Risk factors for car accidents due to reduction of visual abilities during low light conditions

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Background

According to a widely held theory of vision, the rods are responsible for vision under very dim levels of illumination (***scotopic vision***) and the cones function at higher illumination levels (***photopic vision***). Photopic vision provides the capability for seeing color and resolving fine detail (6/6 of better), but it functions only in good illumination. Scotopic vision is of poorer quality; it is limited by reduced resolution (6/60 or less) and provides the ability to discriminate only between shades of black and white.

There is a common misconception that the rods are used only at night and the cones only during the day. Actually, both rods and cones function over a wide range of light intensity levels and, at intermediate levels of illumination, they function simultaneously. The transition zone between photopic and scotopic vision where the level of illumination is equivalent to twilight or dusk, is called ***mesopic vision***. Neither the rods nor the cones operate at peak efficiency in this range, but both actively contribute to visual perception. Mesopic vision is the intermediate range between photopic and scotopic in which both cones and rods are functioning. The definition of the lighting conditions for mesopic vision varies from one study to another, the lower boundaries of luminance being in the range of 0.001-0.034 cd/m2. Mesopic vision may be of primary importance at night because some light is often present during night operations.

The effects of decreased illumination on operational visual functions can be dramatic. Visual acuity may be reduced to 6/60 or less, color vision is lost, blue-green lights will appear brighter while red lights will appear dimmer, vision is further limited by night myopia, depth perception is degraded and glare becomes a factor limiting visual functions. The potential effects of these factors on the operational aspects of night vision will now be considered.

Dark adaption

Dark adaptation is an independent process during which each eye adjusts from a high-luminance setting to a low-luminance setting. The exact mechanisms are unclear, but they are known to include biochemical, physical, and neural. Rods and cones differ markedly in their rate of dark adaptation. Cones attain maximum sensitivity in 5-7 minutes, while rods require 30-45 minutes or longer of absolute darkness to attain maximum sensitivity after exposure to bright light.

In addition to adaptation caused by changes in photopigment concentrations, the eye has other mechanisms for adapting to changing light conditions. Retinal adaptation can be affected by physical changes in the size of the pupil. The diameter of the pupil can contract to 1.5mm and expand to 8mm, which equates to a 30-fold range in the quantity of light entering the eye.

Another light-adaptive mechanism is neural adaptation, which is generated by retinal neurons at successive stages of the visual chain in the retina. A change in "neural gain" occurs in seconds and can improve night vision by a factor of 10 or more. Furthermore, greater sensitivity may result from summation of retinal input between photoreceptors[1]. Moreover, enhanced sensitivity by spatial summation between neurons occur at higher cortical levels [2-4].

Night Vision

Visual acuity (VA) is reduced at night under low illumination and 6/6 vision cannot be sustained below a level of deep twilight. Objects can be seen at night only if they are either lighter or darker than their background and can be discriminated by subtle differences in contrast. Visual acuity is critically influenced by small differences in the brightness (contrast) between objects and their background. At night, contrast discrimination is reduced due to low illumination.

Night myopia

Visual functions at night are more demanding and stressful than during the daytime. People who do not normally wear spectacles, or those who wear visual correction, may have a myopic shift in vision under extremely reduced illumination. This near-sighted or myopic shift is called the dark focus of the eye. The dark focus of the eye may become a problem whenever there is a lack of adequate distance objects upon which to focus. Night myopia is a common phenomenon that most healthy people have experienced, usually while driving at night. Moreover, during those conditions, visual acuity may fell from 6/6 to 6/18 and up to 6/60 in lower illumination conditions[5]. This change in refraction may cause blurred vision and its degree is larger in younger people’s eyes than in the eyes of elderly people. The high degree of loss in visual acuity cannot be solely accounted for myopic shift (typically between –0.50-1.00 DS), rather, it is more plausible that neural changes are more responsible for this large visual acuity loss[5].

The problem

Visual acuity (VA) is currently the gold standard clinical measurement, while qualification for driving license is warrant only if the VA is better than a certain level. However, during the recent years there are many studies shown that measurements of standard VA are not a good predictor for visual performance, especially during demanding task under low illumination conditions. Under these conditions, some people with normal visual system and normal VA might fail to perform properly. This problem is, of course critical for drivers at night. Therefore, it is very important to develop a reliable technique and device that can discriminate between drivers who may have problems at night and those who may have good vision under reduced illumination. We developed a new technique that is based on implementation of measurement of visual acuity and contrast sensitivity under simulated conditions of night vision and can potentially be used to proper screening out drivers that are at risk during night-time vision.

Contrast sensitivity

The central visual system can detect small, local luminance differences (contrast) to extract visual objects. Contrast is the most important parameter to activate neurons in the visual cortex. Contrast threshold is the lowest luminance differences needed for target detection. Contrast Sensitivity (CS) is the reciprocal value of contrast threshold. An individual that requires high level of contrast in order to identify a target has a low CS level, and an individual that requires low level of contrast in order to identify a target has a high CS level. CS expresses the overall sensitivity of the visual system at different levels, starting with the light input that is being absorbed proceeding at the level of the photoreceptors, up to its end at the level of the visual cortex.

The standard Snellen-type visual acuity (VA) tests is the most popular clinical measurement of spatial vision for over a century, does not fully capture the visual abilities of an individual. Usually, these VA tests measure only the ability of the patient to resolve a gap in high (almost 100%) contrast targets, and thus they are serving as a resolution task. However, much of the everyday life tasks are to detect luminance differences (contrast) mainly at low contrast situations. Contrast sensitivity testing determines the lowest contrast level, which can be detected by patient for a given size target. Contrast sensitivity function (CSF) measures size

and contrast, while visual acuity tests measure only size. CSF has been shown, in many clinical conditions [6-10] to be a good predictor for male functioning of the visual system and is more reliably capturing the function of the visual system as a whole.

Standard CS is measured in normal room lighting. Measurements of CS in conditions of low illumination might reveal the sensitivity of the system at scotopic conditions. Therefore, accurate and sensitive CS measurement should be performed after dark adaptation.

Currently, there is no reliable test to screen out subjects who may suffer from impaired visual functions at dark, giving that their daytime visual functions are normal. This impairment may have a critical impact on the performance of drivers during night, an effect that may expose them to critical risks.

We took an advantage from our finding that foveal dark adaptation may be of short duration, taking less than one minute. We used our short and simple CS testing in dark to test the visual functions of drivers at day and night vision.

Figure 1 - *examples of Gabor Paches to be used in the poposed study to measure the contrast sensitivity function (CSF). Left side showing a Gabor patch (small) with high spatial frequency which requires good visual acuity to detect it. The right side shows an example of Gabor patch with lower spatial frequency (bigger). The contrast here is enhanced for demonstration purposes, however, the contrast in the real experiment will be near to the detection level.*

Methods

Contrast sensitivity function (CSF) were measured using psychophysical methods. The measurements of night conditions were performed in a dark room, which mimics the so-called "real" conditions that reflect more accurately the individual function in starlight outdoor environment or in a darkened room with no artificial lighting. In order to preserve this minimal illumination level, the testing monitor illumination level was decreased to a level of 0.03 candles/m2 using natural density filters covering the monitor.

Procedure

All subjects performed the standard visual acuity test and are qualified for driving license. We than tested them with the Early Treatment Diabetic Retinopathy Study chart (ETDRS) that is more accurate.

Visual Stimuli and experimental testing

Stimuli were displayed as a gray-level modulation on a Philips 107P color monitor. Screen resolution is 1024 x 768 pixels occupying a 9.2^0x12.2^0 area. The mean display luminance in photopic testing is 20 cd/m^2 in an otherwise completely darkened room. For mesopic testing, the monitor is covered with neutral density filters that allow luminance of only 0.03 cd/m². Gamma correction was applied. The stimuli were viewed from a distance of 3 meters.

The method used here was similar to Polat & Sagi[11, 12]. The stimuli consisted of one Gabor target (Figure 1), at the fixation point, with spatial frequency (SF) between 1.5 to 12 cycles per degree (cpd). The spatial luminance distribution of the target was described by the Gabor function; a cosine grating multiplied by a Gaussian envelops[13].

Transient method

A temporal two-alternative forced-choice procedure was used. Each trial consisted of two stimuli presented sequentially, only one of which had a target. Each stimulus display included four peripheral high contrast crosses, marking the target stimulus interval presentation. Before each trial, a small fixation circle was presented at the center of the screen. The trial sequence which consisted of: a no stimulus interval (500 msec), a stimulus presentation for 320 msec, another no stimulus interval (800 msec) and a second stimulus presentation for 320 msec started when the patients were ready. The observers' task was to determine which of the stimuli contained the target. Given the subjects' average age and to exclude confounding

factors such as motor errors, subjects performed an oral response, which was converted into a button press response by the experimenter. An auditory feedback was given immediately for an incorrect response. Screen luminance was kept constant during the stimulus and the stimulus intervals. A 3:1 staircase method was used to determine the contrast threshold level at 79% correct[14].The procedure was repeated for each SF (3 and 6 cpd for photopic; 1.5 and 3 cpd for mesopic) in randomized order to avoid bias of results, or confounding affects of fatigue and adaptation time.

Photopic testing was initially performed, followed by a short break (until subjects were prepared to start the second session), a 1-minute dark adaptation, after which mesopic testing began. Each complete session testing lasted approximately 15 minutes.

Static method A four spatial forced choice task is used. The Gabor target is presented on 1 of 4 possible locations (marked by visible white circle) on the monitor; up, down, left or right. The target remained on the monitor, until the subject reported to the experimenter, in which location the target appeared. An auditory feedback is given after a wrong response. After each trial the target appear randomly in one of the four locations. A 2:1 staircase method is used to determine the contrast threshold level at 70.7% correct[14]. The procedure is repeated for each spatial frequency (3 - 12 cpd) in a randomized order to avoid bias of results, or confounding affects of fatigue and adaptation time.

Subjects

A total of 50 subjects participated in the experiments, and divided in to 3 groups:

First group - twenty five young (18 years old) eligible for driving license (male and female) participated in the first set of experiments. This group was measured with the transient method

Second group - new nineteen (18-30 years old) eligible for driving license (male and female) participated in the second set of experiments. This group was measured with the static method to serve as control for the older group that can be tested with the static method only.

Third group - six older (40-60 years old), eligible for driving license (male and female) participated in the second set of experiments. This group was measured with the transient method.

Summary of the procedure

1. Each subject is tested by certified optometrist to see if the subject is eligible for driving license.

2. a more detailed visual equity using ETDRS

3. Measurement of contrast sensitivity at night

4.measurement of VA at night using our computerized method

5. repeating 3-4 with additional + 0.50 diopter to study the effect of night myopia (for the younger drivers)

The study was approved by the ethic committee of Sheba Medical Center.

Results

Contrast sensitivity (CS)

Contrast sensitivity was measured in two conditions(day and night). The results are presented in figure 2. As the results show, CS at night is reduced dramatically. Comparing spatial frequency of 3 cpd that was tested in the two conditions show that CS was reduced dramtically from 55 to 5 and that of 6 cpd reduced from 24 to 2. This result indicate that the contrast sensitivity at night for briefly presented stimuli is reduced to only 10% of the capabilities at the day time.

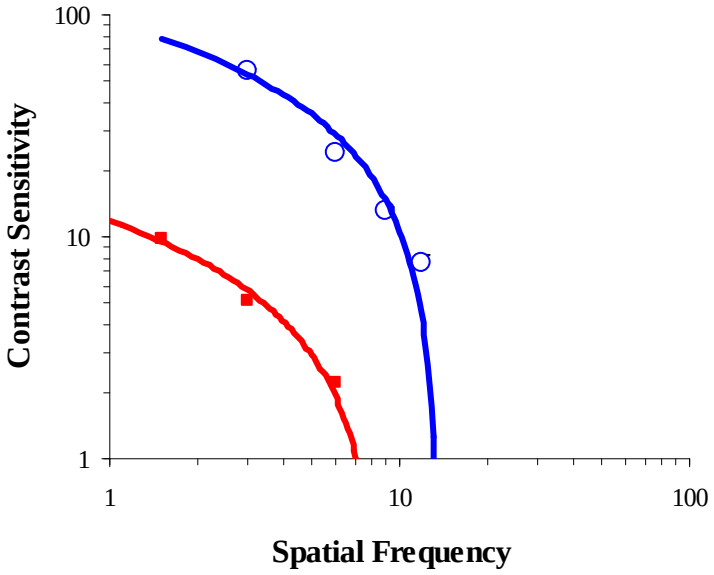


Figure 2 - *Contrast sensitivity functions (CSF) measured with the transient method and young group. Day condition (day, open circles, blue line) and for mesopic condition (night, filled circles, red line). The y axis represent the contrast sensitivity in log scale and the x axis spatial frequency (3, 6, 9, 12 cycles/degree) in log scale*

We note that CSF of older drivers cannot easily be measured using the triensient method. Therefore we developed a static method that the can perform easily, while the results are similar in both ethods [15]. In order to compare the CSF of young and older drivers, we tested new group of young driver (19) with the static method. The results show (Figure 3) that the CSF at night is reduced, but less than for the transient method, to 70% of the day performance. This indicate that the performance at night requires longer processing time.

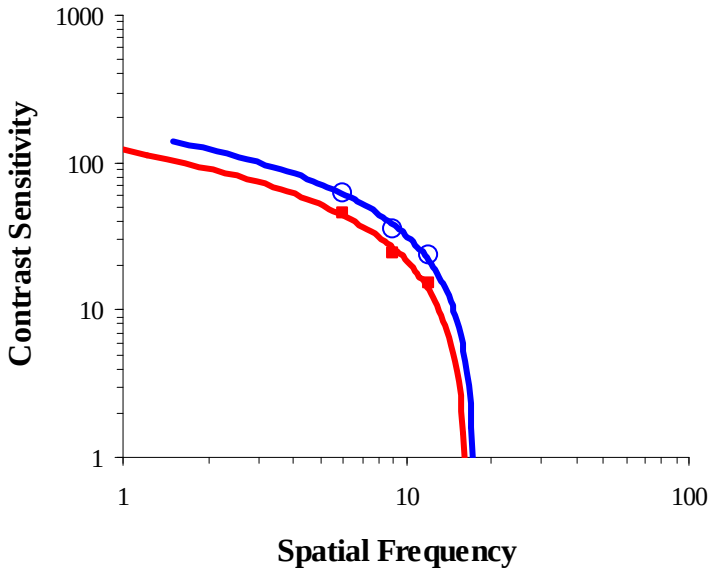


Figure 3 - *Contrast sensitivity functions (CSF) measured with the static method and young group. Day condition (day, open circles, blue line) and for mesopic condition (night, filled circles, red line). The y axis represent the contrast sensitivity in log scale and the x axis spatial frequency (3, 6, 9, 12 cycles/degree) in log scale*

The contrast sensitivity of the older group is measured with the static method. The results are presented in figure 4. The first thing to note is that the day CSF of the older group similar to the night CSF of the young group. The second thing to note is the dramatic reduction of the CSF at night of the older group. The sensitivity at night is only about 15% of there performance at the day time and that of the night young group. Thus, the visual abilities of the older group is very limited at low light conditions.

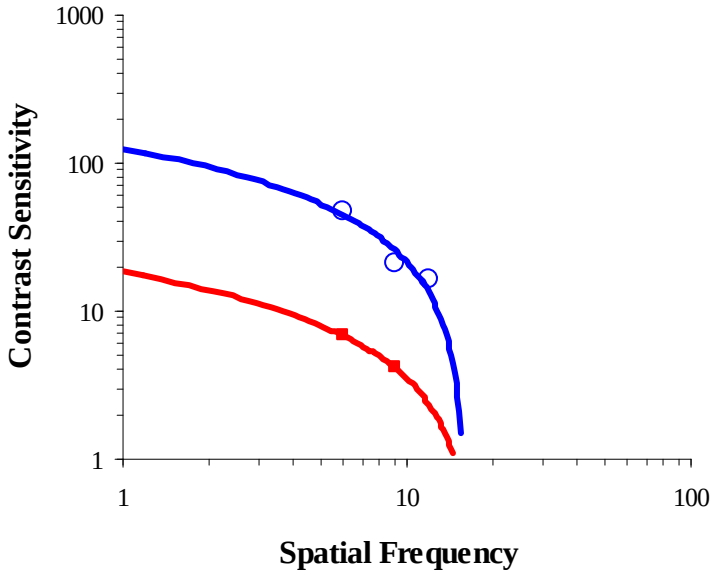
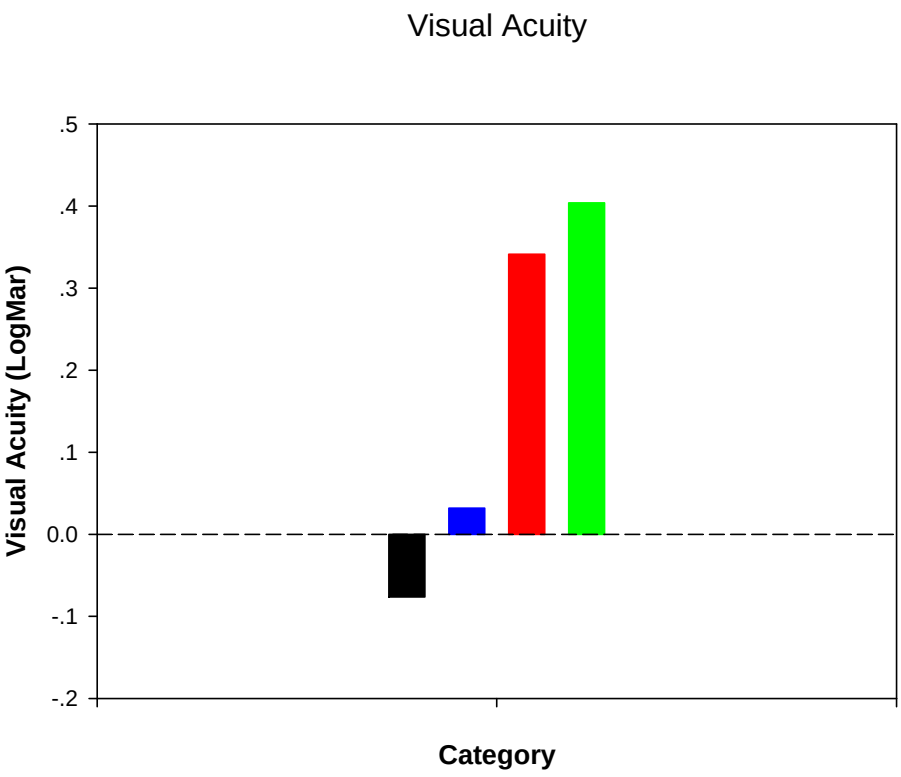


Figure 4 - *Contrast sensitivity functions (CSF) measured with the static method and the older group. Day condition (day, open circles, blue line) and for mesopic condition (night, filled circles, red line). The y axis represent the contrast sensitivity in log scale and the x axis spatial frequency (3, 6, 9, 12 cycles/degree) in log scale*

Night myopia

The dramatic decrease in vision abilities of people in vision-limiting conditions, e.g. night vision, reduces their capabilities and places them at higher risks. Night myopia is a condition considered to be caused mainly due to a change in the refraction toward myopic shift in young people during low light intensity. Still, there is no objective and practical tool for assessing the vision abilities in visual-limited conditions, in either the individuals with an impaired or an outstanding nigh-vision. We developed a paradigm that enable us to measure visual acuity and contrast sensitivity, which may provide an objective and easy tool for detecting individuals with impaired or outstanding nigh-vision abilities. We measured visual acuity and contrast sensitivity during day and night conditions using computerized techniques. We also

tested if addition of +0.50 diopter induce night myopia, and on the other side if correction of -0.50 diopter improve visual abilities at night.



<u>Figure 5</u> – ***Effect of night myopia:*** *Visual acuity for day condition (day, black coloumn) and for scotopic condition (night, red coloumn). The y axis represent the visual acuity logMar (0 = 6/6, 0.3=6/12). The blue coloumn show the VA in day condition with +0.50 diopter and the green coloumnshow the VA in day conditions with +0.50 diopter. The results show that +0.50 diopter reduce the VA by 25%.*

The results for the young group show (Figure 5, 6) that visual acuity is slightly reduced (~25%, one line), as expected from the optical intervention of ± 0.50 diopter, inducing night myopia. However, contrast sensitivity is remarkably reduced (by about 60%) due to induction of the myopic shift by +0.50 diopter.

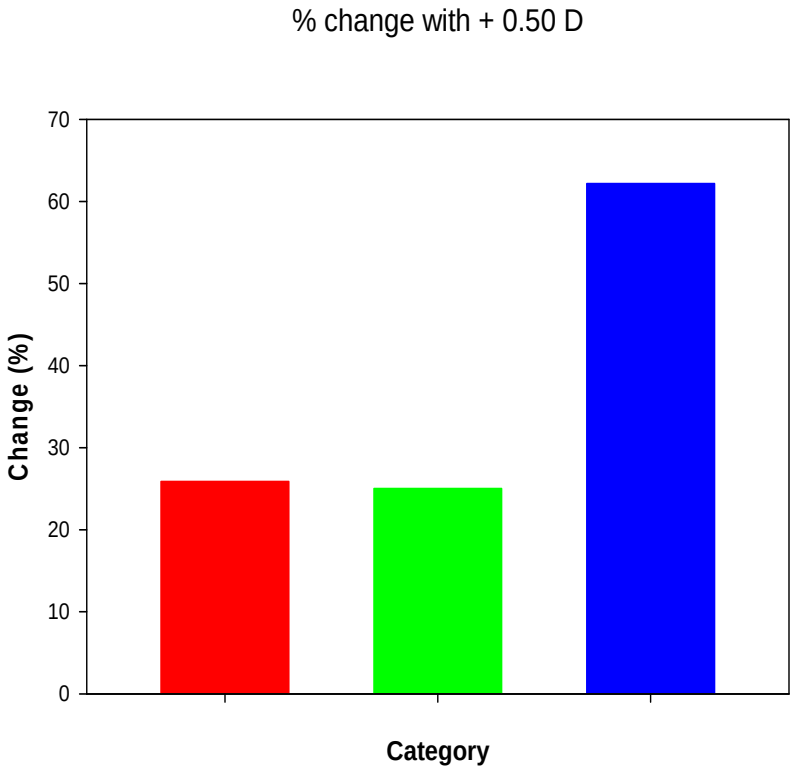


Figure 6 – ***Effect of night myopia:*** *The y axis represent the visual acuity logMar (0 = 6/6, 0.3=6/12). Reduction of visual acuity after inducing myopic shift (+0.50 diopter) for day condition (day, red coloumn) and for scotopic condition (night,green coloumn). The blue coloumn show the reduction of CS in day condition. The results show that +0.50 diopter reduce the VA by 25% but the CS by 60%.*

VA was tested at night for the older group as well. While the baseline VA of the older group is not different than the younger group, the reduction of the VA at night condition is remarkebly larger. The results are showing in Figure 7. While the VA in the young group is reduced by about 10% the older group VA reduced by over 120%. In othe words, the VA of the older group reduced by 4 lines, bringing them to the zone were they no more eligible for driving liecnces without further correcting their vision.

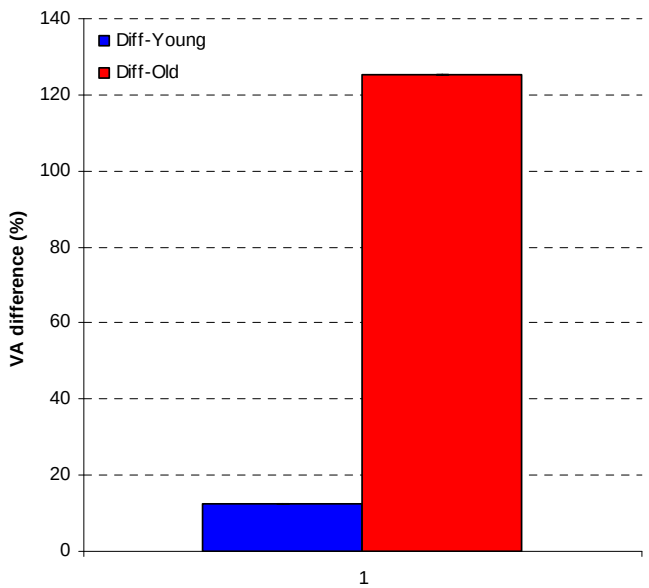


Figure 7 – ***Effect of night vision:*** *The y axis represent the reduction of visual acuity in percentage. Reduction of visual acuity of the young group (blue coloumn) and for the older group (red coloumn). The results show that the VA reduced by 10% for the young group butby over 120% for the older group.*

Summary

The current research shows that, while visual acuity tests are not reliable for predicting deficiencies in night vision, our technique of measurement can be reliably used for predicting the night-vision abilities. The main results are:

1. Many drivers may be at risk while driving at night
2. Tthere are a remarkeable reduction of the visual abilities at night
3. The reduction is much more severe for the older age
4. VA is not a good measurement to predict the loss of vision at night
5. Night myopia in young driver reduced there CS by about 60%
6. The visual acuity of the older group during night condition is reduced below 6/15, becomes to a level below the limit of VA required for safety driving.

Practical suggestions and future research

1. Developing easy and fast technique to test visual disabilities at night conditions
2. Testing contrast sensitivity function in addition to the visual acuity. Testing CSF becomes a requirement in a few states in the US. For exaple, in california, CSF is beining tested when drivers are renuening their driving liecnces (see below).
3. Periodic testing of the visual function. The visual functions are deteriate with age.
4. Expanding the research to include larger sample size
5. Measurements of reaction time and visual tracking as a function of light conditions

NEW DMV ASSESSMENT TOOLS

A Public Service Agency

In keeping with a new law, the Department of Motor Vehicles is piloting some new assessment tools (described below). They will be used in making licensing decisions during a pilot program that runs in selected Northern California field offices from May through September, 2007.

The new assessment tools include:

1. Observation for any physical limitations that could affect safe driving.
2. A cognitive exercise that will require you to recall in writing your Social Security Number (SSN), or your zip code if you have never been issued a SSN.
3. A vision test that measures contrast sensitivity. Contrast sensitivity refers to the ability to see objects as distinct from their background, such as a dark car parked in the shade or a light car in the fog. You will be referred to a vision specialist for further evaluation if your test results indicate a severe reduction in contrast sensitivity.
4. Perceptual Response Test (PRT). This is a computer-based test that measures how well you process visual information, by identifying silhouettes as belonging to either a truck or a car. The PRT test is reserved for applicants who do not perform well on the standard tests and/or the new assessment tools.

Failure on any of the standard tests and/or the new assessment tools listed above may require a behind-the-wheel road test.

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