In case the user cannot alter the polarity which is quite likely in many cases of ocular pathology, use of anti-reflection filter may be indicated. The use of anti-reflection coated filter is very useful for screens with dark background in the presence of

screen reflections. Reflection problem can also be mitigated by adjusting the screen brightness with the help of brightness adjustment range of computer display itself in case of white background. Another way to prevent reflection is to put a hood on the computer display to stop light from impinging on it. This is like placing a visor over the screen. But they are not very effective as they completely block light and allows light only from selective directions.

He discussed that an optometrist can only suggest the remedial measures for reflection related issues if he himself conducts a workplace evaluation. he said that the following suggestions may help:

- Remove the source of the reflections, if possible. Use window blinds or turn off the offending lamp.
- Tilt or rotate the display to some other direction.
- Alter the workstation orientation to eliminate specular reflection.
- Replace the computer monitor if it is too old and scratched.
- Switch the polarity to dark characters on a light background.

O. Ostberg mentioned that laser optometer technique can be used to assess fatigue in the visual accommodation system. It was shown that accommodation levelling-out (distance myopia and near hyperopia) resulted from a period of work at a visually taxing vdu task, and to some extent also by less taxing vdu tasks. (*Accommodation and visual fatigue in display work*)

Sumio Yano, Shinji Ide, Tetsuo Mitsuhashi, Hal Thwaites said that the images that are displayed are of two kinds. One was a stereoscopic image sequence produced experimentally about 10 years ago called 'Waffen'. The other was a stereoscopic image recorded in Africa in 1998, entitled 'Africa'. The difference between the two was the setup of the camera that was used to record the scene. They said 2D images were displayed by supplying a left eye picture from the stereoscopic pair to the two projectors. The subjects wore polarized filter glasses in the case of viewing a 2D image and the stereoscopic image. In their experiment, accommodation

response was measured in the before and after conditions for viewing the stereoscopic image and 2D image. And in the case of a subjective estimation, the evaluation value of the subject's response was measured via a voltage change of a potentiometer, which was then converted by an AD converter and recorded on a PC. They used a standard analysis technique for evaluating the visual fatigue from accommodation responses. The change of amplitude of accommodation response was measured for evaluating visual fatigue. They found that when viewers watched stereoscopic HDTV images for about 1h, some felt visual fatigue, and the degree of fatigue depended on the display and pickup system of the images. The subjective estimation of visual fatigue was 2.35 for the stereoscopic image and 3 for the 2D image as a simple average of the five subjects. The visual fatigue caused from viewing stereoscopic images was examined by the change of accommodation response before and after watching stereoscopic and 2D images. However, they cannot understand which image scene affects viewers as regards visual discomfort from only evaluating the

accommodation response before and after watching test images. They required subjects to evaluate test images using a single stimulus quality evaluation (SSCQE) at the point of visual comfort and discomfort and this human visual function suggested that subjects perceive double images for moving objects in the stereoscopic images. They presumed that the image display method and electric properties in their experiment did not affect the evaluation of visual fatigue. First, stereoscopic HDTV images were converted to field sequential stereoscopic HDTV images, because if the feature characteristics of test images are calculated in the stereoscopic HDTV video format, huge memory and fast computing equipment are necessary. They studied visual fatigue caused by 2D and stereoscopic images that were picked up using a cross set and parallel set stereoscopic camera. We measured that the degree of visual fatigue from the change of accommodation response before and after viewing images for about 1h, and evaluated using a subjective test method. They detected visual discomfort image scenes from the test program using the single stimulus continuous

quality method for the viewing images. The relationship between the results of SSCQE and the feature characteristics of test stereoscopic images were examined. A local low subjective evaluation appeared for both high degree of correlation, which means large parallax, and large amount of motion in the test stereoscopic images. Otherwise, even if the amount of parallax was large but motion components were very small, the subjective evaluation value was rarely very low. They said that the results will be used for the study of visual comfort of stereoscopic images and investigation of the cause of visual fatigue when viewing stereoscopic images.

(A study of visual fatigue and visual comfort for 3D HDTV/HDTV images)

Susumu saito said electrooculography which detects the steady potential of eyeball and the optical method which utilizes optical reflection of infra-red rays from the corneal surface are considered to be the most appropriate tools for ergonomic application. The optical method was used in their study to detect binocular eye movements in horizontal

and vertical directions with relatively high accuracy. The records of eye movement during many visual tasks such as VDT operation and document reading shows the discrete and intermittent trajectories. They said that these eye movements are called saccades. The obtained eye movement data were fed into a computer and divided into saccadic and fixation phases using an optimum computer algorithm. Characteristics of eye movements were analysed and divided into two categories, namely fixation and saccadic phases. Fixation phase was numerically expressed in terms of its two-dimensional location and stationary time duration. Saccadic phase was characterized by its frequency, amplitude and direction. They said that integrated features of eye movements in various visual works could be expressed by the following in two ergonomic indices. The first, fixation area, was obtained from the numerical product of horizontal and vertical standard deviations of spatial distribution of fixation points. The second, average saccadic velocity, was computed as the product of saccadic frequency multiplied by mean saccadic amplitude. The former index represents the viewing

extent and spatial characteristics of eye movements in the work. The latter value corresponds to the temporal aspects and is considered to stand for the amount of restless eye movements. They said that these analyses are able to describe objectively and quantitatively ergonomic aspects of different kinds of work. They have also mentioned that it may be possible to compare the various visual works with each other using the two indices. They have said that there is a possibility that a display polarity can affect eye movement because a positive type CRT which has dark characters on light background was recommended to be more suitable than a negative one for VOT use according to the physiological analyses of lens accommodative response (Saito et al. 1989) and of pupil response. In their Data Analysis they have mentioned about Critical flicker frequency (CFF) which was measured intermittently throughout the experiment. The CFF value which they obtained before the start of the eye tracking tasks was considered as control data. In their Statistical Analysis Analysis of variance was used to analyse the characteristics of eye movements, frequency of tracking tasks, correct

percentage of character discrimination and display polarity. Analogue voltages corresponding to fixation points of both eyes were recorded on a pen recorder during eye tracking tasks and simultaneously fed to the magnetic tape of a data recorded for further analysis. For their experiment the subjects were six adult males' with an average age of 20-8 with standard deviation 12 years. None of the subjects had any visual defects.

(Does fatigue exist in a quantitative measurement of eye movements)

Masaru Miyao, Selim s. Hacisalihzade, John s. Allen & Lawrence w. Stark 's purpose of their paper is to examine the effect of VDT quality on visual fatigue and to measure the effect of character size and display resolution on readability. In their paper the effects of VDT resolution on visual fatigue and readability were studied. They used two kinds of displays with different resolutions (1664 x 1200 pixels and 720 x 350 pixels) and fonts. They carried out measurements of reading, visual smooth pursuit tracking, and blink rate on subjects reading from VDTs of different resolutions. High

resolution VDTs have recently been introduced to the mass consumer marketplace. They mentioned that subjective claims have been made that these high resolution VDTs reduce the amount of eye strain in their users (Anon. 1987). There studies of EEG P-300 latency (the P-300 is a positive, large amplitude electroencephalographic potential that peaks about 300 ms after the presentation of a novel stimulus) indicate that smaller characters presented on a VDT are processed more slowly than larger ones (Fagan et al. 1986).

Their subjects read from two different video display terminals : (1) a high resolution laser view terminal built by Sigma Design, Fremont, California (1664 x 1200 pixels = 2.0 Mpixels; line distance = 0.25 mm; luminance range, 6 [dark] to 91 [bright] candelas/m²; contrast ratio = 15); and (2) a standard display terminal (720 x 350 = 0.25 Mpixels; line distance = 0.5 mm; luminance range, 4 to 76 candelas/m²; contrast ratio = 19). They said that the 19 inch, high resolution laserview terminal will hereafter be referred to as the H type display; the 12 inch standard terminal will be called the S type display. They mentioned Aa

displayed page was made up to 30 lines of text with 73 characters lline. Their subjects were allowed to assume their preferred viewing distance and seating posture. Lighting and environmental conditions were identical throughout their experiments. Their primary visual task consisted of reading continuously and without rest from each of the terminals in separate 1h sessions on different days. They mentioned that visual fatigue due to reading from standard resolution and high resolution video display terminals could not be satisfactorily measured in their study. Furthermore, they also said that no difference between the two terminals in subject performance could be discerned through before and after reading measurements of visual smooth pursuit tracking. They found that blink rate was lower for subjects reading from the high resolution terminal. Their analysis of reading eye movements for displayed texts with different character formats and resolutions demonstrated that the display resolution did not have a significant effect on readability of sufficiently large characters. However, they found that for very small characters, higher resolution

improves readability.

(Effects of VDT resolution on visual fatigue and readability: an eye movement approach)

Atsushi Uetake, Atsuo Murata, Miho

Otsuka and Yosuke Takasawa developed equipment that can simultaneously measure pupillary change, focal accommodation, and eye movement. The changes in these three physiological measures, taken during a VDT task, were used to propose an index for evaluating visual fatigue by them. They mentioned that a few studies have revealed significant relationships between the photometric characteristics of VDTs, such as screen flicker, excessive luminance, the contrast ratio between screen and environment, and reflected glare. They have also said that at present there is no definite method to evaluate visual fatigue in individuals working with VDTs. In other words they meant decreases in both focal accommodation and activity of the autonomic nervous system, which are major characteristics of mental fatigue, must be considered as a whole to assess visual fatigue. Eye movement, pupil diameter and focal

accommodation were measured. Using these measurements, the following parameters were obtained by them : Maximum and minimum pupil diameters, velocities of focal accommodation for constriction and dilation, and width of focal accommodation. They suggested that the decrease in focal accommodation and pupil diameter becomes more and more outstanding with time. The partial correlation coefficient obtained by them were valid only for the subjects in their study. They have mentioned that for a different population, a unique regression equation must be obtained using a similar experimental paradigm. They said that once the equation is obtained, the index can be used to evaluate visual fatigue for the population. Using both pupil diameter and focal accommodation, visual fatigue in VDT tasks can be evaluated effectively. They said the index proposed by them can be used to evaluate visual fatigue in VDT tasks if the following three conditions are met :

- Head movement is limited and infrequent.
- The task requires the subject to use his or her function of focal accommodation.

- During the task, there is no outstanding change in the lighting environment.

(Evaluation of Visual Fatigue during VDT Tasks)

Tsuneto Iwasaki & Shinji Kurimoto

described that relaxation time in accommodation lengthened and the latency of the positive wave appearing at about 100 ms in VEP increased with the increase in visual load. They said that complaint rate for eye-strain was higher in the group given heavier visual work. They said there was no significant difference in amplitude of VEP before and after the visual task. They studied dynamics of VEP and accommodation as objective findings in eye-strain by experimentally changing the amount of visual stimulation. Their investigation of subjective symptoms was made before and after each visual task using the questionnaire for differential diagnosis of eye-strain (Suzumura 1974). The time of measurement of VEP and accommodation movement were recorded before and just after the visual task. The measurements before were made after a 30-minute rest

in a test room, VEP was recorded before accommodation. Nine women, free of eye disease with an average age of 22 years, with emmetropia, showing an accommodation whom accommodation times could easily be measured, were selected as subjects. Muscular accommodation was measured using an infrared optometer and the VEP are methods of objectively assessing the condition of visuo-physiologic function independent of any subjective response. Relaxation time was lengthened after visual tasks, more so after a heavier load. Incidentally they mentioned about, Baschera and Gratidjean (1979) who gave subjects three kinds of repetitive mental tasks, similar in quality but different in difficulty and compared the changes in value of critical flicker fusion (CFF). According to them, CFF frequency fell most in the group given the easiest task, while it did not change at all in the group with the task of intermediate difficulty. The CFF of those given the most difficult task fell, but less than that of those subjected to the easy task. If CFF can be used as an index of cerebral action, they said it may be suggested, using their data that the decrease in cerebral

activity after the task with a low or high degree of difficulty may have developed as follows: through monotony, in the case of repetitive task with a low degree of difficulty, or in the case of difficult task through a possible centrencephalic fatigue. To clarify the mechanism of eye-strain caused by visual work, they said it was necessary to make the study from both sides of the central hypofunction in the cerebral cortex, controlling the activation and arousal function and the local hypofunction in muscles such as the conduction area of stimulation and ciliary muscle.

(Eye-strain and changes in accommodation of the eye and in visual evoked potential following quantified visual load)

Chia-Fen Chi and Fang-Tsan Lin described seven methods of measuring visual fatigue accommodation power, visual acuity, pupil diameter, critical fusion frequency (CFF), eye movement velocity, subjective rating of visual fatigue, and task performance – for their sensitivity to visual load. They said actual or potential applications of this research include using some of these assessment

techniques for the design of adaptive displays. They mentioned that Saito, Taptagaporn, and Salvendy (1993) and Iwasaki and Kurimoto (1987) measured the degree of eyestrain caused by visual work by measuring the temporary change in accommodation power following VDT work. Haider, Kundi, and Weissenbock (1982) measured visual acuity before and after the working period in order to indicate functional changes in the accommodation mechanism, and they reported that the decrease of visual acuity during work correlated well with different lengths of working periods. They mentioned that an increase in pupil size adversely affects the depth of focus and the precision required of the accommodative responses and thus pupil size has been used as an indicator of visual discomfort. They said that accommodation power, visual acuity, pupil diameter, eye movement velocity, CFF, subjective rating scales, and task performance are all potentially useful measures of visual fatigue. They said short viewing distance may increase the muscle strain in the oculomotor mechanisms of accommodation and convergence, and this change in muscle

strain can best be measured by the change in accommodation power. They have also mentioned that low luminance contrast may reduce the visual resolving ability in the retina, and this change in visual resolving ability can be best indicated by the decrease in CFF. Viewing distance, luminance contrast, and target velocity were manipulated in the monitoring, reading, and tracking tasks, respectively. They described that tracking targets moving at high velocity may create eye movement load, and this load can be best measured by the eye movement velocity, the pupil diameter, or both. They used a three factor within subject design for the sensitivity analysis. Task, load, and measurement technique were the factors with three, two, and seven levels, respectively. After each experimental task was performed, they have shown a rating scale for seven descriptive items on screen to collect a subjective rating of visual discomfort (Laubli, Hunting, & Grandjean, 1981; Saito et al., 1994) and those are :

- (a) My eyes feel tired (visual fatigue);
- (b) Eye dry, irritated or burning;
- (c) Eye pain;
- (d) Hard to focus my vision;

- (e) Double vision on screen;
- (f) Flicker vision;
- (g) Headache.

Each item was rated on a five-point scale for severity of discomfort. After the participant completed the subjective rating scale, accommodation power, CFF, and visual acuity were measured again. Pupil size, eye movement amplitude, and frequency data were collected during the task performance. They said that visual acuity was sensitive to the luminance contrast ($p=.005$) in reading and accommodation power was sensitive to the viewing distance in monitoring. Tracking speed in tracking ($p = .049$), and visual acuity was sensitive to the tracking speed in tracking. They mentioned about a nonsignificant load effect on task performance indicated that participants maintained the same performance level across two load levels by devoting more resources to the high-load conditions. Eye movement velocity and subjective rating of visual fatigue were both very sensitive to the changes in target velocity for this dynamic visual task. In contrast to Taptagaporn and Saito's (1990) finding, they said pupil diameter was significantly related to the subjective rating of

visual fatigue. It was suspected that the subjective rating could be affected by accommodation power, which was in turn adversely affected by an increase in pupil diameter. However, the correlation supporting this interpretation was not strong. Their current experiment compared the sensitivities of visual fatigue measurement techniques with the commonly seen stressors in VDT tasks: short viewing distance, low luminance contrast, and fast-moving targets. They chose to manipulate the load levels differently for three different VDT tasks in order to compare how the sensitivities of measurement techniques varied among tasks. They mentioned about Malmstrom, Randle, Murphy, Reed, and Weber (1981) who suggested the need for an integrated model for studying visual fatigue. The lack of a simple one-to-one correspondence between task characteristics and measurable visual symptoms is somewhat disappointing to human factors engineers seeking diagnostic tools to improve VDT task conditions. However, they mentioned that as visual fatigue has become a great concern in the design of human-computer interfaces, some of these assessment techniques

could potentially be applied to the design of adaptive displays. That is, the human computer interface (display) could be adapted to the level of visual fatigue evaluated by reliable indicators, such as pupil diameter and eye movement velocity. They mentioned that perhaps the wording and tone of help messages could be adapted depending on the visual fatigue of the users (Eberts, 1994).

(A Comparison of Seven Visual Fatigue assessment techniques in three data acquisition VDT tasks)

Agnieszka Wolska & Marcin Switula

said that visual fatigue was measured both by a subjective evaluation of different visual complaints (asthenopic symptoms) and by objective measurements of changes in the following visual functions: accommodation, convergence, habitual horizontal phoria, critical fusional frequency (CFF), and visual acuity. They performed same experiments for CRT (Cathode Ray Tube) and LCD TFT (Liquid Crystal Display with Thin Film Transistor) screens. The results

of their study have shown that there was no significant influence of the value of surrounding luminance on the asthenopic symptoms for either type of screen. A general tendency towards bigger visual complaints for LCD TFT than for CRT participants was found in their study. They described the way of establishing appropriate lighting parameters, especially for new and complex types of visual work, through modeling different lighting conditions and investigating both the subjective evaluation of lighting and the objective measurements of visual performance or visual fatigue. They said that visual performance is usually evaluated by measuring the time needed to perform the task and the number of mistakes. It has been stated that visual fatigue manifests itself in the weakening of a variety of visual functions. It usually manifests itself in the form of specific complaints reported by persons who perform strenuous and extended visual tasks. They said that the term that is used to describe symptoms associated with the use of eyes is asthenopia. They described that the subjective evaluation of the visual complaints

(asthenopic symptoms evaluation) was established by a questionnaire (Visual Analog Scale 0-100, where 0 means no complaints and 100 means very intensive complaints) filled in by the participants at the end of each experiment. They have mentioned that questionnaire form was taken from a standardized research protocol of the MEPS project Musculoskeletal, visual and psychosocial stress in VDT operators in optimized environment. They mentioned that Gunnarson and Soderberg (1983) found a decrease in the near point of accommodation after strenuous VDT work but those changes were accompanied by increases in the subjective symptoms of visual discomfort, which did not occur in their present study. They have said that these results are supported by the results of Gunnarson and Soderberg (1983), who reported an increase in the near point of convergence (i.e., a reduced ability to converge) after VDT work (Megaw, 1995).

(Luminance of the Surround and Visual Fatigue of VDT Operators)

Kimiko Kawashima, Jun Okamoto, Kazuo Ishikawa and Kazuno Negishi said that the Simulator Sickness Questionnaire (SSQ) is used to evaluate visually induced motion sickness and viewing fatigue, and the Visual Analogue Scale (VAS) is used to evaluate relief from fatigue by requiring the consumption of certain healthy food. They said that these methods are targeted for people who feel extreme exhaustion. biomedical assessment methods who evaluate viewer sensitivity or comfort by measuring their vision. They have conducted experiments on visual fatigue induced by 3D monitors and content, and Visual Display Terminal (VDT) tasks using biomedical assessment methods. No generalized index of visual fatigue has been established in their study. Their aim was to choose specific parameters of biomedical assessment methods that can be used to assess visual fatigue with a high degree of accuracy, similar to conventional subjective quality assessment methods. Therefore they concluded that, CFF was not able to evaluate visual fatigue induced by 3D videos in which the quality of left and

right frames differ due to encoding. Their results showed that the greater the difference between the left and right frame quality in the 3D videos, the greater the number of eyeblinks. Their result matched the accuracy of conventional subjective quality assessment methods of "visual fatigue". Therefore, they determined that eye-blink could be used to evaluate visual fatigue induced by 3D videos in which the quality of left and right frames differ due to encoding. They mentioned that in a previous study, the results showed that the number of eye-blinks was higher when watching 3D video than in 2D video. They said that eye-blinking was considered as an indicator for measuring visual fatigue. Then they determined that pupil constriction rate could not be used to evaluate visual fatigue induced by 3D videos in which the quality of left and right frames differ due to encoding. With the analysis of eye-movements and consider whether pupil diameter and other parameters of eye-movements can be used to evaluate the visual fatigue or not they chose biomedical assessment parameters that can be used to evaluate the visual fatigue with

about a 5% significant difference using the paired t-test, and that match the accuracy of the conventional subjective quality assessment methods of "visual fatigue". They mentioned that out of these parameters, eyeblink is a possible parameter for assessing visual fatigue induced by 3D videos in which the quality of left and right frames differ due to encoding.

(Parameter Comparison of Assessing Visual Fatigue Induced by Stereoscopic Video Services)

Atsuo Murata , Atsushi Uetake , Miho Otsuka & Yosuke Takasawa said that the study described in their article was designed to evaluate visual fatigue induced during video display terminal (VDT) tasks. They mentioned about newly developed equipment which was used which can simultaneously measure pupillary change, focal accommodation, and eye movement. The changes in these 3 physiological measures, taken during a VDT task, were used to propose an index for evaluating visual fatigue. Through multiple regression analysis, an index to describe the psychological sense of visual

fatigue was obtained. They said that the index can be used to assess visual fatigue induced during a VDT task if the following 3 conditions are satisfied:

1. Head movement is limited and infrequent.
2. The task requires focal accommodation.
3. During the task, there is no outstanding change in the lighting environment such as luminous intensity or brightness.

They said when evaluating fatigue, it is necessary to use multiple measures, and the change of these measures does not necessarily reflect the fatigued state. Therefore, they said that it is possible that the evaluation of fatigue using only one measure leads to low reliability. They have cited that the evaluation of fatigue using multiple measures is desirable and may increase the reliability of evaluation. A combination of measurements is important to evaluate fatigue with high reliability. They mentioned about Takeda et al. (1985) and Takeda et al. (1988), using stereoscopic pictures, tried to evaluate visual fatigue on the basis of a few measures (focal accommodation, eye movement, and changes in iris area). Their studies only compared measures before and after an experimental task

and concluded that clear accommodative responses to stimuli might cause visual fatigue. They mentioned that none of these studies proposed an index to evaluate visual fatigue based on a combination of measurements.

They said that if we predict that the symptoms of visual fatigue contribute to general fatigue—particularly, mental fatigue—visual fatigue cannot be evaluated properly with only one measure. They stressed that evaluation must be performed from multiple viewpoints, including simultaneous consideration of focal accommodation, eye movement, and pupillary change. In other words they said that it decreases both focal accommodation and activity of the autonomic nervous system, which are major characteristics of mental fatigue, and it must be considered as a whole to assess visual fatigue. They have also mentioned that it is also important not to compare these measures before and after a VDT task, but to explore the change in these measures during the task. Using these measurements, they obtained the following parameters: maximum and minimum pupil diameter, velocity of focal accommodation

for constriction and dilation, and width of focal accommodation. The velocity of focal accommodation was calculated using the time series of focal accommodation and differentiating the time series with time. It corresponded to the mean value of more than five local maxima. They have said that visual fatigue is induced during a VDT task lasting about 1 hr and mentioned that this type of fatigue did not affect work efficiency. They mentioned that decrease in focal accommodation and pupil diameter becomes more and more outstanding with time. They mentioned that it is well known that the pupil is innervated by the autonomic nervous system. A decrease in pupil diameter indicates the dominance of the parasympathetic nervous system and the deceleration in activity of the autonomic nervous system. The decreases in velocity of focal accommodation for constriction and width of focal accommodation reflect that the focal accommodation function deteriorated with time. They found that pupil diameter, velocities of focal accommodation for dilation and constriction, and width of focal accommodation all had negative

correlation coefficients with the rating score of visual fatigue. They have also found that correlation coefficient between minimum and maximum pupil diameters was very high. The correlation coefficients between the percentage correct and other measured items were very low. They mentioned that a decrease in pupil diameter is indicative of a decrease in the activity of the autonomic nervous system. They said that this shows that the parasympathetic nervous system is dominant. They found that a decrease in velocity of focal accommodation for constriction and width of focal accommodation indicates the decreased function in the visual system itself. As predicted, they have shown that it is not proper to evaluate visual fatigue using only focal accommodation. They attempted to assess visual fatigue from physiological, psychological, and performance aspects. In their study, which required the participants to perform a VDT task lasting 1 hr, the effect of visual fatigue on performance seemed to be, at most, very weak. On the other hand, they found that the signs of visual fatigue appeared clearly in both physiological and

psychological measures. They reported that psychological feeling (rating) of visual fatigue was strongly related to physiological measures that reflected the functions of the autonomic nervous system and focal accommodation.

(Proposal of an Index to Evaluate Visual Fatigue Induced During Visual Display Terminal Tasks)

F Mocci, A Serra, G A Corrias said their investigation was conducted on a selected population of subjects with superimposable environmental working conditions and work duties. All the subjects were without oculovisual abnormalities. They said that this selection was made to reduce or exclude the presence of asthenopic disturbances resulting from environmental, and ergonomic factors, or refractive conditions of the subject. In these conditions, their study showed clearly that several psychological factors were predictors of visual complaints. The model elaborated in the regression analysis accounted for 30% of the variance in the reporting of visual complaints with video display terminals.

Out of a population of 385 bank workers, a group of 212 subjects without organic visual disturbances (as determined by ophthalmological examination) who share a work environment and job duties was selected. They administered three questionnaires to their subjects: (a) the NIOSH job stress questionnaire; (b) a questionnaire investigating subjective discomfort related to environmental and lighting conditions of the workplace; (c) a questionnaire on the existence of oculovisual disturbances. Correlation and multiple regression analyses were performed by them to examine for the presence of predictors of asthenopia. They calculated Pearson's correlation coefficient to evaluate the relation between the psychological factors and asthenopia; the same relation with the environmental variables was calculated by them with Kendall's tau-b because of their non-normal distribution. A hierarchical regression procedure was used to assess the presence of predictors of asthenopia and eventual variables with moderating effects. In the first step, the main effects of age, sex, and environmental discomfort were assessed; age and sex were controlled because they

may event both the stressors exposed to, and reactions to these stressors. In the second step the psychological variables (role stressors, support from coworkers, mental workload, underuse of skills, work satisfaction, interpersonal conflict, self esteem) were inserted. To verify a moderating effect of colleague, support on the relation between psychological stressors and asthenopia, in the third step the cross product terms between each stressor and support from coworkers were entered by them. (*Psychological factors and visual fatigue in working with video display terminals*)

Donghyun Kim, Sunghwan Choi, Sangil Park and Kwanghoon Sohn in their paper proposed an experiment that assesses the fusional response curve and eye-blink rate to measure visual fatigue induced by stereoscopic videos. From the experimental results, they verified that while watching 3D video, viewers who have slow fusional response and low fusional limits are more sensitive to visual fatigue. In addition, eye blinks were more frequent when viewing the video with moderate visual fatigue

than with low visual fatigue. They predicted the visual fatigue using the analysis of parallax distribution by dividing the image into nine regions. Objective measurements of visual fatigue, including accommodation, visual acuity, pupil diameter, critical fusion frequency and task performance were compared by them. They mentioned that Barkowsky and Callet conducted a search task experiment with an eye tracker to measure the length of the visual track, duration of fixations, number and angle of saccades and number of blinks. They mentioned that Emoto et al. assessed subjective visual fatigue by measuring changes in the fusional amplitude and the ratio of accommodative convergence to accommodation demand (AC/A) after 1-hour of viewing conventional 2DTV and 3DTV. In their paper, they proposed an experiment that assesses the fusional response curve and eye-blink rate to measure visual fatigue induced by stereoscopic videos. They said that fusional limit and response were analyzed to discriminate the individual ability of 3D fusion and compared with subjective evaluation and descriptive self-

report. In addition, they classified videos into two sessions; videos with moderate visual fatigue and videos with low visual fatigue. Then, they compared the number of eye blinks between the sessions and the average number of eye blinks over the first and second half of the sessions. Many factors that affect the eye blinks, such as luminance of contents, condition of subjects, laughing or yawning were observed. In addition, they mentioned that 3D glasses degrade luminance and eye blinks naturally have large individual differences. Therefore, they said they must analyze the individual eye blink characteristics, in order to utilize eye blinks as an indicator of visual fatigue. (*Stereoscopic visual fatigue measurement based on fusional response curve and eye-blinks*)

J. Kuze, K. Ukai developed a questionnaire to subjectively assess visual fatigue caused by viewing various types of motion images. The questionnaire was evaluated using four types of moving images; playing a TV game using an HMD or a TV, viewing images with and without stabilization

of camera shake, viewing a movie with and without colour break-up and viewing either a stereoscopic movie (anaglyph method) or a nonstereoscopic movie. Their factor analysis revealed five factors: (1) Eye Strain (2) General Discomfort (3) Nausea (4) Focusing Difficulty and (5) Headache which were effective for classifying motion images.

(Subjective evaluation of visual fatigue caused by motion images)

A.J. Dittner, S.C. Wessely, and R.G.

Brown said with the growing recognition of fatigue as a major clinical problem in many conditions, there has been a proliferation of measures of fatigue, often referred to by synonyms or abbreviations shared with other scales. They said that information that are derived depends on the questions being asked and those were based on the scale developer's own conceptualisation of fatigue and will in turn be answered by the respondent based on his or her own interpretation. They mentioned that these will be based on the scale developer's own conceptualisation of fatigue and will in turn be answered by the respondent

based on his or her own interpretation which means that different scales may be measuring fundamentally different aspects of the fatigue experience or even potentially distinct constructs. In addition they mentioned, where an instrument has been developed specifically to measure fatigue in one clinical condition, its use in other patient groups may not be justified if the fatigue experience differs from group to group. Their purpose of the present review is to describe the range of instruments available and to provide guidance on choosing a scale for a specific use. They said it does not seek to compare scales directly although published studies that have sought to do were discussed by them. Medical Library Subject Heading (MESH) term "fatigue" (synonym "lassitude," previously "tiredness") said the scope of this term is defined as "the state of weariness following a period of exertion, mental or physical characterised by a decreased capacity for work and reduced efficiency to respond to stimuli." They said it is distinguished from "muscle fatigue" defined in MESH as "a state arrived at through prolonged and strong contraction of a muscle." They said this

is one of the best known and most used fatigue scales. They mentioned that the FSS principally measured the impact of fatigue on specific types of functioning rather than the intensity of fatigue related symptoms.

(The assessment of fatigue: a practical guide for clinicians and researchers)

Tsuneto Iwasaki, Shinji Kurimoto &

Kageyu Noro in their study used two groups of normal subjects who were loaded an experimental visual task, or a calculating and discriminating task, on a CRT display screen under different work speeds and amounts. The colour (red, green and yellow) CFF values of the subjects were measured every 15min during the task and their accommodative function, represented by the accommodation time, was measured before and after the task. In their study the two groups of subjects showed no significant differences in the pattern of change in the colour CFF values. The green and yellow CFF deteriorated significantly at 30min after the start of the task. The red CFF values decreased significantly at 15 min after the start of

the task and this conditions continued to the end of the task. Both groups showed a lengthening accommodation relaxation time but no change in the accommodation relaxation time after the task was observed by them. This increase in the relaxation time was larger in the group of subjects who were loaded a larger amount of work at a higher speed. The results of their study suggested that the decrease in the CFF value of the subject, particularly when the subject sees light directly using a CRT - display screen, does not signify the decline in the activity or consciousness level of the brain centre alone, but it is said that the decrease in the CFF value is correlated with the appearance of mental fatigue and the deterioration of the arousal and consciousness levels of the brain centre (Simonson and Enzr 1941, Hashimoto 1960, Hashimoto 1963, Oshima 1979, Baschera and Grandjean 1979, Weber et al. 1980, Kumashiro et al. 1984, Kawamoto et al. 1984, Nishimura and Morimoto 1986). They mentioned that the CFF value is used as a measure of quantification, not for fatigue at the periphery of the visual system but for fatigue at the centre of the visual system

or mental fatigue. They mentioned that in the field of psychiatry, CFF examination is used to judge the psychological sedative effect of drugs (Fink and Irwin 1982, Parrott 1982, Hobi et al. 1982). They mentioned that the CFF value is not so sensitive to drugs as the variation of the brain wave is, but it is confirmed that CFF value is a sufficient index of the activity of the cerebral function. CFF value was observed to decrease with increasing intraocular pressure within a normal range and a positive correlation was noted between the intraocular pressure and CFF value. They said that CFF value decreases with the short wavelength of blue and long wavelength of red and is the largest with the medium wavelengths of green and yellow, or varies with the wavelength of specific light sources when the light sources are of the same luminance. The CFF values of the subjects were measured with a dicker photometer using light-emitting diodes (Handy Flicker HF@, Neitz). Light-emitting diodes of the same luminance as that of red (660 nm), green (555 nm) and yellow (570 nm), respectively, were used as targets. the yellow, red and green CFF values of each subject

were determined in one trial by the ascending method. Three measurements were averaged to obtain the CFF value of the subject. The three colours were measured in three sequences so that each colour came to the first, second and third positions of the sequences Kowa Campbell and Robson 1959, Suzumura 1973, Iwasaki et al. 1982, Sun and Stark 1986, Kruger and Pola 1986, Iwasaki and Kurimoto 1987) was used to measure the accommodative function of the subjects. The accommodation contraction time and accommodation relaxation time of the subjects were objectively recorded. They asked the subjects to fixate on the far target and near target (accommodation stimuli of 3 to 5 diopters) that were alternately presented for 5s each. As the subjects repeated their accommodation five times during this course of time, the change in the accommodative movement was recorded as a waveform. From the recording obtained, the time to the completion of accommodation was measured as accommodation contraction time and accommodation relaxation time (Suzumura et al. 1979, Tucker and Charman 1979, Iwasaki and

Kurimoto 1988), and the mean values of the accommodation contraction and relaxation time were calculated. They explained the measurement of colour CFF values and accommodative movements: The accommodative movements of the subjects were measured before and after the visual task. Since the instillation of oxybuprocaine hydrochloride produced an eye stimulus in the accommodation examination, the accommodative movements of the subjects were measured immediately after the flicker examination to eliminate the effect of the presence or absence of the eye stimulus on the CFF values of the subjects. In their statistical analysis they explained: The differences in the CFF values at the corresponding points of measurement and the differences in the CFF values by colour and the accommodation time between the 2s and 4-6 groups of subjects were tested with paired t-test for significance. The colour CFF values decreased with increasing visual distance, when the visual distance was 10 cm, similar CFF values were obtained with the three colours. When the visual distance is 33 cm or longer, the falling pattern of the red CFF values

was more pronounced than that of the green and yellow CFF values. The standard error increased with increasing visual distance and the variability of the measured CFF values was noted. When the visual distance was 33cm, the standard error was minimum and the results obtained were used as reference data for establishing the visual distance. They found that the green and yellow CFF values exhibited similar changes with time, but the red CFF values exhibited a different pattern of change with time. A statistically significant decline was noted in the red CFF values at 15 min after the start of the visual task and the decline continued to the end of the visual task. The green and yellow CFF values exhibit no statistically significant decrease until 30 min after the start of the visual task. The green and yellow CFF values at 45 min and 60 min after the start of the visual task were somewhat smaller than those before the start of the visual task, but no statistically significant differences were observed in their study. They mentioned that Osaka (1985) loaded subjects a Kraepelin test on the CRT screen for 30 min and measured CFF values with respect to

various colours before and after the visual task. He reports that the reduction in the green and yellow CFF values is smaller than that in the red and blue CFF values and that eyestrain is lower with the green and yellow light sources than with the red and blue light sources. They mentioned that Osaka also discussed that the differences in the green, yellow and red CFF values are correlated with the sensitivity peaks of the respective colours on the sensitivity curve of the retina. They have also mentioned that Hokama (1968) reports that the variations of the colour CFF values of patients having eye disease with the wavelength of colour light sources appear different between diseases of the retina, such as retinal detachment, central retinitis and macular degeneration, and diseases of the optic' nerve, including retrobulbar neuritis and a arachnoiditis opto-chiasmaticus. In other words, patterns of change in the colour CFF values closely represent abnormality of the affected part and especially the periphery of the visual system like the optic nerve and retina. They mentioned that Kelly (1978) reports that the CFF thresholds mainly depend on the action of the visual cells and bipolar

cells in the retina and it is difficult to estimate the meaning of a drop in CFF values as observed in visual tasks of different content from the present visual task and in visual tasks of longer duration than the present visual task. From the results of the present experimental work they said that it cannot be conclusively said that the decrease in the colour CFF values reflects only the activity or consciousness level of the cerebrum.

(The change in colour Critical Flicker Fusion (CFF) values and accommodation times during experimental repetitive tasks with CRT display screens)

Lisa White-head stated that the aim of her article is to present a critical review of fatigue measures, the populations in which the scales have been used, and the extent to which the psychometric properties of each instrument have been evaluated to provide clinicians and researchers with information on which to base decisions. Seven databases were searched for all articles that measured fatigue and offered an insight into the psychometric properties of the scales used over the period

1980-2007. She mentioned that the criteria for judging the “ideal” measure were developed to encompass scale usability, clinical research utility, and the robustness of psychometric properties. She mentioned that a small number of short instruments demonstrated good psychometric properties (Fatigue Severity Scale [FSS], Fatigue Impact Scale [FIS], and Brief Fatigue Inventory [BFI]), and three comprehensive instruments demonstrated the same (Fatigue Symptom Inventory [FSI], Multidimensional Assessment of Fatigue [MAF], and multidimensional Fatigue Symptom Inventory [MFSI]). She mentioned that only four measures (BFI, FSS, FSI, and MAF) demonstrated the ability to detect change over time. It was also mentioned that the clinician and researcher also should consider the populations in which the scale has been used previously to assess its validity with their own patient group, and assess the content of a scale to ensure that the key qualitative aspects of fatigue of the population of interest are covered.

(The Measurement of Fatigue in Chronic Illness: A Systematic Review of Unidimensional and Multidimensional

Fatigue Measures)

E. M. A. Smets, B. Garssen, B. Bonke and J. C. J. M. De has mentioned about Multidimensional Fatigue Inventory (MFI) which is a 20 item self-report instrument designed to measure fatigue. It covers the following dimensions : General Fatigue, Physical Fatigue, Mental Fatigue, Reduced Motivation and Reduced Activity. It was mentioned that this new instrument was tested for its psychometric properties in cancer patients receiving radiotherapy, patients with the chronic fatigue syndrome, psychology students, medical students, army recruits and junior physicians.

(The multidimensional fatigue inventory (mfi) psychometric qualities of an instrument to assess fatigue).

Sumio Yano, Masaki Emoto, Tetsuo

Mitsuhashi stated that the relationship between convergence eye movement and the accommodation function based on binocular fusion, which are shown with Donders’ line, is examined from the

viewpoint of depth of focus. Basic visual perception of stereoscopic images based on binocular fusion, which is related to convergence eye movement and the accommodation function, are examined. They mentioned that Percival's visual comfort area, which was derived from Donders' line, suggests that visual fatigue may be caused by viewing stereoscopic images when stereoscopic images are displayed far from or near to the viewer. They mentioned that the range of Percival's viewing comfort area depends on the individual characteristics of the visual function. There is also an experimental result that indicates the characteristics of binocular fusion for a still stereoscopic image measured using a large number of subjects. They said that gaze point by convergence eye movement and the focus point by accommodation are at the same position when the stereoscopic images are displayed within the depth of field. They said that it is presumed that the visual fatigue from viewing stereoscopic images is not a serious problem under these visual conditions because the gaze point coincides with the accommodation point. They said that one important

point is that these experiments are carried out using only still stereoscopic images, and the motion components of stereoscopic images are not considered in this experiment. They said that the relationship between Donders' line, which shows the relation between convergence eye movement and the accommodation function, and binocular fusion, was examined in terms of the depth of focus based on experimental results to date. They stated that the examination showed that both of these substantial characteristics were almost equivalent

(Two factors in visual fatigue caused by stereoscopic HDTV images)

Kazuhiko Ukai, Peter A. Howarth said it is important to evaluate visual fatigue and sickness caused by viewing images using subjective methods. They mentioned that the Simulator Sickness Questionnaire (SSQ) developed by Kennedy et al is a well known and a well established useful measurement tool for evaluating motion sickness caused by motion images. They said that this was applied to four types of moving images : playing a TV

game using a HMD/TV, viewing images with and without stabilization of camera shake, viewing a movie with and without colour-break-up and viewing either a stereoscopic movie (anaglyph method) or a two-dimensional movie. Factor analysis revealed five factors: (1) eye strain, (2) general discomfort, (3) nausea, (4) focusing difficulty, and (5) headache, which were effective for classifying motion images. They found that results indicated that stereoscopic movies caused several visual fatigue compared to other media. They mentioned that one of the symptoms of visual fatigue is focusing difficulty and accommodative functions have been identified as a valuable index of fatigue. Seven methods of measuring visual fatigue caused by VDU work, accommodation, visual acuity, pupil diameter, critical fusion frequency (CFF), eye movement velocity, subjective rating of visual fatigue, and task performance, were compared. However, they said that subjective rating was not parallel to the other methods consistently. Further, they also said accommodative functions depend on age and accommodative responses are too small in presbyopic people to

detect abnormality, even though visual fatigue is a common symptom in the early stage of presbyopia. They said that pupillary responses reflect the balance of autonomic nervous activity. Moreover, they are also related to the accommodative function, and therefore, they mentioned many investigators consider that the role of the pupil in near reflex should be investigated. They discussed about certain proteins in the saliva increases with mental and/or physical stress. Chromogranin A (CgA) is one such protein that respond only to mental stress and therefore could be used as a marker for fatigue. They mentioned that it has been used for example, to evaluate visual fatigue before and after presenting a visual load using images with and without colour breakup by using one chip DLP projectors. They said that quantitative analysis of accommodative responses is not easy because it has an inherent inaccuracy due to accommodative lag and lead. They said accommodation is sometimes used as one of the few physiological indicators of visual fatigue, and thus is subjected to many types of measurements. It has been said that

the reaction velocity of step responses, especially velocity of dis-accommodation, and amplitude of the response has been used as the main indicators of fatigue. They mentioned about Yano et al. who all have measured visual fatigue using a subjective method and compared it to changes in accommodation before and after viewing images by stereoscopic HDTV. They reported that the mechanism mediating convergence eye movement and the accommodative function in depth of focus, as well as conflict of convergence eye movement and accommodative function, affected visual fatigue.

(Visual fatigue caused by viewing stereoscopic motion images: Background, theories, and observations)

O. Ostberg said that laser optometry for measurement of the refractive state of the eye will perhaps become a flourishing research field and will possibly take over or vitalize the eye movement research domain. He also said that visual fatigue that may result from vdu work and that laser optometry is one way of objectifying visual fatigue. The visual problems of micro-scope work and automobile driving are other areas where laser optometry has proved useful. He mentioned that it could well be that temporary after-effects which can also be demonstrated after intense book reading, but such findings do not invalidate the results of after-effects from vdu reading, rather they indicate that closer attention should be paid to visual fatigue in general.

(Accommodation and visual fatigue in display work)

Chia-Fen Chi and Fang-Tsan Lin said that it was suspected that the 20-min task in their study was too short and that sensitivity of these measurement techniques for visual fatigue could

be improved if the same tasks were performed for a longer period. One of their experiment showed that the sensitivities of accommodation power, visual acuity, and CFF to load differences were greatly improved by extending the task performance time from 20 to 60 min. They mentioned that visual fatigue comparisons between studies must take differences in task time into account and the significant findings of the current study suggest the need for further study to test all three loadings (viewing distance, luminance contrast, and target speed) using a dynamic visual task. They suggested that such a study could further reveal the effects of each of the loading manipulations and their connection with measurable visual fatigue symptoms.

(A Comparison of Seven Visual Fatigue Assessment Techniques In Three Data-Acquisition VDT Tasks)

Kimiko Kawashima, Jun Okamoto, Kazuo Ishikawa and Kazuno Negishi said that they will develop objective visual fatigue evaluation methods based on eye-blink in order to develop video compression

and delivery methods to achieve higher image quality with lower bit-rate and lessen visual fatigue. *(Parameter Comparison of Assessing Visual Fatigue Induced by Stereoscopic Video Services)*

Atsuo Murata, Atsushi Uetake, Miho Otsuka & Yosuke Takasawa said because the participants in their study were in their early 20s and it is well known that focal accommodation decreases with age, their future research must include similar experiments carried out for other age groups to confirm the validity of their study. They mentioned that they also need to define the limitations of the proposed index and determine to which age groups it can be applied. In addition, they mentioned that because reliability is assured only when variations in the lighting environment are minimal, future research must investigate what variations in the lighting environment can be used with the proposed index so that finally limitations of the proposed index for practical application must be determined. *(Proposal of an Index to evaluate Visual fatigue induced during Visual display terminal tasks)*

F Mocci, A Serra, G A Corrias said introduction of some more objective measures of visual disturbances and the various stressors present in the work environment in future research is needed. They said that this approach, which has been used in research on analogous problems despite its own limitations, to be the most promising. They mentioned that future research should be aimed at investigating the relations between various stressors (group conflict and underuse of skills are true stressors, coworker support which refers to the provision and receipt of tangible goods, services, and benefits—such as informal encouragement and reassurance, and self esteem are that have been found in previous research to act as moderators of the weight of stressors on health complaints), and at verifying with field studies some of the hypotheses that have been confirmed in the present work (for example the role of colleague support as a moderating factor in the perception of stress), but which still lack confirmation by experimental studies. They said that measures to stimulate colleagues to

support one another could reduce the effect of work related stressors and confirm the theoretical studies on stress conducted to date.

(Psychological factors and visual fatigue in working with video display terminals)

Donghyun Kim, Sunghwan Choi, Sangil Park and Kwanghoon Sohn said in the future, they will extend their research to address additional visual fatigue related indicators using an eye tracker and electro-oculography.

(Stereoscopic visual fatigue measurement based on fusional response curve and eye-blinks)

J. Kuze, K. Ukai said that further study is needed to create an increasingly suitable questionnaire for subjective evaluation of visual fatigue in order to keep abreast of progress in technology.

(Subjective evaluation of visual fatigue caused by motion images)

Tsuneto Iwasaki , Shinji Kurimoto & Kageyu Noro said the difference in the pattern of change in the CFF value with the type of colour can be understood

more readily as the appearance of a uniform drop in the physiological function of a given part than as the difference in the effect on functionally different parts and the part with the clearest functional differentiation in connection with colour is the retina rather than the brain centre according to the results reported to date.

(The change in colour critical flicker fusion (CFF) values and accommodation times during experimental repetitive tasks with CRT display screens)

Sumio Yano, Masaki Emoto, Tetsuo Mitsuhashi said after reflecting on their study results, that two major issues need to be examined in future research. One is that the results are not supported by a detailed understanding of convergence eye movement and the accommodation function and a sophisticated method of measuring accommodation behavior needs to be developed, and the relationship between convergence eye movement and the accommodation function must be clarified for motion stereoscopic images. The second issue that they discussed is that the binocular

stereoscopic images must be limited to the display range in the depth direction, and so one of the most suitable display methods is to allow the individual viewer to control the display range in the depth direction. And for this purpose, they said that an algorithm of signal processing for controlling the distance and depth must be developed. They expected that a suitable stereoscopic image system will be achieved as a result of these research projects.

(Two factors in visual fatigue caused by stereoscopic HDTV images)

Kazuhiko Ukai, Peter A. Howarth said that recently, a viewing system that can change the apparent screen distance for accommodative stimuli have been designed to reduce the discrepancy between accommodation and convergence. They said that as image quality improves, it is expected that these systems will become increasingly necessary. They have also mentioned that under natural conditions, accommodation and convergence are strongly affected by the proximity of objects. However, they have also said that the proximity

of objects cannot be easily controlled in the laboratory although many attempts have been carried out. Similarly, safety issues related to stereoscopic images are discussed in their article but the contents of the images, such as stories which can give prediction of distance change, relation between objects where attention of the viewer is given and background, and static and dynamic screen plays which emphasize the depth perception, are hardly dealt with at present.

They suggested that in the future, the relation between susceptibility to stereoscopic visual fatigue and migraine should be investigated in more detail.

(Visual fatigue caused by viewing stereoscopic motion images: Background, theories, and observations)

Chia-Fen Chi and Fang-Tsan Lin said in their experiments, 10 participants performed a monitoring task at two viewing distances, read articles under two levels of screen contrast, and tracked a visual target moving at two different velocities. The same set of measurement techniques (excluding pupil diameter and eye movement velocity) were further compared by extending the task time from 20 to 60 min to determine possible improvements in sensitivity. Their task performance was measured to ensure that participants maintained the same level of performance across different load conditions. Their results indicated that the sensitivities of visual fatigue assessment methods varied widely between tasks and between loading manipulations. They have also mentioned that sensitivities of accommodation power, visual acuity, and CFF were greatly improved by a longer task period. However, they said these three measurement techniques were highly interrelated and were not sensitive enough to differentiate between the different VDT tasks. Eye movement velocity and subjective rating of visual fatigue were sensitive in differentiating

tracking from reading and monitoring tasks and were also sensitive to target velocity changes in the tracking tasks. (*A Comparison of Seven Visual Fatigue Assessment Techniques In Three Data-Acquisition VDT Tasks*)

Agnieszka Wolska & Marcin Switula said improper luminance ratio between the screen and the wall behind the screen is one of the factors that can significantly contribute to the level of visual fatigue during VDT work. They mentioned that daylight, which can meaningfully influence the surrounding luminance value and, in fact, luminance ratios could be a problem. The subjective evaluation of the surface brightness in the visual field at the studied real VDT workstations showed that this factor does not seem to be the cause of perceived discomfort. They said that work with VDT itself affected asthenopic symptoms regardless of the luminance of the surrounds and it was shown that intensities of some symptoms like lacrimation, burning, piercing, and sensitivity to light were significantly

bigger for the LCD TFT than for the CRT screen. The tendency towards bigger visual problems during work with a flat panel screen (compared with a CRT screen) were observed in their study which is confirmed by other studies too (Saito, 1997; Saito, Miyao, Kondo, Sakakibara, & Toyoshima, 1997) and it stated that subjective complaints among flat panel users were greater among CRT users. They mentioned that recorded results in the range of luminance ratio up to 1:60 confirmed the ISO (Standard No. ISO 9241-3:1992; ISO, 1992) luminance balance requirement that "for stationary visual field a significantly higher than 1:10 ratio of mean luminances between task area and its surrounds should not have any adverse effect." They talked about very high luminance ratios (much bigger than 1:100) which can affect the growth of visual fatigue, which (in some cases, especially for negative polarity screens) can accompany discomfort glare. Therefore, they stressed that for prolonged and strenuous VDT work, both luminance ratios smaller than 1:60 and breaks for a rest (10-15 min after every 2

hrs of work) should be ensured. For casual VDT work, bigger than 1:60 luminance ratios should not have any significant influence on visual fatigue. Results of their present study showed that there was no significant influence of the luminance ratio value on asthenopic symptoms for either type of screen and there was significant influence of the type of screen on those symptoms. They also mentioned that measurements of changes of the visual functions, contrary to asthenopic symptoms, showed an influence of the surrounding luminance value on visual fatigue and lack of significant differences between screens.

(Luminance of the Surround and Visual Fatigue of VDT Operators)

F Mocci, A Serra, G A Corrias said that some part of the complaints about visual health reported by VDT workers are likely indirect expressions of psychological discomfort related to working conditions. They said it has to be recognised that work stress can produce both physical and emotional complaints and job demands both physical and

psychological—influence the severity and frequency of health complaints of VDT operators and they have shown relations between the presence of asthenopia and environmental variables, including lighting characteristics of the workplace, and physical variables—such as the refractive index of the subjects. They said that as is known, these measures, which are certainly the most commonly used in research, introduce several problems which is evidence that their use can lead to an overestimate of the correlation between stressor and dysfunctioning. Their analysis of the influence of psychological factors on asthenopia increases the possibility of preventive interventions in occupational medicine aimed at creating conditions of well being, and thus the reduction of disturbances.

(Psychological factors and visual fatigue in working with video display terminals)

Donghyun Kim, Sunghwan Choi, Sangil Park and Kwanghoon Sohn said that for instance, individual differences of 3D perception ability is a difficult research issue because the subjects that

researchers screen most often by simple stereopsis tests are potential victims of 3D videos. In addition to these difficulties, guidelines for safe stereoscopic imaging and tools to measure the comfort of stereoscopic images should be prepared to facilitate the successful introduction of 3DTV.

(Stereoscopic visual fatigue measurement based on fusional response Curve and eye-blinks)

Tsuneto Iwasaki, Shinji Kurimoto & Kageyu Noro mentioned that experimental results of their study suggest that the CFF values obtained with a short task load of 1h constitute an index that indicates not only mental fatigue or and consciousness levels of the cerebrum but also the deterioration of other physiological functions in some cases which questions conventional physiological concept between fatigue and the CFF value.

(The change in CFF and accommodation times during experimental repetitive tasks with CRT display screens)

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