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A Clinically Useful Tool to Determine an Effective Snellen Fraction: Details

by William A. Monaco, Joseph M. Heimerl, and Joel T. Kalb

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14. ABSTRACT
A patient's visual function has been routinely assessed by a visual acuity measurement, usually by means of a Snellen chart. More recently, visual acuity measurements have been extended to measure the progress of disease or the efficacy of therapeutic interventions. Thus, accurate and reproducible visual acuity measurements are needed.
However, the intrinsic variability in line-by-line scoring is high because only 50%–80% of the letters in a line need be correctly identified to score a successful reading of the entire line. To reduce this high test-retest variability, we developed a tool whereby the cumulative letter-by-letter logarithm of minimum angle of resolution (LogMAR) values of a patient's responses are converted into an effective Snellen fraction. With these concepts, test-retest visual acuity measurements are known to be more precise by up to a factor of 2.
These concepts have been combined into a spreadsheet that automatically and transparently calculates the effective Snellen fraction. This spreadsheet is simple to use, making its introduction into the clinic straightforward. This report documents the details of the processes constituting this tool, which is available for download from the Pennsylvania College of Optometry web site: www.salus.edu.

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*EXCEL is a registered trademark of Microsoft Corp., Redmond, WA.

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1. Background

Colenbrander (*1*) provides a brief history of the evolution of the Snellen chart, introduced in 1862. Since then, improvements and innovations to correct its deficiencies have been proposed (*2–4*) (for reviews, see [*5*, *6*]), but rarely implemented (*7*, *8*). Use of a Snellen chart has a number of shortcomings, one of which is the test-retest variability in the determination of a patient's visual acuity (*9*). Reduction of this test-retest variability is the topic of this report.

Gibson and Sanderson (*10*) reported on the repeatability of distance visual acuity tests for 64 outpatients. Only a third of patients were found to have the same distance visual acuity on two occasions, separated by 2–8 weeks. The majority of the acuity variation was one line; however, 13% of the visual acuity measurements differed by two lines or more. (Near visual acuity measurements exhibited a similar degree of variability [*10*].) This large variability is significant since standard clinical practice considers a change of at least two lines of the Snellen chart as a cut-off for clinically meaningful change in visual acuity (*11*).

Many disorders can affect visual acuity (*1*), and so the most common clinical measurement of visual function is visual acuity. It is used to determine the need for, and outcome of, many interventions (*12*); it is also used to monitor the course of eye disease (*7*). Visual acuity data are subject to measurement error. When a patient is tested and subsequently retested, the resultant visual acuities tend to differ, even in the absence of any actual change (*10*). Nevertheless, the clinician monitoring a patient over time must, on the one hand, disregard apparent changes resulting from test-retest variability, and must, on the other hand, recognize any change reflecting a genuine alteration in clinical status. Failure to do the former results in unwanted false-positives (i.e., loss of specificity), whereas failure to do the latter compromises the test's sensitivity to change (*13*).

Because visual acuity is employed to measure the progress of therapeutic interventions, there is a need for accurate and reproducible visual acuity measurements (*8*). The monitoring of patients' progress or the comparison of results with colleagues may be compromised whenever poor repeatability of visual acuity measurements occurs (*10*). If one could reduce the test-retest variability, then smaller, genuine changes in a patient's acuity could be detected reliably (*13*). According to Elliot and Sheridan (*14*), the main problem with the Snellen chart, when used in a longitudinal study, is the lack of a precise scoring system.

It is a common practice to assign visual acuity scores in increments representing the range of letter sizes available. A criterion, such as correctly reading 60%, 70%, or 80% of the letters in a line, has been used to decide whether patients are given credit for reading a given line satisfactorily (*15*). (Rosser et al. [*7*] even defined the acuity score as the value of the lowest line on which at least half of the letters were named correctly.) However, it is far better to give partial credit for correctly read letters within a line, and this is most readily achieved by giving credit for every letter read (*15*). Bailey et al. (*16*) show that making the scoring scale finer always improves the sensitivity of the test. Vanden Bosch and Wall (*11*) report that the variability of repeated visual acuity measurements is less when letter-by-letter scoring is used than when the more traditional line-by-line scoring is used. Raasch et al. (*17*) report: "A scoring method that awards credit in single letter increments produces scores that are more repeatable." In this regard, Stewart (*18*) summarizes Bailey et al. (*16*):

> The finer the grading scale, i.e., the smallest increment change possible on the test, the more repeatable the test is likely to be and therefore the greater the sensitivity with which change can be detected.

Westheimer (*19*) found that the logarithm of minimum angle of resolution (LogMAR) transformation provides a good approximation to a scale for visual acuity that has equally spaced just noticeable differences. This report describes a process to score Snellen chart responses through the use of the LogMAR transformation that accounts for each letter read. This process provides more sensitivity to detect changes in visual acuity, and is more precise than line-by-line scoring commonly employed (*6*, *15*). The final step in the process presented here is to invert the cumulative LogMAR score into an effective Snellen fraction. All the mathematical transformations are calculated automatically, and are transparent to the clinician.

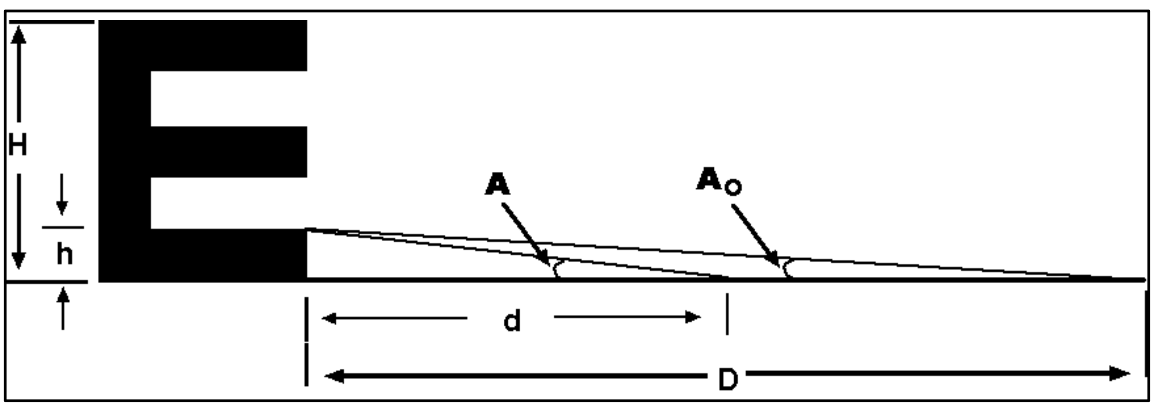
To summarize: the purpose of this report is to provide the clinician a tool that can reduce the variance in test-retest measurements of visual acuity by up to a factor of 2. We are not aware of any such too l that can be shared among ocular-care providers. They need this kind of tool to clearly assess a patient's visual capability, which is crucial to early diagnosis, treatment, and medical management of a broad spectrum of ocular maladies. Thus, the primary audience for this report includes those clinicians who treat or monitor diseases of the eye.

In developing this tool, we relied on the literature to assess the current status of visual acuity measurements (*10*, *11*, *13*), and to provide an estimate of the decrease in test-retest variance (*11*, *15–18*). For decades, clinicians have not utilized these well-known improvements to the Snellen chart. Presumably the cost/benefit of employing letter-by-letter scoring and LogMAR principles had been too high for the clinician to implement them.

In this report, we have combined concepts and results found in the literature into an EXCEL* spreadsheet that automatically and transparently calculates an effective Snellen fraction based on letter-by-letter scoring and LogMAR principles. This EXCEL spreadsheet is simple to use, making its introduction into the clinic straightforward. The simplicity of this spreadsheet permits ready modifications to accommodate other transformations, such as true LogMAR charts like Early Treatment of Diabetic Retinopathy Study (ETDRS). The mathematical manipulations reported in the following section detail those processes taking place during the execution of the EXCEL spreadsheet.

2. Snellen Fraction and LogMAR

This section examines the relationship between the Snellen fraction and the LogMAR transformation. We begin with the definition of the Snellen fraction. Figure 1 shows a representation of the Snellen letter, E.



Notes: h = the height of the smallest segment used to construct the letter.
H = the total height of a letter; typically H = 5h.
d = the testing distance, e.g., 20 ft.
A = the visual angle subtended by h at the testing distance, d.
D = the distance at which h subtends the angle A_o, normally taken as 1 min of arc.

Figure 1. A representation (5) of the Snellen letter, E.

Construct the tangent of both angles shown in figure 1.

$$\tan A = h/d \quad \text{and} \quad \tan A_o = h/D. \tag{1}$$

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For small angles:

$$A \approx h/d \quad \text{and} \quad A_o \approx h/\,D, \tag{2}$$

or

$$Ad \approx h \quad \text{and} \quad A_o\,D \approx h. \tag{3}$$

Since h is the same in both expressions, we have:

$$Ad = A_o\,D, \tag{4}$$

or

$$d/D = A_o/A. \tag{5}$$

The ratio d/D is recognized as the Snellen fraction for visual acuity, and so Ao/A is the ratio of angles corresponding to the Snellen fraction. Snellen specifically adopted 1 min of arc for the value of Ao2,3,5,6, and so we can write:

$$\text{Visual acuity} = \text{Snellen fraction} = d/D = 1/A, \tag{6}$$

where A is now the minimum angle of resolution in units of minutes of arc. If we also require d = 20 ft, then equation 6 becomes:

$$20(\text{ft.})/D = 1(\text{min arc})/A. \tag{7}$$

Inverting equation 7, we find:

$$D/20 = A/1. \tag{8}$$

If D is measured in feet and A is measured in minutes of arc, then equation 8 is composed of dimensionless ratios, which allows us to take the logarithm of equation 8:

$$\log_{10}[D/20] = \log_{10}[A/1], \tag{9}$$

or

$$\log_{10}[D/20] = \log_{10}[A]. \tag{10}$$

The right-hand side of equation 10 is the LogMAR.

We shall use equation 10 in the next section. Here we review some observations made by others. First, the Snellen fraction, d/D in equation 5, signifies nothing more than D is the smallest size of letter recognized and correctly identified by a patient at distance, d. The Snellen fraction also expresses the fact that when D = d, the height of the letter subtends a visual angle of 5 min of arc and the width of each of the letter's component lines subtends an angle of 1 min of arc (*2*) (see figure 1).

Next, equation 5 is a general relationship between the Snellen fraction and the ratio of the visual angles. However, equation 6 no longer is a general relationship because the value of 1 min of arc has been assigned to Ao5. (Equation 7 becomes even more particular when we assign the value of 20 ft, or any other fixed value, to d.)

One minute of arc has an empirical basis. According to Brown and Lovie-Kitchin (*20*), Snellen recognized the arbitrary nature of selecting one minute of arc as a "standard" for visual acuity. Hartridge and Owen (*21*) state that for the eye to resolve a grating consisting of alternate white and black bars, the centers of the black bars must subtend an angle of 58 s (i.e., ~1 min) of arc; a limit determined experimentally. Ehlers (*22*) found that the average visual acuity for 100 randomly selected Danes of different ages was 0.85 min of arc.

Additionally, Ogle (*3*) writes:

> It is common knowledge that emmetropic (i.e., normal) eyes can discriminate detail subtending a visual angle of considerably smaller than 1.0 min of arc. The median in the distribution of (1,190) subjects in the age group 20–35 years was found by van Beuningen (*23*) to be 53 s (i.e., ~0.9 min) of arc.

Anand et al. (*24*) found that an average binocular visual acuity of (0.85 ± 0.10) min of arc for 15 healthy, elderly people whose mean age was (71 ± 5) years.

Green (*2*) remarked:

> In persons of exceptionally sharp sight, the angle under which the component lines of Snellen's letters are recognized, as shown by the correct naming of most of the letters in the line, is not very infrequently as small as 0.4 min of arc, and a visual angle of 0.8 min of arc is observed in so large a proportion of all the eyes examined as to have suggested the proposal to adopt this value as the unit of reference.

Nevertheless, Green concludes that neither the Snellen fraction, in which D = d corresponding to a visual angle of one minute of arc, nor "any arbitrarily chosen unit can be accepted as a standard of normal acuity of vision."

Evidently, Snellen's choice of 1 min of arc is not very far from reality. Prior to the invention of the telescope astronomers, such as Tycho Brahe (1546–1601) (*25*) and Johannes Evelius (1611–1687) (*26*), constructed naked-eye instruments to measure celestial positions down to 1 min of arc. Most likely, Snellen was aware of the astronomers' naked-eye visual limit. Snellen's choice of 1 min of arc has been supported subsequently by the experimentally determined limit of resolution of ~1 min of arc quoted by Hartridge and Owen (*21*), the average of 0.85 min of arc found by Ehlers (*22*), the median of 0.9 min of arc found by van Beuningen (*23*), the predominance of 0.8 min of arc observed by Green (*2*), and the average of 0.85 min of arc found by Anand et al. (*24*). Even though a visual angle of one minute of arc does not represent "normal" or "standard" vision, this value appears to be a convenient and useful marker or reference point (Westheimer [*19*] employs the term "anchor point"), and we continue to use it here.

Next, the question may be raised whether the Snellen fraction can be used legitimately to designate a test made at a distance other than the actual numerator distance. Rosser et al. (*13*) answered in the affirmative. They reported: "The relationship between measured acuity and viewing distance was as predicted theoretically." Finally, Ogle (*3*) stated: " … the only logical designation of visual acuity …[is] the visual angle subtended by the critical details of the test character." Bailey (*15*) uses more modern terminology and notes:

> … the Snellen Fraction specifies two quantities, the first for the test distance [here, d] and the second is a measure of the print size [here, h], and together these represent an angle [here, A]. It is the angle [A], a single dimension that represents the acuity.

Bailey and Lovie-Kitchin (*4*) combined the idea that visual angle is the primary variable to be measured with the constraint that the visual acuity demand be essentially the same at each size level on the acuity chart. They first introduced scoring visual acuity as a LogMAR value, and recommended a set of design principles for the construction of visual acuity charts. These principles have been incorporated into the design of the ETDRS chart (*6*). (The ETDRS chart with its Sloan optotypes and Bailey-Lovie layout has become the de facto standard for research in Western countries [*6*].) Nevertheless, Bailey (*15*) himself expressed concern that the newer design principles leading to extensive use of LogMAR to designate visual acuity would not be easily implemented in the clinic. He stated:

> It should be recognized that clinicians are more likely to be reluctant to change their ways and adopt a new scoring system for visual acuity measurement.

Indeed, Hussain et al. (*8*) note, some 20 years later, that the Snellen chart is still the universally accepted tool for testing visual acuity despite its poor reliability and reproducibility (*10*). The continued use of Snellen charts exists in the face of the need for more accurate and reproducible visual acuity measurements. Newer LogMAR charts, e.g., the ETDRS chart, have overcome the disadvantages of the Snellen chart and are now available (*9*). Furthermore, a visual acuity chart based on LogMAR design is judged superior in its scientific principles, clinical precision, and reproducibility (*9*). Stewart (*18*) states:

> Calculations of the repeatability of each test have revealed that detecting a real change in visual acuity with certainty requires at least 3 lines difference for the Snellen chart compared with 1.5 lines for log-based tests.

Nevertheless, Hussain et al. (*8*) opine that the Snellen chart is well entrenched in current clinical practice, and that this may be the single biggest factor preventing LogMAR-based charts from replacing the Snellen chart.

Based on the historical record, the use of LogMAR in clinical practice will be gradual, at best. Therefore, we have devised a method, detailed in the next section, by which each letter in the Snellen chart is evaluated. The end result is a single, effective Snellen fraction. Such a letter-by-letter evaluation method is known to be more precise than the more common, line-by-line evaluations (*11*, *15*, *16*, *18*).

3. An Effective Snellen Fraction

This section describes how each Snellen letter, correctly identified by a patient, can be quantitatively scored and subsequently converted into an effective Snellen fraction. In the computations that follow, we presume that a Snellen-chart testing-distance of 20 ft is used in the acuity test. If 20 ft is not the actual test distance, then an arithmetic adjustment to 20 ft is necessary to readily employ the method presented here. The adjustment is given by:

$$(d/D) * (c/c) = (c*d)/(c*D) = 20/(c*D), \qquad (11)$$

where c is a constant so that (c*d) = 20 ft. One must exercise care to multiply the Snellen denominator on the right-hand side of equation 11 by the same constant, c, as the Snellen numerator. Selected values of c are given in table 1.

Table 1. Selected values of c (see equation 11).

Multiply Actual Testing Distance (d)	**By Factor (c)**	**To Arrive At (ft)**
20 ft	1	20
10 ft	2	20
6 m	3.3 ft/m	20
4 m	5.0 ft/m	20

Table 2 shows a representation of the Snellen chart used. The actual testing distance was 10 ft, as shown. These Snellen fractions were adjusted to 20 ft using the c = 2 from table 1. Given an actual or adjusted testing distance of 20 ft as the numerator in the Snellen fraction (see equation 11), we now focus on the denominator of the Snellen fraction.

Table 2. A representation of the Snellen chart used. The test distance was 10 ft.

Line Identification	**Snellen Letters**	**Snellen Fraction**
1	L	10/200
2	T E	10/100
3	D F A	10/70
4	O T C L	10/50
5	A Z O T H	10/40
6	V E C T V L	10/30
7	E C T V D F A	10/25
8	O T H D F A V L	10/20
9	Z O T V C L D F A	10/15
10	V E C T V L A Z O T H	10/10

The values in columns N and A of table 3 are taken from the Snellen chart used in the acuity test, whose representation is given in table 2. (The appendix shows how the clinician can deal with Snellen charts whose letters are different than those shown in table 2.)

In table 3, the number in column N identifies each line in the Snellen chart. The number in column A shows the adjusted value of the Snellen denominator (in feet) corresponding to each line of the chart.

Column B shows the LogMAR value for each Snellen denominator given in column A. Each LogMAR value is computed from equation 10 written as:

$$\text{LogMAR}(N) = \log_{10}[\text{Snellen Denominator}(N)/20]. \qquad (12)$$

Column C shows the line-to-line change in value of LogMAR, whose values are given by:

$$\Delta\text{LogMAR}(N + 1) = \text{LogMAR}(N + 1) - \text{LogMAR}(N) \qquad (13)$$

and

$$\Delta\text{LogMAR}(1) = 0,$$

which recognizes there is no change in the first line, N = 1, and its value is set to 0.

In table 4, columns N and A are the same as in table 3 and are presented for ease of reference between the two tables.

Table 3. Conversion of Snellen denominator values into LogMAR format for Snellen fractions of the form: (20/…).

From Snellen Chart		LogMAR	
N	A	B	C
Line ID	Snellen Denominator (20/…)	LogMAR	Line-to-Line Change in LogMAR
1	400	1.30	0.00
2	200	1.00	– 0.30
3	140	0.85	– 0.15
4	100	0.70	– 0.15
5	80	0.60	– 0.10
6	60	0.48	– 0.12
7	50	0.40	– 0.08
8	40	0.30	– 0.10
9	30	0.18	– 0.12
10	20	0.00	– 0.18

Table 4. Showing the method used to determine an effective Snellen denominator from a patient's response to a Snellen acuity test.

From Snellen Chart			Patient's Response				
N	A	D	E	F	G	H	J
Snellen Line ID	Snellen Denominator	No. Snellen Letters	No. Snellen Letter Errors	No. Snellen Letters Correct	Fraction Correct	Patient's ΔLogMAR	Patient's Cumulative LogMAR
1	400	1	0	1	1.00	0.00	1.30
2	200	2	0	2	1.00	– 0.30	1.00
3	140	3	0	3	1.00	– 0.15	0.85
4	100	4	0	4	1.00	– 0.15	0.70
5	80	5	0	5	1.00	– 0.10	0.80
6	60	6	0	6	1.00	– 0.12	0.48
7	50	7	1	6	0.86	– 0.07	0.41
8	40	8	5	3	0.38	– 0.04	0.37
9	30	9	9	0	0.00	0.00	0.37
10	20	11	11	0	0.00	0.00	0.37
—	—	—	—	—	—	Patient's effective Snellen denominator	47.2

Column E records the number of letter-identification errors made by a patient on each line of the Snellen chart. A patient is encouraged to guess the identity of the Snellen letters because, according to Hartridge and Owen (*21*), "…the recognition of a letter involves mental processes with a strong personal factor." Column F records the number of letters correctly identified by a patient on each line of the Snellen chart. The values in columns E and F are related through the total number of Snellen letters in a line, which is listed in column D. At each line, N:

$$\text{Number(Column D)} - \text{Number(Column E)} = \text{Number(Column F)}. \qquad (14)$$

In words: at each line in the Snellen chart, the number of letters in the line of the chart minus the number of letters the patient misidentified equals the number of Snellen letters the patient correctly identified.

The decimal fraction of the number of letters correctly identified by the patient is given in column G. For each line, N:

$$\text{Number(Column G)} = \text{Number(Column F)} / \text{Number(Column D)}. \qquad (15)$$

When a patient correctly identifies all the letters in a line, a perfect score of 1.00 is recorded. When a patient does not correctly identify any of the letters in a line, a score of 0.00 is recorded. Therefore, column G has a range of values from 0.00 to 1.00.

Column H in table 4, labeled "Patient's ΔLogMAR," shows the line-to-line change in the patient's LogMAR value. Each of these values is computed by taking the value of ΔLogMAR for a perfect score given in column C of table 3, and multiplying it by the corresponding fraction the patient correctly identified, i.e., multiplying by the corresponding values in column G of table 4. For each line, N:

$$\text{Value(Column H)} = \text{Value(Column C)} * \text{Value(Column G)}. \qquad (16)$$

As a specific example, consider N = 7 in table 4. Then, using equation 16, we can write:

$$\text{Value(Column H)} = (-0.08) * (0.86), \qquad (17)$$

and multiplying, we find:

$$\text{Value(Column H)} = -0.07. \qquad (18)$$

Column J of table 4 shows the cumulative sum of the patient's LogMAR values. For each line N, the values in column J are computed from:

$$\text{Patient's Cumulative LogMAR(N)} =$$

$$\text{Patient's Cumulative LogMAR(N} - 1) + \text{Patient's } \Delta\text{LogMAR(N)}, \qquad (19)$$

and

$$\text{Patient's Cumulative LogMAR}(1) = 1.30, \tag{20}$$

which is the LogMAR value computed from equation 12 for the Snellen denominator of 400, listed in table 3, column B, N = 1.

The patient's LogMAR value, 0.37, which is given in table 4, column J, N = 10, can be converted into the effective Snellen denominator, 47.2, shown at the very bottom of table 4 by using equation 21):

$$\text{Effective Snellen Denominator} = 20*10^{[\text{Value(Column J, N=10)}]}. \tag{21}$$

Figure 2 illustrates the cumulative processes leading to an effective Snellen denominator. Consider first the plot of the perfect score. In figure 2, the perfect score for the Snellen denominator, column A, is plotted against the "Accumulated Correct Letter Choices." These letter choices are the partial sums derived by successively adding the values in column D, table 4 line-by-line. Specifically, in column D:

"Accumulated Correct Letter Choices"(N + 1) =

"Accumulated Correct Letter Choices"(N) + Number(Column D, N + 1).

Additionally, we see from table 4, column D, that:

"Accumulated Correct Letter Choices"(1) = 1.

The sum of all the correct letter choices of column D, table 4 is 56. This is the highest value plotted along the abscissa in figure 2.

Next, consider the points for the patient's (partial) scores in terms of Snellen denominators. They are calculated from the values in column J, table 4:

$$\text{Snellen Denominator}(N) = 20*10^{[\text{Value}(N)]}. \tag{22}$$

These computed values of the Snellen denominators can be found only in the plot of figure 2. Equation 22 is the same functional form used in equation 21, in which the particular value corresponding to N = 10 was used.

Figure 2 shows that the Snellen denominator for the patient's score is perfect for the first six lines. At line 7 (i.e., N = 7), the patient's score begins to deviate from the perfect score when one of seven letters is missed (see table 4, column E). In line 8, the patient missed five of eight letters, and in lines 9 and 10, the patient missed all the letters. The plot of the patient's score plateaus to a minimum Snellen denominator value of 47.2, labeled in figure 2. The dashed line to the ordinate value of 47.2 in figure 2 highlights this patient's limit. The effective Snellen fraction for this patient is 20/47.2.

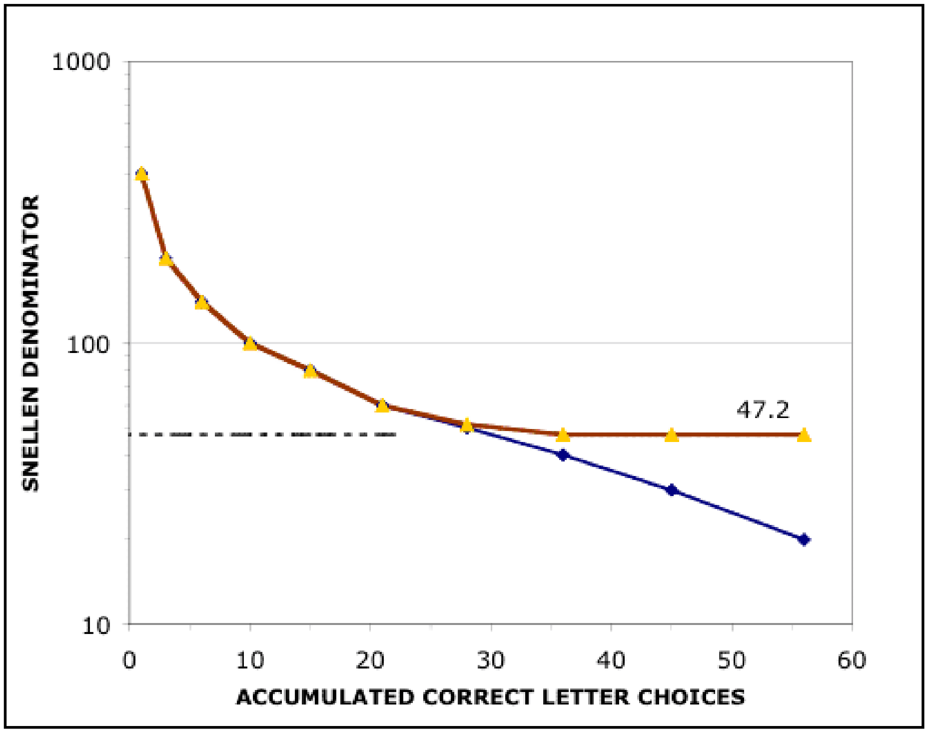

Figure 2. Patient's response and scores are plotted (Δ) against accumulated correct letter choices. The dashed horizontal line indicates the limit of the patient's score. A perfect score is plotted (♦) for reference.

In summary, to compute an effective Snellen fraction, we start with an actual or adjusted testing distance of 20 ft. The data placed in table 3 are either taken from the Snellen chart in use or are computed using equations 12 or 13. Table 4 includes the number of Snellen letters per line, which is again taken from the Snellen chart in use. The number of patient errors (or the number of correct letter identifications) for each line of the Snellen chart is recorded. The decimal fraction of correct patient responses is computed (equation 15) and, together with the perfect ΔLogMAR scores, the patient's ΔLogMAR scores are computed using equation 16. These patient's ΔLogMAR scores are summed equation 19, and this sum is converted to an effective Snellen denominator (equation 21), from which the effective Snellen fraction is found.

The appendix shows that the testing distance, the corresponding Snellen denominators, and the actual Snellen letters used need be entered just once into a spreadsheet for each clinical setting. Once these clinically determined values are in place, only the patient's Snellen letter responses need be recorded, and the equivalent Snellen denominator, hence the Snellen fraction, is computed automatically.

The identification of the Snellen lines, N, and the separation of columns A–J in tables 3 and 4 were presented here for pedagogical reasons. The appendix shows that these computations are transparent to the clinician.

4. Discussion

In order to illustrate two unique features of a plot of the cumulative Snellen Denominator vs. Accumulated Correct Letter Choices, we fabricate a hypothetical example, i.e., a fictitious response to a Snellen acuity test. Table 4 is the template for table 5. Columns E and F in table 5 show "errors" only in lines 6 and 10, which are highlighted. All the other lines show perfect responses, i.e., no errors. An effective Snellen denominator of 36.3 is computed for the fictitious response given in table 5. The corresponding effective Snellen fraction for the fictitious response is: 20/36.3.

Table 5. A fictitious response used to illustrate plot features. The errors are highlighted.

From Snellen Chart			Fictitious Response				
N	**A**	**D**	**E**	**F**	**G**	**H**	**J**
Snellen Line ID	**Snellen Denominator**	**No. Snellen Letters**	**No. Snellen Letter Errors**	**No. Snellen Letters Correct**	**Fraction Correct**	**Patient's ΔLogMAR**	**Patient's Cumulative LogMAR**
1	400	1	0	1	1.00	0.00	1.30
2	200	2	0	2	1.00	–0.30	1.00
3	140	3	0	3	1.00	–0.15	0.85
4	100	4	0	4	1.00	–0.15	0.70
5	80	5	0	5	1.00	–0.10	0.60
6	60	6	4	2	0.33	–0.04	0.56
7	50	7	0	7	1.00	–0.08	0.48
8	40	8	0	8	1.00	–0.10	0.38
9	30	9	0	9	1.00	–0.12	0.26
10	20	11	11	0	0.00	0.00	0.26
—	—	—	—	—	—	Patient's effective Snellen denominator	36.3

Figure 3 shows plots of the perfect score, as in figure 2, and of the fictitious response, computed using equation 22), as before. In figure 3, the fictitious response is the same as the perfect response for the first five Snellen lines. On the sixth line of table 5, four errors are recorded out of six possible letters. These letter-errors shift the plot of the fictitious response upward to a value of 72.7 for the (partial) Snellen denominator, away from the perfect response of 60. The dashed extrapolation shows that, even if no other errors were committed, the effective Snellen denominator would have been 24.2. More broadly we infer that, once a letter-error has been made in any line, a perfect score cannot be attained. Moreover, the greater the number of letter-errors, the farther the visual acuity score is displaced from a perfect score.

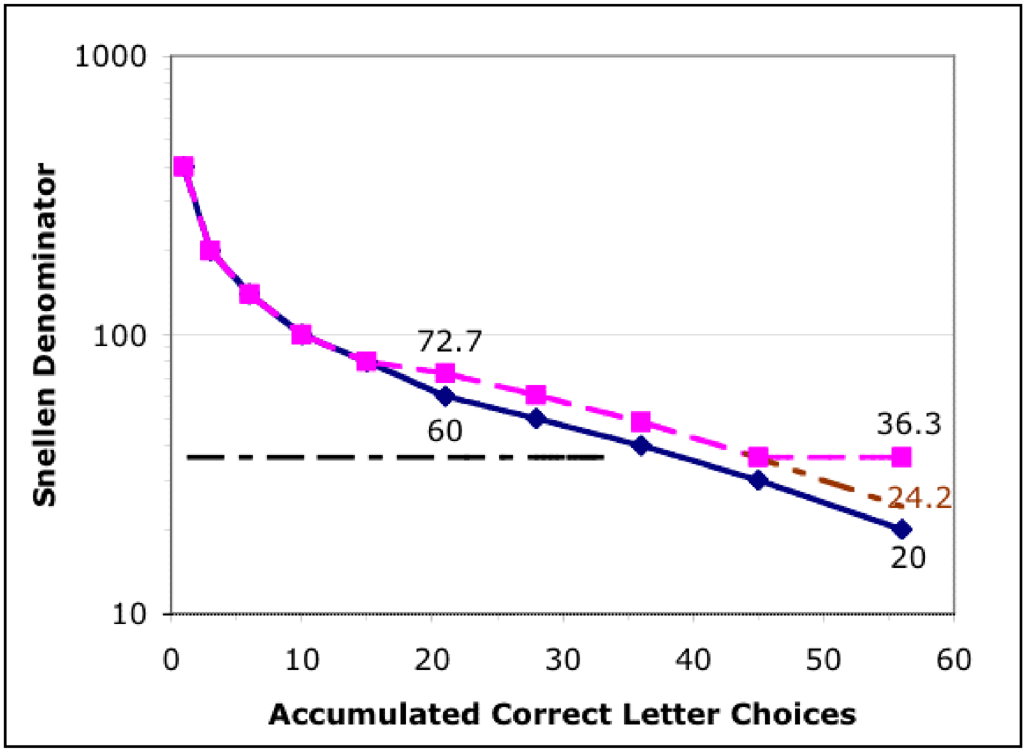

Figure 3. A perfect score is plotted (♦) for reference. The fictitious response data and scores given in table 5 are plotted (□). The dashed horizontal line indicates the limiting value of this fictitious response. The extrapolation at the bottom right indicates the fictitious response if the errors had occurred only in line 6 of the Snellen chart.

We also see the limiting value, 36.3, of the Snellen denominator for the fictitious response in figure 3. Line 10 of table 5 shows no correct letter responses, i.e., all 11 letters are missed. This means that nothing (i.e., zero) is added to the cumulative LogMAR score in line 10, and so the effective Snellen denominator retains the same value it had in line 9. We have seen such a limiting value previously in figure 2 for a patient's response.

This hypothetical example highlights the greater precision of the letter-by-letter scoring method just detailed relative to the more traditional line-by-line scoring methods. Specifically, the Snellen fraction scored line-by-line might have been clinically determined as 20/30, whereas letter-by-letter scoring results in a Snellen denominator of 36.3 (see table 5) that would yield an effective Snellen fraction closer to 20/40.

The method detailed here converts the cumulative LogMAR value for a patient's visual acuity, equation 19, into an effective Snellen denominator, equation 21, and then into an effective Snellen fraction. This more precise Snellen fraction allows the clinician to better gauge the rate of any expected improvement due to treatment, or to better track the rate of any deterioration in visual acuity due to organic causes.

Westheimer (*19*) recommended the LogMAR transformation over linear, exponential and reciprocal transformations, and so the LogMAR transformation has been used here. However, if another transformation (see for example [*6*, *12*, *19*]) were found to be more suitable, the process presented in this report could be modified to use it. The mathematical restrictions are: the transformation must be continuous and have an inverse over the range of interest.

As previously noted, patients are encouraged to guess. According to vanden Bosch and Wall (*11*), guessing could alter the results of visual acuity testing. Subjects often stop when the letters are difficult to see, yet sometimes are able to read one or more additional lines without errors, when encouraged to do so. Moreover, guessing may have different effects depending on the scoring method. A one-letter difference in letter-by-letter scoring method might register as a small change in the final result. However, a one-letter difference in a line-by-line scoring method might register as a one-line difference in the final result.

As stated earlier, the clinician only slowly adopts proposed corrections and innovations to the Snellen chart. Weymouth (*27*) had expected that the minimum angle of resolution (MAR) would come into general use, since MAR is a true threshold measurement. (The eye is unique in that its sensitivity [i.e., the visual acuity] is used for its rating, rather than the threshold [i.e., MAR], as is customary with other sense organs [*27*].) About 30 years later, Bailey (*15*) more realistically assessed that extensive use of LogMAR would not be easy to implement in the clinic. After an additional 20 years, Hussain et al. (*8*) noted that the Snellen chart is still the currently accepted tool for testing visual acuity. Even recently Bailey (*6*) "…expect[ed] resistance to adopting new units such as LogMAR …". The method presented here may facilitate the clinician's acceptance and use of LogMAR concepts.

Brown and Lovie-Kitchin (*4*) wrote about making tests of visual function more sensitive. Modifying current test procedures to enhance their sensitivity seemed a logical approach to the problem of early detection and diagnosis of ocular disease. This is especially the case for visual acuity, since Snellen acuity is well established as the primary measure of vision, it is almost universally used, patients understand it, and it is more likely to be adopted by clinical practitioners in a modified form than in an unfamiliar acuity testing methodology, like LogMAR.

Because of the historical record dating back at least 50 years, it can be assumed with some confidence that the Snellen chart will remain the test of choice in clinical settings. For the reasons just stated, we are seeking to improve the precision associated with the interpretation of the patients' responses to the Snellen visual acuity test. Specific application of this improvement, which is designed for the practicing clinician's use, is given in the appendix.

One of the objectives of this report is the presentation of a straightforward, user-friendly tool (see the appendix). We think it could be globally integrated into clinics and vision screening settings wherever Snellen notation is used. The mathematical algorithm that defines this tool may facilitate and expedite the transition to LogMAR methodology whenever there is a demand for greater sensitivity (i.e., less variability) in the quantification and assessment of visual function or the performance of specific visual tasks, such as driving.

Whether a patient is given credit for reading a complete line in a Snellen chart depends on the percentage of letters actually read correctly. This percentage may vary from 50% to 80% of the letters in a line (*7*, *15*). In the early 1980s, visual acuity results from various nationwide testing centers could not be reliably compared with each other, and the U.S. Navy had been spending about one million dollars per year to reassign pilot applicants because of these ambiguities. During this period, the U.S. Naval Research and Development Command recognized the problem and funded a special project to provide a national standard for the visual acuity testing of Naval aviation applicants (*28*). Had the method discussed in this report, and its corresponding tool, been available then, there would not have been any need to create a special visual test for pilots. Rather, a more precise comparison of pilots' visual acuity results, taken at the different testing centers, would have been at hand.

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Appendix. Effective Snellen Tool

Holladay[1] and Bailey[2] have published visual acuity conversion tables linking Snellen denominators with a variety of other measures, including LogMAR. According to Rosser et al.,[3] either reference to a set of tables or the use of a calculator for Snellen single letter measurements is too slow, and is impractical in a clinical setting.

This objection can be overcome if one replaces charts already in use with virtually identical ones. Table A-1 is the face of such a chart. Its background mathematical functions that compute an effective Snellen fraction as described in this report are not included. A working copy of this EXCEL[*] file, complete with the background mathematical functions, may be downloaded from the Pennsylvania College of Optometry's website: www.pco.edu; click on the Research Page. This file is a clinical tool designed to be used either as a sheet of paper, or as direct computer input.

A copy of the original, downloaded file should be saved as the local master file. A copy of this master should be made for each clinical setting, which is composed of Snellen charts and testing distance. Specifically, make a copy of the local master file for each Snellen chart whose letters are different; simply overwrite the letters actually being used onto the copied, downloaded file. Then make a copy of these files, one for each clinical testing distance, whose entry is labeled "Enter Test Distance Used (ft)." Finally, enter the Snellen denominators for each test distance used. (The values for the denominators are usually found on the Snellen charts.) The line-by-line sequence of Snellen denominators follows that given in table 2 for c = 2 (see table 1). Tables with different sequences of Snellen denominators can be created.

In table A-1, the testing distance and Snellen denominators are shaded in grey because they need only be entered one time for each clinical setting, and then each may be electronically copied (or printed) as needed for the testing of patients.

The header of table A-1 allows for entry of: (1) the patient's identification (i.e., a name, number or code), (2) the date of test, and (3) the examiner's name or code. The fourth line, labeled "Other," allows for an entry or other identification required by the test or by the clinic.

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[1]Holladay, J. T. Visual Acuity Measurements. *J Cataract and Refract Surg* **2004**, 30, guest editorial.

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[*]EXCEL is a registered trademark of Microsoft Corp., Redmond, WA.

Table A-1. Hypothetical letter-by-letter scoring of the patient's response listed in table 4 for the representation of the Snellen chart given in table 2. The effective Snellen denominator, 47.2, is automatically computed. Only the face of this tool is shown. The corresponding executable EXCEL file is downloadable from the Salus University Web site.

	PATIENT ID:														
	DATE:														
TEST	ADMINISTRATOR:														
	OTHER:														
	ENTER PATIENT LETTER IDENTIFICATION CORRECT = 1 ERROR = 0												ENTER TEST DISTANCE USED (ft.)	10	Enter Snellen Denominators for Test Distance Used
YOU MAY		L													
OVERWRITE		1													200
LETTERS =>		T	E												
FROM SNELLEN		1	1												100
CHART USED		D	F	A											
		1	1	1											70
		O	T	C	L										
		1	1	1	1										50
		A	Z	O	T	H									
		1	1	1	1	1									40
		V	E	C	T	V	L								
		1	1	1	1	1	1								30
		E	C	T	V	D	F	A							
		1	0	1	1	1	1	1							25
		O	T	H	D	F	A	V	L						
		0	1	1	0	0	0	1	0						20
		Z	O	T	V	C	L	D	F	A					
		0	0	0	0	0	0	0	0	0					15
		V	E	C	T	V	L	A	Z	O	T	H			
		0	0	0	0	0	0	0	0	0	0	0			10
													Patient's Effective Snellen Denominator [20/…]	47.2	

The downloadable versions of table A-1 are initialized with either all zeros or all ones. Choose whichever more closely suits your local custom or preference. In theory, as the patient calls out the identification of the Snellen letters, the examiner would place a 1 for a correct response or a 0 for an error into the box below the appropriate letter. In practice, since the response matrix is initialized with either all 0s or all 1s, the examiner need only overwrite those responses that are opposite the initialization.

The preferred mode of operation is to enter the patient responses directly into a computer file. This requires the examiner to move the cursor from response-box to response-box and, as required, enter either a 0 or a 1, but not both. In this mode, the patient's effective Snellen fraction, in [20/…] notation, is immediately computed and supplied to the examiner in the bottom right, shaded box (see table A-1, for example).

An alternate mode of operation uses a paper printout of the file, which only copies the face of this tool, as seen in table A-1. Thus, the information placed on the paper form would have to be re-entered into a corresponding computer file to calculate the effective Snellen fraction. The use of paper printout of the file is not recommended.

The format of the downloadable chart represented in table A-1 is a matrix with 10 lines and 11 possible letter entries per line. This format accommodates charts that have any number of letters per line (up to 11 letters). To modify these charts to conform to actual Snellen charts in clinical use, simply overwrite the letters on any single line (see table A-1), with blanks if necessary, or place letters into trailing blank spaces as needed.

The downloadable versions of table A-1, available from the Salus University website, have two locations of hidden columns. If one downloads the file and registers the left most column as column A in Excel, then the first set of hidden columns lies between columns M and AA. This hidden section performs the bookkeeping for the matrix of Snellen letters and its patient-response entries. The second set of hidden columns lies between columns AC and AI, which are to the right of the face of this tool. The LogMAR and other computations are performed in this hidden section. These hidden sections of the downloadable EXCEL file may be modified to accommodate true LogMAR charts, such as the ETDRS chart, or even other charts that use non-letter forms in place of letters, like Landolt-C forms. Sample ETDRS charts are provided in separate spreadsheets contained in the EXCEL file at the Salus University Web site.

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