guest editorial

Visual acuity measurements

Modern visual acuity charts are designed so the letter sizes on each line follow a geometric progression (ie, change in a uniform step on a logarithmic scale).[1–3] The accepted step size has been chosen to be 0.1 log unit, which is equivalent to letter sizes changing by a factor of 1.2589 between lines. This standard gave rise to the logMAR (logarithm of the minimum angle of resolution) notation as shown in Table 1, column 3. The **bold** values correspond to the accepted logMAR steps. Values that are not in logMAR steps such as 20/30, 20/60, 20/70, 20/150, and 20/300 are included because of their common appearance in older visual acuity charts. A geometric progression of lines on the visual acuity chart was chosen because it parallels the way our visual system functions. If patient 1 has a visual acuity of 20/20 and patient 2 has a visual acuity of 20/40, we conclude that patient 1 has two times better visual acuity than patient 2 because he/she can recognize a letter twice as small. Once we have chosen to compare vision as a ratio using a reference visual angle (20/20), a geometric progression results and a geometric mean must be calculated for a meaningful result.

Notice that in Table 1, the only values that increase linearly are the line numbers and the logMar notation. Snellen acuity, decimal acuity, and visual angle increase by the geometric factor of 1.2589. Once we have decided that equal steps in visual acuity measurement are geometric and not arithmetic, we must use the appropriate geometric mean to compute the correct average.

In Table 1, we see that line 0 is the 20/20 Snellen acuity that corresponds to the logMAR value zero, since 20/20 is the standard. We also see that line 10 is 20/200 Snellen visual acuity, which corresponds to a logMAR value of 1.0 (10 times or 1 log unit worse than 20/20). Intuitively, it would appear that halfway between line 0 and line 10 would be line 5 or 20/63. This is the correct average, because geometrically it is halfway between 20/200 and 20/20.

Calculating the average visual acuity and standard deviation in a series of patients is not difficult, but has been done incorrectly in most studies.[4] The basic problem relates to the difference between the arithmetic and geometric mean for a set of numbers. For the correct average visual acuity, the geometric mean must be used, which gives significantly different values than the arithmetic mean.

The simplest method for computing the proper average visual acuity from any notation is to convert the value to the logMAR equivalent and then take the average of the logMAR values. The easiest way to compute the logMAR value is to convert to the decimal notation and then take the negative of the logarithm. For example, 20/20 = 1 and the log of 1 is 0, and 20/200 = 0.10 and the negative of the log is +1.0; the average of 0 and +1.0 is 0.5 logMAR units. Converting back from the logMAR value of 0.5, the corresponding visual acuity is 20/63, the correct geometric average.

The formulas for going from decimal to logMAR and then back are as follows:

$$\text{logMAR} = -\log\,(\text{decimal acuity}) \tag{1}$$

$$\text{decimal acuity} = \text{antilog}\,(-\,\text{logMAR}) = 10^{-\text{logMAR}} \tag{2}$$

Two other considerations occur when sets of visual acuity measurements are evaluated: (1) what to do with values of counting fingers, hand motion, light perception, etc., and (2) how to compute the correct value if the patient did not read all the letters on the line completely.

Counting Fingers, Hand Motion, Light Perception, No Light Perception

Counting fingers at a given distance can be converted to a Snellen equivalent by assuming that the fingers are approximately the size of the elements of a 200 letter. Therefore, a person who can count fingers at 20 feet would have approximately 20/200 vision.[5] A person able to count fingers at 2 feet would have 2/200 vision or the equivalent of 20/2000. This value is somewhat conservative because a hand against a white coat is much lower contrast than a black letter on a white background. Also, the examiner usually uses 4 or fewer fingers, making the

0886-3350/04/$–see front matter
doi:S0886-3350(03)00125-7

Table 1. Visual acuity conversion chart.

				Distance				Near					
					Snellen Equivalent								
Line Number	Visual Angle (min)	Spatial Frequency (Cyc/deg)	LogMAR	% Central Visual Efficiency	Feet 20/	Meter 6/	Decimal	% Central Visual Efficiency	Inches (14/)	Centimeters (35/)	Revised Jaeger Standard	American Point-Type	"M" Notation
−3	**0.50**	**60.00**	**0.30**	**100**	**10**	**3.0**	**2.00**	**100**	**7.0**	**17.5**	**–**	**–**	**0.20**
−2	**0.63**	**48.00**	**0.20**	**100**	**12.5**	**3.8**	**1.60**	**100**	**8.8**	**21.9**	**–**	**–**	**0.25**
−1	**0.80**	**37.50**	**0.10**	**100**	**16**	**4.8**	**1.25**	**100**	**11.2**	**28.0**	**–**	**–**	**0.32**
0	**1.00**	**30.00**	**0.00**	**100**	**20**	**6.0**	**1.00**	**100**	**14.0**	**35.0**	**1**	**3**	**0.40**
1	**1.25**	**24.00**	**−0.10**	**95**	**25**	**7.5**	**0.80**	**100**	**17.5**	**43.8**	**2**	**4**	**0.50**
—	1.50	20.00	−0.18	91	30	9.0	0.67	95	21.0	52.5	3	5	0.60
2	**1.60**	**18.75**	**−0.20**	**90**	**32**	**9.6**	**0.63**	**94**	**22.4**	**56.0**	**4**	**6**	**0.64**
3	**2.00**	**15.00**	**−0.30**	**85**	**40**	**12.0**	**0.50**	**90**	**28.0**	**70.0**	**5**	**7**	**0.80**
4	**2.50**	**12.00**	**−0.40**	**75**	**50**	**15.0**	**0.40**	**50**	**35.0**	**87.5**	**6**	**8**	**1.0**
—	3.00	10.00	−0.48	67	60	18.0	0.33	42	42.0	105.0	7	9	1.2
5	**3.15**	**9.52**	**−0.50**	**65**	**63**	**18.9**	**0.32**	**40**	**44.1**	**110.3**	**8**	**10**	**1.3**
—	3.50	8.57	−0.54	63	70	21.0	0.29	32	49.0	122.5	—	—	1.4
6	**4.00**	**7.50**	**−0.60**	**60**	**80**	**24.0**	**0.25**	**20**	**56.0**	**140.0**	**9**	**11**	**1.6**
7	**5.00**	**6.00**	**−0.70**	**50**	**100**	**30.0**	**0.20**	**15**	**70.0**	**175.0**	**10**	**12**	**2.0**
—	5.70	5.26	−0.76	44	114	34.2	0.18	12	79.8	199.5	11	13	2.3
8	**6.25**	**4.80**	**−0.80**	**40**	**125**	**37.5**	**0.16**	**10**	**87.5**	**218.8**	**12**	**14**	**2.5**
—	7.50	4.00	−0.88	32	150	45.0	0.13	6	105.0	262.5	—	—	3.0
9	**8.00**	**3.75**	**−0.90**	**30**	**160**	**48.0**	**0.13**	**5**	**112.0**	**280.0**	**13**	**21**	**3.2**
10	**10.00**	**3.00**	**−1.00**	**20**	**200**	**60.0**	**0.10**	**2**	**140.0**	**350.0**	**14**	**23**	**4.0**
11	**12.50**	**2.40**	**−1.10**	**17**	**250**	**75.0**	**0.08**	**0**	**175.0**	**437.5**	**–**	**–**	**5.0**
—	15.00	2.00	−1.18	16	300	90.0	0.07	**0**	210.0	525.0	—	—	6.0
12	**16.00**	**1.88**	**−1.20**	**15**	**320**	**96.0**	**0.06**	**0**	**224.0**	**560.0**	**–**	**–**	**6.4**
13	**20.00**	**1.50**	**−1.30**	**10**	**400**	**120.0**	**0.05**	**0**	**280.0**	**700.0**	**–**	**–**	**8.0**
16	**40.00**	**0.75**	**−1.60**	**5**	**800**	**240.0**	**0.03**	**0**	**560.0**	**1400.0**	**–**	**–**	**16.0**
20	**100.00**	**0.30**	**−2.00**	**0**	**2000***	**600.0**	**0.01**	**0**	**1400.0**	**3500.0**	**–**	**–**	**40.0**
30	**1000.00**	**0.03**	**−3.00**	**0**	**20000†**	**6000.0**	**0.001**	**0**	**14000.0**	**35000.0**	**–**	**–**	**400.0**

Bold values are standard logMAR progression.
LogMAR = logarithm of the minimum angle of resolution
*20/2000 is equivalent to counting fingers @ 2 feet
†20/20000 is equivalent to hand motion @ 2 feet

number of forced choices less than the number of Snellen optotypes (10).

From studies we have performed in our low-vision clinic, hand motion at a given distance is 10 times worse than counting fingers; ie, a person who can detect hand motion at 20 feet has approximately 20/2000 Snellen visual acuity equivalent. A person who has hand motion at 2 feet would have an equivalent Snellen acuity of 20/20000.

Light perception with and without projection and no light perception are not actually visual acuity measurements, but simply the detection of a stimulus. These cases should be excluded and described in the materials and methods section of the manuscript.

Patient Cannot Read Entire Line

It is very common for visual acuity sets to include values in which the patient did not read all of the letters on a single line correctly. Although recording the last

Table 2. Visual acuity data set for 7 theoretical eyes.

Eye	Measured Visual Acuity*	Snellen Equivalent	Decimal Equivalent	LogMAR Equivalent
1	20/10	20/10	2.000	−0.30
2	20/10 − 2	20/10 − 2	2.000 − 2	−0.26
3	20/40	20/40	0.500	0.30
4	20/40 + 3	20/40 + 3	0.500 + 3	0.24
5	20/200	20/200	0.100	1.00
6	CF** @ 2 ft	20/2000	0.010	2.00
7	HM*** @ 2 ft	20/20000	0.001	3.00
Mean ± SD		20/142 ± 12.4 lines	0.141 ± 12.4 lines	0.85 ± 1.24

CF = counting fingers; HM = hand motion; LogMAR = logarithm of the minimum angle of resolution
*Bailey-Lovie visual acuity chart with 5 letters on each line

line that was read completely or the majority of letters (3 out of 5) is an acceptable method, it reduces the precision of the measurement, similar to rounding off laboratory measurements. A more accurate method is to interpolate between the values of the logMAR acuity using the fraction of the number of letters correctly read on a visual acuity line.

For example, suppose our acuity chart had 5 letters on each visual acuity line and the patient read all the letters on the 20/50 (logMAR = +0.4) line but only 3 of the 5 letters on the 20/40 (logMAR = +0.3) line. Three fifths (3/5 = 0.6) of the way from logMAR +0.4 to +0.3 is logMAR +0.34. The logMAR value of +0.34 is the correct value for this patient's visual acuity. For studies that involve large data bases, in which converting the values manually is tedious, we have published the formulas that allow direct conversion from the Snellen acuity value to the interpolated logMAR value.[6] These formulas work only if there are an equal number of letters on a line, such as the Bailey-Lovie visual acuity chart[3] and other standardized charts.[6]

Unfortunately, if the number of letters on the acuity chart are not equal on each line (as occurs on many projector and wall charts), a table must be created that shows the conversion interpolation for each line and a single formula is not possible.

Sample Calculations

Once the logMAR value for the visual acuity of each patient has been obtained, statistical analyses on the data set can be performed. All statistical calculations (means, standard deviations, standard errors of the mean, correlation coefficients, etc.) must be calculated using logMAR values for visual acuity. Performing these analyses using any other value for visual acuity will lead to erroneous results.[7,8]

Table 2 gives a 7-patient sample data set to illustrate the correct calculations and serves as a guide for an investigator to use to validate his/her calculation method. The average value and standard deviation are calculated using the logMAR values. The average logMAR acuity was 0.85 and the standard deviation was 1.24, normally expressed as 0.85 ± 1.24. To determine the equivalent decimal acuity for the average, we must use equation 2 above:

$$\text{Decimal Visual Acuity} = 10^{-\text{LogMAR}} = 10^{-0.85} = 0.141$$

$$\text{Snellen Visual Acuity Denominator} = 20/\text{Decimal Acuity} = 20/0.141 = 142$$

$$\text{Snellen Visual Acuity} = 20/142$$

The only meaningful conversion of the standard deviation in logMAR units is to lines of visual acuity. Since each line of the standardized visual acuity chart increases by 0.1 log units, a standard deviation of ±1.24 log units is equivalent to ±12.4 lines (1.24/0.1). In this data set of 7 patients, the mean visual acuity and standard deviation are 0.85 ± 1.24 logMAR units, 0.141 ± 12.4 lines in decimal units, and 20/142 ± 12.4 lines in Snellen units.

Other statistical calculations such as correlation coefficients, Student *t* test, analysis of variance should be performed using the logMAR values, as shown above for the mean and standard deviation. Using these techniques will provide meaningful analyses of data sets and allow valid comparisons of different data sets.

Near-vision measurements must conform to the same visual angle as distance measurements and the most common near distance is 14 inches (35 centimeters). In Table 1, line 0 with a visual angle of 1 minute of arc is 14/14 and 35/35. The "M" notation in the last column used in low-vision patients uses the 20/50 angular size to be equivalent to 1 M and all the remaining values are proportional. For example, 2 M print is 20/100 and 0.5 M print is equivalent to 20/25 angular size.[5]

Jaeger values have undergone a number of revisions over the years, but the "revised Jaeger standard" was adopted in the late 50s and is shown in the 3rd to the last column in Table 1.[9–12] The approximate American point type used by printers is shown in the next to last column in Table 1. Finally, percentage central visual efficiency was standardized in 1993 by the American Medical Association.[13] The percentage central visual disability is 100% minus the central visual efficiency (eg, if the central visual efficiency is 30%, the central visual disability is 70%). It should be noted that the distance visual efficiency decreases almost linearly with logMAR steps. However, near central visual efficiency decreases abruptly after the 20/40 distance equivalent. This abrupt drop is because most newspaper and other periodical print are near the 20/40 distance equivalent level.

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