An Investigation of Limiting Magnitude Determination: A Pilot Study

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Three methods for determining the stellar limiting magnitude are compared: counting the stars in a pre-designated area, looking for the faintest star using direct vision, and looking for the faintest star using averted vision. Concerning the latter two methods, averted vision yields significantly better limiting magnitudes than direct vision, as may have been expected. Furthermore, the results of the averted vision method and the "star count" method are comparable, indicating that observers tend to use this method with averted vision. Obviously, there is a need to make explicit which viewing technique must be used for determining the limiting magnitude.

1. Determining the limiting magnitude

Traditionally, indications of stellar limiting magnitude (in short, SLM) used to be taken by identifying the faintest visible star in one's field of view and then looking up its apparent magnitude by looking it up in an authoritative atlas. This "faintest star method" presented its difficulties, especially when the identity of the faintest star was in doubt or when it turned out to be a variable. Nowadays, thanks not least to the stadardization which the *IMO* has introduced in meteor work, it has become fairly standard procedure to estimate SLM using the method whereby one counts the number of stars visible in one or more pre-designated areas. This "star count" technique, once established, never had any serious contenders. Admittedly, for a time, observers based in the United Kingdom did hold a preference for a polar sequence method. This was, in many respects, a variation of the star count method, with the all important difference that the region close to the north celestial pole was the one and only area; it was selected, irrespective of the area of the sky being observed. The limitations of this procedure have been quickly acknowledged since, obviously, the relevant stellar limiting magnitude reading must refer to that area of the sky being observed.

The star count method has been described as a "very unprejudiced and convenient method to determine the limiting magnitude." Star regions are selected for embracing the following set of characteristics: *(i)* a fairly regularly spaced sequence of stars with different apparent magnitudes in the visual range; *(ii)* the relative absence of variable stars in the visual range; and *(iii)* the absence of spectral class M stars whose apparent magnitude is difficult to determine. Once these conditions are met, then the identification of a number of stars in any one star region may be expected to translate into a fairly good representation of the extant SLM. The technique, dependent as it is on the judgment of individual observers, is therefore also sensitive to individual differences in perceptual ability, even in cases where observers are carrying out watches of the same general field from the same site at the same time.

There are 27 such star regions scattered all over the gnomonic meteor plotting maps in use round the world today. Their relatively large number means that 3 or 4 are typically within, or very close to, any observer's field of view at any one time. This also permits observers to count star numbers in more than one area; this serves as a cross-checking device, allowing a fair degree of corroboration as well as permitting a sensitivity to different SLM conditions which may be obtained in different parts of an observer's field.

2. Aims

One detail which seems to have been overlooked in these discussions is the use of direct or averted vision in determining SLM readings. No one appears to have raised any concern as to how individual observers should identify the number of stars in any "star count" area, for the purpose of determining SLM. The present study aims to investigate the differences, if any, in SLM determination using three different methods: the star count method; the faintest star method using direct vision; and the faintest star method using averted vision.

3. Method

The data for this preliminary study was accumulated between April 30 and May 8, 1994, during the observations of the η-Aquarid meteor shower. The 4 participating observers were all seasoned with many years of meteor watching experience. They estimated the SLM using each of the three methods mentioned above at various times during each watch.

Table 1 – SLM estimates according to three methods.

Observer	Star Count	Faintest Star (Direct Vision)	Faintest Star (Averted Vision)
BALAN	5.1	3.2	4.4
	3.4	3.8	4.4
	5.0	4.2	4.9
	4.8	4.2	5.0
	6.0	4.4	5.4
	5.1	3.8	4.4
	5.2	4.4	5.4
	5.1	4.4	5.4
	5.0	4.3	4.4
	5.3	4.4	5.4
	5.3	4.4	5.4
	5.3	5.0	5.4
	5.3	5.0	5.4
BALGO	3.4	3.0	3.2
	3.1	3.1	3.6
	4.7	3.0	4.6
	4.8	3.2	4.9
	5.0	3.4	4.6
	5.0	3.2	4.9
	5.0	3.4	4.9
	5.2	3.9	4.9
	5.1	4.0	4.4
	5.1	4.4	4.2
	5.6	3.7	5.6
	5.3	3.7	5.1
MULUM	5.7	5.3	5.7
	5.4	4.7	5.4
	5.4	4.6	5.3
	5.2	4.5	5.0
	5.7	5.1	5.6
	5.5	4.8	5.3
	5.5	4.9	5.4
	5.4	4.9	5.4
	5.9	5.6	5.9
	6.2	5.9	6.2
	6.3	6.0	6.1
	6.2	6.0	6.3
CAMED	3.4	3.4	5.5
	3.4	3.4	5.5
	3.4	3.5	5.5
	4.6	3.7	4.4
	4.6	3.7	4.4
	4.6	3.7	4.4
	4.6	3.7	4.4

Fourty-four sets of estimates were eventually submitted by the four observers for analysis as follows:

> Anna Baldacchino (BALAN; 13 estimates), Godfrey Baldacchino (BALGO; 12 estimates), Umberto Mule' Stagno (MULUM; 12 estimates), and Edwin Camilleri (CAMED; 7 estimates).

The data-set collection is tabuled in Table 1.

The data were then analyzed with a statistical package (SYSTAT Version 5.03) on a personal computer.

The available data were used to test the null hypothesis that there is no difference between the SLM determined using the direct and averted vision techniques. The SLM determined by each of these two methods was also compared with that obtained by the "star count" method.

Testing of conformity to a normal distribution using a χ^2 test indicated that the data for the direct vision deviated significantly from normality. Tests for statistically significant differences between the three datasets were therefore carried out using Wilcoxon's Signed Ranks Test for pairs of variables. This was used in preference to other techniques (such as the t-test) since this is a non-parametric test and therefore is reliably applicable to data which is not normally distributed. A cut-off level of 0.05 was established for tests of significance. Similar tests and criteria were subsequently applied to the data of each observer in order to detect any individual trends.

4. Results

Entire data set

An inspection of the means obtained for each set of readings immediately indicated a disparity between SLM readings obtained by direct and by averted vision (Table 2). This difference is statistically significant.

Table 2 – Mean SLM values obtained by the three methods.

Star Count Method	Faintest Star Method (Direct Vision)	Faintest Star Method (Averted Vision)
5.0	4.2	5.0

Comparison of the mean SLM obtained by the "star count" method with the means of the other two groupings suggests a high affinity between the "star count" and the "averted" data. In simpler terms, it appears that observers in this pilot study systematically resorted to averted vision in determining the number of stars visible in the "pre-designated" star areas, from which the SLM reading is eventually derived. Analysis actually confirms that there is no statistically significant difference between the means of these two groups.

Individual observers

The data available were further broken down by observer as shown in Table 3.

Table 3 – Mean SLM values obtained by the three methods.

Observer	Star Count Method	Faintest Star Method (Direct Vision)	Faintest Star Method (Averted Vision)
BALAN	5.1	4.3	5.0
BALGO	4.8	3.5	4.6
CAMED	4.1	3.6	4.9
MULUM	5.7	5.2	5.6

Firstly, it can be noted that, for all observers, the mean SLM using averted vision is better than that using direct vision. This difference is statistically significant for all four observers.

Secondly, the mean SLM resulting from the "star count" method is better than that obtained using direct vision. This also holds for all four observers. This difference is statistically significant for BALAN, BALGO, and MULUM. The aberrant result for CAMED may be a consequence of the small sample size (only seven estimates); or of poor observing conditions which make any SLM determination technique unreliable.

Finally, the difference in mean SLM between the "star count" method and the averted vision method is within 0.2 magnitude for all observers except CAMED (where the difference is 0.8 magnitude). The differences in the case of BALAN, BALGO, and MULUM are statistically insignificant. This confirms the observation made earlier that each observer is likely to have undertaken the "star count" method of SLM determination using the averted vision method.

5. Discussion

It would be intuitively expected that averted vision permits a higher number of stars to be seen than does direct vision. The reason for this is physiological.

The retina of the human eye comprises two forms of photosensitive cells: these are known as rods and cones. Rods are stimulated by low-light intensities and therefore contribute to night vision. Cones respond to high-light intensities and are therefore most useful during daytime. The distribution of these two types of cells is not uniform and indeed approximates the mutually exclusive: cones are concentrated on the central part of the retina directly perpendicular to the lens. In contrast, rods are distributed throughout the retina, although at lower densities at the center.

Averted vision would therefore predominately stimulate rod cells at the sides of the retina. Since the concentration of rods is greatest away from the center of the retina, use of averted vision in conditions of low light is more likely to elicit a visual response than is direct vision.

Such information is of course staple knowledge to other amateur astronomers such as comet and nova hunters as well as variable star observers.

The results obtained are consistent with the hypothesis that SLM determination using direct vision gives significantly brighter (that is, weaker) limiting magnitudes than does the averted vision method. This implies that use of direct vision data would contribute towards an apparent increase in estimates of zenithal hourly rates relative to rates calculated using the averted vision or "star count" methods. The similarity between data collected using the latter two techniques suggests that the observers concerned calculated their "star count" SLM using averted vision.

6. Implications

If averted vision is indeed the basis for calculating SLM using the "star count" method, this needs to be made explicit; the limited sample used in this preliminary investigation is suggesting that the difference between direct an averted vision techniques amounts to a mean of 0.8 magnitude. This is a very considerable discrepancy for meteor work and carries serious implications for the derivation of activity rates.

The results of this pilot study confirm that SLM readings may vary from observer to observer according to individually favored methods of SLM determination rather than simply as a consequence of perceived different sky conditions. Inadvertent errors of this kind need to be weeded out of the rate reduction process. It is therefore not desirable but necessary that clear and unambiguous guidelines be established and circulated regarding the standardized determination of the all-important SLM statistic.