Night Myopia : Etiology and Correction

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April 14, 1997
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Introduction

Night myopia is an increase in myopia that tends to develop whenever the light level of an individual's environment is substantially reduced. This myopic shift has been reported to be as high as 3.0 to 4.0 diopters but has an average magnitude of 1.0 to 1.5 diopters[1]. These values refer to a young adult eye under scotopic illuminance levels. Individuals who are affected by night myopia appear emmetropic with their appropriate refractive correction under high luminance conditions but become nearsighted as luminance levels are decreased. The eye does not focus on infinity but rather on an intermediate distance under dim lighting conditions. The blur created by this myopic shift can create significant problems for individuals performing activities in a dimly lit environment. In 1990 the National Traffic Highway Safety Administration found that the nightime automobile accident rate was 3.7 times higher than in daytime[2]. Statistics released by the National Safety Council attribute 5.4 deaths per million vehicle miles traveled at night versus 1.6 deaths per million vehicle miles traveled during the day[2]. It is important that decreased visual efficiency be considered as a contributing factor to these statistics. It is the purpose of this article to examine the possible causes of night myopia and describe techniques for its evaluation and correction.

History of Night Myopia

The first person known to write on the phenomenon of night myopia was the English astronomer Maskelyne. He was the first to report that his eyes became more myopic in dim illumination[3]and consequently corrected his problem by using minus lenses to improve his vision at night when observing the stars. A century later, in 1883, Lord Rayleigh elaborated more on this phenomenon and thus the discovery of night myopia has been attributed to him. He found that a -1.0 diopter spectacle lens gave him his greatest visual acuity in a dimly lit room[4]. Lord Rayleigh hypothesized that night myopia resulted from spherical aberration of the eye that manifest itself when the pupil was dilated.

During World War II, it was realized that the ability to detect ships and aircraft at night was crucial[3]. The interest in night myopia became widespread in this country and Europe and the study of its causes and characteristics began. Many independent investigations into this phenomenon have been published since that time. Unfortunately, much of the literature on night myopia contains conflicting results with no real answers for its basic cause or consequent treatment. As a result, this topic remains a subject of great theoretical and clinical debate.

The published values of night myopia vary from author to author primarily because the exact lighting conditions and methods under which night myopia has been measured differ widely from experiment to experiment. For example, in older literature it is often refered to as 'twilight' myopia[3] which seems to imply a mesopic type luminance level. Whereas, Otero and Duran conducted experiments under scotopic conditions and are credited with the origination of the term 'nocturnal' or night myopia[4]. Still other authors compare night myopia with the dark focus of the eye which refers to the refractive state of the eye in complete darkness. Charmin[3] has restricted the use of these terms into three categories; twilight myopia refering only to anomalous myopic changes which appear under mesopic conditions in which both rods and cones are active (10^{-3} to 3 cd/m^2), night myopia to scotopic conditions under which only rods are functional (10^{-6} to $10^{-3} cd/m^2$), and dark focus to complete darkness.

Following World War II, Lord Rayliegh's spherical abberration theory was met by many competing hypotheses. In the last 50 years many theories have been developed in order to explain night myopia. One of the more popular theories was that of Otero and Duran[7]. In 1943, they postulated that scotopic vision shifts the chromatic abberration of the eye towards the blue end of the spectrum thus causing the eye to become more myopic. It was not until the early 1960's that night myopia appeared to be caused partly by an innapropriate level of accommodation associated with scotopic illumination levels. However, the technology that had been used to assess accommodation under scotopic light levels were difficult to apply and to calibrate. Fortunately, in the 1970's, the development of the laser speckle optometer allowed for the first time larger groups of subjects to be studied and produced more accurate and repeatable values concerning the accommodative response under scotopic illuminations[6]. Laser studies confirmed a link between accommodation and night myopia.

A review of the published literature concerning night myopia indicates that several factors are involved: accommodation, spherical abberratin and chromatic abberration. All seem to contribute to night myopia but in differing degrees in different individuals.[5]

Causes of Night Myopia

1. Chromatic aberration

Chromatic aberration is the result of shorter wavelengths being focused in front of the retina. The normal human eye is afflicted with undercorrected chromatic aberration in much the same way as a simple lens.[4]. Otero and Duran[7] found that the normal eye is basically emmetropic in light of about 550 millimicrons but becomes increasingly more myopic for shorter wavelengths of approximately 510 millimicrons. As the eye becomes dark-adapted, the shift from cone to rod vision causes the eye to become more sensitive to blue light[4]. This is because blue light is predominant in darkness and red light is predominant in daylight[6]. In the dark-adapted eye, the special sensitivity of the retina is shifted toward the shorter wavelengths, thus the eye becomes more myopic for those wavelengths that are most affective in stimulating the retina[5]. Studies on this phenomenon conducted by Otero and Duran indicate that only about 0.25 diopters of myopia could be attributed to chromatic aberration[7]. This effect has been substantiated by Ronchi and Wald whose measurements indicated that chromatic aberration could account for as much as 0.59 diopters[7]. As well, Wald and Griffin, from their own studies involving the chromatic aberration of the eye, concluded that it contributed 0.35 to 0.4 diopters of myopia[4].

The differing values reported by various researchers can be attributed to the energy distribution of the testing illumination[4]. However, all the values reported in the literature refering to chromatic aberration and myopia are low in regards to the overall values of night myopia reported. Thus, some other source other than chromatic aberration must contribute to the large values of night myopia reported in the literature.

2. Spherical aberration

Spherical aberration is characterized by peripheral and paraxial rays focusing at different points along the axis. The spherical aberration of the eye is usually undercorrected. The outer zones of the eye's optical system have a greater optical power or are more myopic relative to the central zones[5]. Under daylight conditions the pupil is constricted, thus light entering the pupil is not effected by the more myopic outer zones of the eye's optical system. However, under scotopic illumination, the pupil dilates thus exposing the more marginal myopic optical zones. This creates a reduction in the role of the central optical zone and the more peripheral zones now provide for a majority of the light responsible for image formation. Since the outer zones have a greater optical power, the undercorrected spherical aberration manifests itself as myopia in the dark adapted eye[4].

This explanation was proposed as early as 1883 by Lord Rayleigh and further elaborated on five years later by Jackson[7] who investigated retinoscopically the refractive power of various zones of the eye. In 1942, Otero and Duran[6] concluded that spherical aberration could only account for about 0.50 diopters of night myopia. Ivanhof had experimented with the spherical aberration of the eye and found that minus lenses used for distance viewing to eliminate night myopia actually induced accommodation which tends to eliminate the spherical aberration of the eye and in this manner the eye becomes essentially aplanatic[8]. The best spectacle correction for seeing at low luminance levels and the amount of accommodation required to eliminate spherical aberration agree very closely[7].

Le Grand[4], in 1942, calculated that spherical aberration combined with chromatic aberration could cause as much as 1.5 diopters of myopia . However, these values seem to contradict most other findings which report much lower values. This may be a result of calculation rather than actual experimentation. Francon and Flamant [4] demonstrated experimentally that there is a connection between these aberrations and night myopia. However, several researchers have independently come to the conclusion that spherical aberration plays no important role concerning night myopia. This is partly because they were unable to demonstrate the presence of any significant amount of spherical aberration in the eyes of their subjects under scotopic conditions. The majority of experimental data available seems to indicate that spherical aberration accounts for only a very small amount of the night myopia found in most individuals effected.

3. Accommodation

Although night myopia has been attributed to many factors, a review of recent literature seems to suggest that for the most part it is a result of the change in accommodation. Much of the earlier research centered on spherical aberration and accommodation and their role as a causative factor in night myopia. Measurements of each of these in dim light were acquired in complex experimental set-ups that manipulated pupil size and accommodation[5]. Some researchers found that cycloplegics reduced night myopia which suggested that accommodation played a significant role in night myopia. On the other hand, other researchers have found the opposite suggesting that night myopia is likely a result of spherical and chromatic aberration[7]. The degree to which spherical aberration or accommodation contributes to night myopia could not be established.

In 1942, Otero and Duran were the first to publish data supporting the role of accommodation in night myopia. They found that after cyclopleging their subjects the magnitude of night myopia decreased[6]. They also found that a presbyope with only 0.5 diopters amplitude of accommodation had only 0.5 diopters of night myopia[4]. They concluded that accommodation is a causative factor of night myopia.

Wald and Griffin, in 1947, also investigated the role of accommodation in night myopia. Subjects viewed an object through binoculars in dim light and were to adjust them as needed to obtain a clear reading. Results were variable and ranged from -3.4 to +1.4 diopters relative to their settings in bright light[9]. Homatropine was then instilled and accommodative reading were again taken in dim lighting. Results showed a decrease in night myopia and the researchers concluded that night myopia to some extent was a result of involuntary accommodation in dim light.

In 1954, Schober introduced the resting state hypothesis to explain the role of accommodation in inducing night myopia[6]. Schober believed that when the eye is relaxed the accommodative focus is not at infinity but rather at an intermediate distance. If no stimulus for accommodation exists, such as in darkness, the eye returns to its resting state placing the focus at an intermediate distance resulting in myopia. Other researchers, Cabello, Jimenez-Landi, Armulf and Francon[4] have further demonstrated that night myopia is not a fixed magnitude but varies with brightness, myopia increasing as brightness decreases.

A major reason that has made it difficult to correlate accommodation with night myopia is because most techniques used to measure the accommodative response under scotopic conditions actually stimulated accommodation. Within the past thirty years most research into accommodation and its correlation with night myopia has included the use of the 'laser speckle' optometer[5]. This device was invented by Rigdon and Gordes in 1962 to allow for the measurement of night myopia without stimulating accommodation[6]. The laser speckle pattern used to measure accommodation under scotopic conditions extends throughout space and therefore does not itself create a stimulus to accommodation[3]. When light from a laser is reflected from a granular surface, a speckled pattern becomes visible. If a subject observing this pattern moves his head, the 'speckles' appear to move. The 'speckles' will move in the same direction as the head movement if the subject is hyperopic; they will move opposite to the head movement if the subject is myopic for this distance[5]. The laser speckle optometer is simple to operate and allows for rapid, accurate measurements. These characteristics now allow larger groups of subjects to be studied quickly and efficiently.

In the 1970's Leibowitz and Owens published several studies on night myopia in which they used a laser optometer. One of these finding showed that the dark focus of 220 college students tested ranged from 0.4 diopters of hyperopia to 4.0 diopters of myopia[10]. A total of 76% of the subjects had night myopia of 1.0 diopters or more[6]. Other studies by Leibowitz and Owens reported on 59 subjects showing a range of myopia from .37 to 2.89 diopters and 124 subjects showing a range of plano to 4.0 diopters of myopia[11]. Epstein, in 1981, found that in a sample of 163 subjects, 47% had night myopia of .75 diopters or more and 11% had night myopia of 2.0 diopters or more under scotopic conditions[12]. These values emphasize the high variablility between subjects and this may account for the inconsistencies found in the earlier literature[4].

Further studies conducted by Liebowitz and Owens, found that as luminance is reduced, the accommodative response gradually shifts from optical infinity toward the dark focus (accommodative response in complete darkness)[1]. Subjects who had a relatively near dark focus exhibited greater night myopia than those with a far dark focus. Their research has shown that the magnitude of night myopia highly correlates with the dark focus therefore an individual's night myopia should be predictable from his dark focus alone. Subjects who have a far dark focus shuld exhibit very little myopia and thus will not benefit from a minus lens correction, while those with a very near dark focus should require a greater than average minus correction. Therefore, night myopia can be interpreted as a shift in accommodation toward the dark focus or resting state[1].

The stability of an individual's dark focus or night myopia over time has also been addressed by several researchers. Leibowitz and Owens measured three subjects twice daily over eight days and found little variablility[10]. Miller measured the dark focus in 21 subjects twice weekly over a three week period. He found a range of 0.39 diopters to 4.45 diopters of myopia[13] which showed a large variation in measurements. Owens and Higgins measured the dark focus of 5 subjects over a 10 to 12 month period. Their measurements demonstrate that the dark focus is highly stable over long periods but short term variation can be dramatic in a few individuals[14]. Experimental data has shown that the mean dark focus is very stable over long periods of time, however, large short-term variations in the dark focus are not uncommon. These short term variations can be induced by such factors as psychological stress[5].

In summary, it has been shown that spherical and chromatic aberrations account for a very small amount of the myopia induced under scotopic light levels. The rest of this increase in myopia is postulated to arise from changes in accommodation[6]. These factors, accommodation, chromatic and spherical aberration, probably combine in different degrees to produce the varying amounts of night myopia .

Factors to Improve Night Vision

The topic of night myopia remains a subject of great clinical debate. Recent literature has cited an increase incidence of accidents at night and a prevelance of vision problems encountered on the road after dusk[2]. As an eyecare professional, one should consider the visual difficulties experienced by night drivers as possibly being related to night myopia. Some authors recommend the corrrection of night myopia by supplying a minus power clip-on over the normal distance correction[4]. Owens and Leibowitz suggest that a minus prescription should be determined by first establishing the individual's dark focus, but because the road at night is not at scotopic illuminance levels, the optimal correction should be one half the dark focus value[11]. They have produced limited evidence to suggest that drivers preferred prescriptions on this basis. However, other researchers have found that when drivers were refracted under simulated road lighting levels in order to find an appropriate night driving correction, only about one third of the sample studied found the prescription helpful[3].

If an eyecare professional were to follow Leibowitz' and Owens' approach to the correction of night myopia, then the patient's dark focus must be determined. There are currently two methods available. The best device to use would be a laser spectacle optometer. Unfortunately these optometers are not available commercially. However, one can easily construct a laser Badal optometer to measure the dark focus in-office and obtain fairly unequivical results[4]. A second, more feasible approach in a clinical setting is a technique designed by Owens termed dark retinoscopy[15]. The procedure involves performiing retinoscopy at 25 to 100cm in a completely darkened room and with the distance correction in place. This procedure has been shown to yield a refractive error that correlates well with the dark focus. To determine the dark focus, this formula must be used[4]: Dark Focus = (Dark Retinoscopy - 0.25D)/0.64. According to Leibowitz, once the dark focus of the eye has been found, a night driving prescription can be determined by dividing the dark focus in half[10].

The dark focus shows a gradual reduction throughout life[3]. This is most likely due to the loss of accommodation when presbyopia is reached. If a presbyopic patient experiences night myopia we must consider ocular aberration as the cause rather than accommodation. Little research has been cited regarding the correction of night myopia beyond minus lenses. However there are a few categories we can discuss that have recently gained attention in improving the night drivers visual world.

The Council of America sponsored a study to address the problem of glare during night driving[2]. The study found that when the eye and face are brightly illuminated and a target of low luminance is being viewed, the reflections from the back and front surfaces of the lenses can significantly degrade vision. Visual acuity was measured under these conditions by recording the loss of contrast sensitivity. When an anti-reflective coat was applied to these same lenses, contrast sensitivity greatly increased.[2]. Further research into this topic should include the non-spectacle wearer who experiences glare due to the normal aberrations of the eye and their response to an AR coated lens.

Waetjen and Schiefer reported that extreme windshield tilt should be avoided[16]. Their study confirmed that an extreme windshield tilt can further reduce the performance of the eye in distance recognition during nighttime driving. In addition, scratched or dirty windshields and any window tints should be avoided. Patients should be counseled to keep both their windshields and spectacle lenses clean when driving at night. Dust, film and deposits can increase scatter and thus degrade images[2]. Windshield and spectacle lens tints should be avoided[16]. Broods and Borisch explain that every 10% of tint reduces a persons distance vision by 10%. They report that with normal headlights, we can see 350 ft at night but by wearing a 10% tinted lens, a person's distance vision is reduced to only 315 ft[2]. Therefore increased tint, whether spectacle or windshield, will only degrade distance vision at night.

Conclusion

Although night myopia has been attributed to several factors, recent literature indicates that accommodation is the primary cause of myopia under scotopic illuminance levels. It is important that night myopia be recognized as a potential problem for drivers under dim lighting conditions. Testing for night myopia should include measurements of the dark focus of the eye and an appropriate minus lens should be prescribed from these measurements. Ocular aberrations should be considered as a primary cause of reduced vision in dim illumination in presbyopic patients. For these cases, the best steps to improving a presbyopic's nighttime vision would include antireflective coats on spectacle lenses, careful cleaning of both spectacles and windshields to minimize scattered light and discourage the use of tints. In conclusion, a derived minus lens correction can be of great benefit to a young patient suffering from night myopia although much more research needs to be given to this topic.

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