# Population Data on Near Field Visual Acuity for Use with the Vision and Lighting Diagnostic (VALiD) Kit

Rea, M. S.



**Publisher's version / Version de l'éditeur:**
https://doi.org/10.4224/20386218
*Research Report (National Research Council of Canada. Institute for Research in Construction), 1988*

National Research Council Canada
Conseil national de recherches Canada

NRC · CNRC

# Population Data on Near Field Visual Acuity for use with the Vision and Lighting Diagnostic (VALiD) Kit

Rea, M.S.

IRC-RR-123

# Population Data on Near Field Visual Acuity for use with the Vision and Lighting Diagnostic (VALiD) Kit

**Mark S. Rea, Ph.D.**

Institute for Research in Construction
National Research Council Canada, Ottawa, ON, K1A 0R6, Canada

## IRC Research Report No. 123

# POPULATION DATA ON NEAR FIELD VISUAL ACUITY FOR USE WITH THE VISION AND LIGHTING DIAGNOSTIC (VALiD) KIT


## ABSTRACT

Although there are a variety of reasons why a person might complain about seeing in the work environment, it is possible that his own visual capacity has created or exacerbated a problem. At present, there are no practical and meaningful field tests available for diagnosing potential problems in visual capacity. Although incomplete as a diagnostic tool for visual performance and ocular health, visual acuity is a sensitive measure of a person's visual potential.

This report documents a large population study of near-field visual acuity as well as a simple empirical model for predicting visual acuity for different target contrasts and observer ages under two illumination levels. A simple field testing procedure, based upon the population acuity data, is also discussed. For application specialists concerned with complaints about seeing in the work environment, this procedure can be a useful tool for diagnosing the source of those complaints.

**INTRODUCTION**

Visual response is affected by several factors such as contrast, adaptation level, colour and size. The last of these, size, has been a favorite topic of study by visual psychophysicists, perhaps because it is relatively easy to measure and control. Generally, these studies have been undertaken to determine the limit of spatial resolution, called visual acuity. Visual acuity (VA) is defined as the reciprocal of the minimum resolvable angle (T) in minutes of arc. Thus,

$$VA = 1/T. \quad (1)$$

Many investigators have developed different kinds of targets to study visual acuity. Snellen, Jaeger and Landolt, for example, designed special optotype arrays in the last century.[1] Although each array is slightly different, all consist, essentially, of printed, high contrast alphanumeric targets on a light background. Other types of targets have been developed, but high contrast, black on white, alphanumeric optotypes are still the most common type of target for assessing visual acuity. Snellen acuity, for example, is used as the primary criterion of visual response for optometrists, the military, physicians, and for transportation regulations.

A problem recognized for many years when assessing visual acuity is guessing by the observer. The conventional Snellen chart, for example, employs a random mixture of letters to minimize the likelihood of correct guessing by the observer. Although this limits correct guessing, the visibilities of different letters of the same stroke width are not equal (Trevor-Roper, 1974). Therefore, acuity measurements for different observers or for the same observer at different times may not be the same because of differences in the letter selection for the test.

The International Organization for Standardization (ISO) has recently sanctioned the Landolt ring as the preferred target for assessing visual acuity (ISO, 1986), reinforcing a standard set earlier by the National Academy of Sciences, National Research Council Committee on Vision (Olzak and Thomas, 1986). The Landolt ring is a special letter C. Except for the gap, the stroke forming the letter is radially symmetric about its centre. The stroke width and the gap height are exactly one fifth the letter height. To limit guessing, the gap can be oriented in any direction about the centre of the letter. Thus, the main advantage of the Landolt ring for assessing acuity over other targets is its radially symmetric composition and random gap location which limits

1. See Borish (1975) and Trevor-Roper (1974) for a more through discussion of these three types of acuity targets.

correct guessing without affecting target visibility as in the Snellen acuity test.

Although somewhat unconventional, acuity targets can also be produced in different contrasts and viewed at various adaptation levels (e.g., Richards, 1977; Nakane and Ito, 1978). These factors also affect acuity, but are not typically studied. Consequently, there are few data on visual acuity for different target contrasts seen at different adaptation levels.

Further, there are few population data on visual acuity under controlled conditions despite the prevalence of laboratory research on the topic (Riggs, 1965; Olzak and Thomas, 1986), particularly where target contrast and adaptation level are used as experimental parameters. Population data on near-field (18 to 22 inches) visual acuity is almost nonexistent. Such data would be quite helpful, however, to applications engineers concerned with complaints about difficult reading conditions. Without a proper diagnosis of a person's visual capacity, it is difficult for the application engineer to ascertain the validity of a complaint about environmental factors such as the lighting or the visual task.

A vision and lighting diagnostic (VALiD) kit (Figure 1) has recently been developed by the National Research Council Canada (NRCC) for use by application specialists concerned with the quality of the work environment. The VALiD kit is capable of diagnosing problems with the lighting, the task or the person's eyesight. To determine whether the problem is caused by the person's eyesight it is necessary to have a measure of what is "typical." In other words, one must be able to compare the visual capabilities of a single person to a large population of his or her peers.

A database of this type was collected from over 1,200 volunteers using a standard task comprised of an array of 156 Landolt rings of various sizes and contrasts. The NRCC standard task (Figure 2) was always viewed under an internally illuminated hemisphere providing uniform illumination across the Landolt ring array.

## VALiD KIT APPARATUS

The VALiD kit apparatus is essentially an internally illuminated 20 inch diameter hemisphere with a viewing port (Figure 1). The NRCC standard task (Figure 2) is positioned with mounting pins on the floor of the apparatus. An opaque metal skirt elevated the hemisphere 4.5 inches above the apparatus floor. The entire Landolt ring array on the standard task could be viewed through a 4 inch high viewing port fixed at the top of the hemisphere. Thus, the distance from the centre of the Landolt ring array to the top of the viewing port was 18.5 inches.

Two pairs of incandescent lamps mounted in open cylinders were also fixed to the floor of the apparatus near the edge. Lamp output under the hemisphere was monitored with a Minolta illuminance meter (Model T-1M). This model is equipped with a remote illuminance probe which was positioned in a hole in the floor of the kit; the plane of the probe's photosensitive element was flush with the apparatus floor.

Illuminance on the NRCC standard task was always uniform to within 2% under the hemisphere as determined by luminance measurements of the standard task's white paper using a calibrated Pritchard photometer (Model 1980A).

All acuity data were obtained with 100 or 1000 lx on the floor of the apparatus. These levels were achieved by the two pairs of lamps. The luminances of the white paper of the standard task near the centre of the Landolt ring array under 100 and 1000 lx was 29.6 and 289 cd/m$^2$, respectively.

**NRCC STANDARD TASK**

The Landolt rings were printed, using an offset process, onto high quality (8 point Cornwall) white paper (Figure 2). The target array was comprised of 13 columns and 12 rows of Landolt rings. The gap orientations for the Landolt rings were randomly determined. All Landolt rings in a given column were the same size, but the size of the Landolt rings in each column differed. The left most column had Landolt rings of the largest gap size; Landolt rings in each successive column decreased systematically in size. Gap sizes are given in Table 1 with the corresponding acuity for 18.5 inches, the minimum viewing distance for this study.[2] Appendix 1 describes the procedure for calculating visual acuity for any ring size and viewing distance.

Six inks were used to produce the Landolt rings in six different contrasts. Two adjacent rows of Landolt rings were printed with the same ink. The ink for the Landolt rings in the top two rows was darkest and the ink for bottom two rows the lightest.

The contrast (C) of the Landolt rings in each row, defined by equation 2, are given in Table 2. The luminance of the white paper ($L_b$) and the luminances of ink squares at the beginning of each row ($L_t$) were measured under the internally

2. Some presbyopic subjects viewed the array from distances longer than 18.5 inches, but the acuity values used for all analyses reflect the observed viewing distances.

illuminated hemisphere with the calibrated luminance photometer.

$$C = (L_b - L_t)/L_b \quad (2)$$

**PROCEDURES**

Over 1,200 volunteers from government buildings and shopping centres viewed the standard task in the apparatus and provided acuity data. Every volunteer was questioned about ocular pathologies, eye colour, and gender. They also had to show the experimenter proof of age, typically with a driver's license. Data from those individuals without proper proof of age were not used.

After the initial demographic questions every volunteer looked through the viewing port, and the experimenter asked them to report, in a prescribed order, the gap orientations for the Landolt rings. Volunteers read one row of every contrast under the two illuminance levels. Volunteers always read the top row (A) first, followed by the third row (C) and so on until the top row of every contrast had been read under the first illuminance level. The experimenter changed the illuminance level and the volunteer read the second row (B) followed, in turn, by the remaining rows of Landolt rings. The order of illuminance levels was counterbalanced across volunteers so that half were presented 100 lx first.

People without presbyopia or with spectacles refracted for that distance viewed the standard task at 18.5 inches. Those presbyopic individuals with spectacles refracted for other distances viewed the task at their prescribed reading distance. The distance from the eyes to the viewing port was always estimated by the examiner, recorded, and then used in the final acuity computations.

After completing the test, participants were given a short description of the test and a summary of their performance. In total, the exercise required approximately five minutes for every volunteer

**RESULTS**

<u>Population Statistics on Near-field Visual Acuity</u>

These results are based upon data from 1,131 volunteers ranging in age from 12 to 80 years. The data from 101 volunteers of various ages (8.9%) were rejected because of self-reported ocular problems (glaucoma, diabetes, etc.). The intent of this study was to obtain acuity data at typical reading distances for the healthy, working population. Although data were obtained on a wider age distribution, we preferentially selected those subjects between the ages of 18 and 67 years old. Ninety-six percent of the sampled population of healthy volunteers (1,131) were within this age range. Table 3 shows the distribution of volunteer ages, broken down into five-year bins.

Acuity values for each of six target contrasts and both background luminance (illuminance) levels were computed for every volunteer. Data from every volunteer were based upon the observed viewing distance and the gap size of the last ring read correctly from each row (n = 12/volunteer). Combining all data (N = 13,572), the median visual acuity was 0.98 which is close to 1.0, the value conventionally taken as "normal." Although perhaps reassuring that this population was "typical", this value is somewhat misleading since the acuity data were quite variable, ranging from zero to 1.9. Contributing to this variability were the differences in the volunteers' ages and the controlled target contrast and background luminance conditions. All of these parameters systematically affected acuity.[3]

By taking these parameters into account, the data from this study can be used to evaluate the performance of a particular person on the NRCC standard task (Figure 2). Table 4 shows the expected acuity for different percentages of the volunteer population with age, target contrast and background luminance as parameters. Thus, a person's visual acuity on the standard task may be compared to that of a large sample population on the same standard task. The same population data from Table 4 are plotted in the 12 panels of Figure 3 which also show the best fitting linear equation for the median visual acuities as a function of volunteer age. The parameters for the linear equations in Figure 3 are provided in Table 5.

## A Simple Model of Near-Field Visual Acuity

From the linear equations in Figure 3 and Table 5 it is possible to develop a simple empirical model of near-field visual acuity as a function of age and target contrast for the two background luminances. (Since only two background luminance were employed in this study, it would be inappropriate to include background luminance as a model parameter.) With such a model, near-field visual acuity can be estimated for <u>any</u> age and target contrast at 29.6 and 289 cd/m$^2$. Figure 4 shows the intercept and the slope estimates from Table 5 plotted as a function of target contrast. The best fitting linear equations for the 12

3. No analyses were undertaken to determine whether other demographic variables (e.g., gender and eye colour) affected the acuity data. A subsequent report will discuss these issues as well as the significance of using volunteers for population statistics.

intercept and the 12 slope estimates were then determined. Although there is a clear separation of intercept values for the high and low adaptation levels, there is no apparent difference in the slope values. Consequently a common slope estimate but different intercept estimates were used for the empirical, near-field acuity model at 29.6 and 289 cd/m$^2$. Figure 5 shows the model predictions with the median values from Figure 3; the model seems to describe the medians reasonably well. Appendix 2 describes the steps necessary for predicting the median visual acuity for different ages and target contrasts at 29.6 and 289 cd/m$^2$ from the empirical model.

The model suggests some conclusions. First, and as shown clearly in Figures 3 and 5, acuity decreases with age as would be expected from a large number of studies (e.g., Burg, 1966; Richards, 1977). As expected too, acuity improves with both contrast and adaptation luminance (Richards, 1977; Nakane and Ito, 1978). As discussed previously, Figure 4 shows a clear separation of intercepts for the two adaptation levels. This figure also shows a steady increase in the intercept values with contrast for both adaptation levels.

Perhaps unexpectedly, Figure 4 shows there is a systematic decrease in slope of the 12 lines in Figures 3 and 5 relating visual acuity to age. For the poorest visual conditions (i.e., contrast = 0.08; background luminance = 29.6 cd/m$^2$) the slope is shallowest; for the best visual conditions (i.e., contrast = 0.90; background luminance = 289 cd/m$^2$) the slope is steepest. This means, essentially, that at this task younger people are helped more than older people by good visual conditions.

Contrary arguments have been put forward for other kinds of tasks, stating, for example, that good lighting helps older people more than younger people (e.g., Hopkinson and Collins, 1970). This is probably true for tasks which have a performance "ceiling", but, apparently, this is not the case with acuity. Lythgoe (1932) has shown that visual acuity continues to improve with adaptation luminance as long as the background luminance is large and uniform. Therefore, a visually "enriched environment" may be relatively more effective for young people than for old people if the task requires fine spatial resolution.

## APPLICATION OF THE DATA

Figure 6 shows data from a typical volunteer revealing a systematic response pattern on the standard task. With few exceptions, the volunteers could correctly report the gap orientations on a given line until the point where no more gaps could be discerned. Thus, there must be a systematic relationship between the acuity data discussed above and, simply, the number of gaps that could not be discerned.

It is possible to miss from zero to thirteen ring gaps on a given row of the NRCC standard task. Visual acuity is computed from the last correctly identified gap in that row. Figure 7 shows a plot of the median visual acuity for those trials producing from one to twelve ring gaps missed per row. Using a non-linear regression analysis the best fitting exponential function relating the two parameters was determined; this function is also shown in Figure 7 and describes the clear, regular relationship between visual acuity and the number of ring gaps missed on a row. Zero and thirteen ring gaps missed per row were not included in the non-linear regression analysis because of, so called, "floor" and "ceiling" effects. For example, some young volunteers could see the smallest gap in the row with the high contrast Landolt rings. Under these conditions it was impossible to determine their maximum visual acuity (a "ceiling" effect). Similarly, some old volunteers could not see the first gap in the row of low contrast Landolt rings (a "floor" effect). Thus, the data for zero and thirteen rings missed per row would not properly characterize expected visual acuities; calculated median acuities for both sets of trials would be biased too low.

For application specialists trying to diagnose the visual capabilities of a person on the standard task, it would be easier to simply count the number of rings missed rather than compute visual acuity. Given the systematic relationship between acuity and the number of rings missed in Figure 7 and because the application specialist is generally concerned only with how this person compares to a reference population, it seems appropriate to develop a table of population data based simply on the number of rings missed on the standard task. Such a table would be simpler than Table 4, but would still provide appropriate information for diagnosing the visual capabilities of a particular person on the standard task.

Table 6 shows the number of rings missed for each age group and the population percentile. Regular, transitive behavior is observed throughout most of the table, but it will be noted that the 58-62 age group deviates slightly from transitivity for specific population percentages. Figure 8 shows some of the data in Table 6 with the best fitting lines for those percentiles. Based upon these best fitting lines the data in Table 6 were "smoothed" and the expected number of rings missed for each age group and population percentile presented in Table 7. This table then, provides application specialists with a "yardstick" for assessing a particular person's performance on the standard task in the VALiD kit under 100 and 1000 lx.

## SUMMARY AND CONCLUSIONS

Acuity is an important measure of visual capabilities. Recently the ISO has sanctioned the Landolt ring as the preferred target for determining visual acuity. There are, however, limited population data available on near-field (i.e., reading distance) visual acuity for Landolt rings of different contrasts presented under specified and uniform illuminance levels. A new standard acuity task employing Landolt rings of different contrast and size was developed at the National Research Council Canada in conjunction with a viewing apparatus (the VALiD kit) that can uniformly illuminate the standard task.

In the present study, near-field visual acuity data were obtained from 1,131 working age (primarily 18 to 67 year old) volunteers. Employing the NRCC standard task and the VALiD kit, their task was to discern the gap orientations in Landolt rings of different sizes and contrasts under 100 and 1000 lx. Population statistics were developed from these data defining the expected visual acuity for different age groups, target contrasts, and adaptation luminances.

A simple empirical model was also developed from these data to predict the expected median visual acuity for different age groups and target contrasts viewed at 29.6 and 289 $cd/m^2$. Interestingly, the acuity model shows that, perhaps contrary to conventional wisdom, for this task, good visual conditions (high contrast and high, uniform illumination levels) are more beneficial to people with good eyesight (young volunteers) than they are to people with poor eyesight (old volunteers).

Finally, to make the VALiD kit easier to use by application specialists, population statistics were developed defining the number of Landolt ring gaps expected to be missed on the NRCC standard task for different age groups. With these statistics application specialists can more easily diagnose visual difficulties in the workplace for early referral to professional oculists.

**REFERENCES**


Borish, I.M., Clinical refraction, Professional Press, Chicago, 1975.

Burg, A., Visual acuity as measured by dynamic and static tests: A comparative evaluation, Journal of Applied Psychology, 50(6), 1966, 460-466.

Hopkinson, R.G., and Collins, J.B., The Ergonomics of Lighting, Macdonald Technical and Scientific, London, 1970.

International Organization for Standards (ISO), Optics and optical instruments - visual acuity testing - standard optotype and its presentation, Draft International Standard ISO/DIS 8596, 1986.

Lythgoe, R.J., X. The measurement of visual acuity, His Majesty's Stationery Office, Medical Research Council, Report No. 173, 1932.

Nakane, Y., and Ito, K., Study on standard visual acuity curves for better seeing in lighting design, Journal of lighting and visual environment, 2(1), 1978, 38-44.

Olzak, L.A., and Thomas, J.P., Seeing spatial patterns, Chapter 7 in Handbook of perception and human performance, Volume 1, Sensory processes and perception, John Wiley and Sons, New York, 1986.

Richards, O.W., Effects of luminance and contrast on visual acuity, ages 16 to 90 years, American Journal of Optometry & Physiological Optics, 54 (3), March 1977, 178-184.

Riggs, L.A., Visual acuity, Chapter 11 in Vision and visual Perception, (C.H. Graham, ed.), John Wiley & Sons, New York, 1965.

Trevor-Roper, P.D., The eye and its disorders, Blackwell Scientific Publications, Oxford, 1974.

Table 1. Landolt ring gap sizes in each column along with the associated visual acuity for a viewing distance of 18.5 inches. Visual acuities for other viewing distances can be determined using Appendix 1.

| Column number | Gap size (in) | Visual Acuity |
|---|---|---|
| 1 | 0.0202 | 0.27 |
| 2 | 0.0183 | 0.29 |
| 3 | 0.0175 | 0.31 |
| 4 | 0.0159 | 0.34 |
| 5 | 0.0141 | 0.38 |
| 6 | 0.0129 | 0.42 |
| 7 | 0.0109 | 0.49 |
| 8 | 0.0097 | 0.55 |
| 9 | 0.0080 | 0.67 |
| 10 | 0.0074 | 0.73 |
| 11 | 0.0055 | 0.98 |
| 12 | 0.0042 | 1.28 |
| 13 | 0.0036 | 1.49 |

Table 2. Landolt ring contrasts in each row.

| Row | Contrast |
|---|---|
| A & B | 0.90 |
| C & D | 0.64 |
| E & F | 0.31 |
| G & H | 0.21 |
| I & J | 0.13 |
| K & L | 0.08 |

<u>Table 3</u>. Frequency distribution of volunteer ages. One symbol represents approximately five occurrences.

| Age Group | | Frequency |
|---|---|---|
| Under 18 | 4 | # |
| 18-22 | 114 | ####################### |
| 23-27 | 124 | ######################### |
| 28-32 | 160 | ################################ |
| 33-37 | 135 | ########################### |
| 38-42 | 159 | ################################ |
| 43-47 | 127 | ######################### |
| 48-52 | 91 | ################## |
| 53-57 | 87 | ################# |
| 58-62 | 49 | ########## |
| 63-67 | 44 | ######### |
| Over 67 | 37 | ####### |
| | ---- | \|----\|----\|----\|----\|----\|----\|---- |
| | | 0 50 100 150 |
| Total | 1131 | |

<u>Table 4.1</u>. Visual acuities for various population percentiles under 100 lx (29.6 $cd/m^2$). Data have been binned into five year (y) age groups. Landolt ring contrast (C) is reported in per cent.

| C | Age, y | 15% | 20% | 30% | 40% | 50% | 60% | 70% | 80% | 85% |
|---|---|---|---|---|---|---|---|---|---|---|
| 8 | 18-22 | 0.42 | 0.49 | 0.55 | 0.57 | 0.67 | 0.67 | 0.71 | 0.73 | 0.73 |
| 8 | 23-27 | 0.42 | 0.49 | 0.53 | 0.55 | 0.67 | 0.67 | 0.70 | 0.73 | 0.73 |
| 8 | 28-32 | 0.42 | 0.45 | 0.49 | 0.55 | 0.58 | 0.67 | 0.67 | 0.73 | 0.73 |
| 8 | 33-37 | 0.38 | 0.42 | 0.49 | 0.52 | 0.55 | 0.57 | 0.67 | 0.71 | 0.73 |
| 8 | 38-42 | 0.35 | 0.38 | 0.42 | 0.49 | 0.51 | 0.55 | 0.67 | 0.67 | 0.71 |
| 8 | 43-47 | 0.31 | 0.34 | 0.42 | 0.43 | 0.49 | 0.52 | 0.55 | 0.61 | 0.67 |
| 8 | 48-52 | 0.28 | 0.30 | 0.34 | 0.38 | 0.42 | 0.47 | 0.52 | 0.56 | 0.58 |
| 8 | 53-57 | 0.05 | 0.29 | 0.32 | 0.36 | 0.41 | 0.44 | 0.49 | 0.56 | 0.58 |
| 8 | 58-62 | 0.00 | 0.27 | 0.32 | 0.33 | 0.36 | 0.42 | 0.45 | 0.56 | 0.56 |
| 8 | 63-67 | 0.00 | 0.00 | 0.00 | 0.33 | 0.37 | 0.40 | 0.48 | 0.52 | 0.56 |
| 12 | 18-22 | 0.54 | 0.55 | 0.67 | 0.73 | 0.73 | 0.73 | 0.79 | 0.98 | 0.98 |
| 12 | 23-27 | 0.55 | 0.57 | 0.67 | 0.73 | 0.73 | 0.75 | 0.80 | 0.98 | 0.98 |
| 12 | 28-32 | 0.55 | 0.55 | 0.62 | 0.67 | 0.73 | 0.73 | 0.75 | 0.78 | 0.98 |
| 12 | 33-37 | 0.55 | 0.55 | 0.57 | 0.67 | 0.71 | 0.73 | 0.75 | 0.80 | 0.95 |
| 12 | 38-42 | 0.49 | 0.49 | 0.55 | 0.57 | 0.67 | 0.69 | 0.73 | 0.73 | 0.76 |
| 12 | 43-47 | 0.42 | 0.49 | 0.51 | 0.55 | 0.57 | 0.67 | 0.69 | 0.73 | 0.73 |
| 12 | 48-52 | 0.39 | 0.41 | 0.44 | 0.51 | 0.55 | 0.59 | 0.62 | 0.68 | 0.73 |
| 12 | 53-57 | 0.38 | 0.42 | 0.45 | 0.52 | 0.55 | 0.57 | 0.61 | 0.71 | 0.73 |
| 12 | 58-62 | 0.37 | 0.39 | 0.42 | 0.47 | 0.52 | 0.55 | 0.58 | 0.63 | 0.65 |
| 12 | 63-67 | 0.33 | 0.35 | 0.43 | 0.49 | 0.51 | 0.57 | 0.62 | 0.69 | 0.73 |
| 21 | 18-22 | 0.71 | 0.73 | 0.73 | 0.98 | 0.98 | 0.98 | 1.00 | 1.06 | 1.28 |
| 21 | 23-27 | 0.73 | 0.73 | 0.73 | 0.77 | 0.98 | 0.98 | 1.04 | 1.28 | 1.28 |
| 21 | 28-32 | 0.71 | 0.73 | 0.73 | 0.75 | 0.96 | 0.98 | 1.00 | 1.03 | 1.28 |
| 21 | 33-37 | 0.67 | 0.73 | 0.73 | 0.75 | 0.79 | 0.98 | 1.00 | 1.03 | 1.11 |
| 21 | 38-42 | 0.57 | 0.67 | 0.73 | 0.73 | 0.75 | 0.80 | 0.98 | 0.98 | 1.03 |
| 21 | 43-47 | 0.55 | 0.58 | 0.68 | 0.73 | 0.75 | 0.77 | 0.96 | 0.98 | 1.00 |
| 21 | 48-52 | 0.52 | 0.55 | 0.57 | 0.60 | 0.71 | 0.73 | 0.76 | 0.83 | 0.90 |
| 21 | 53-57 | 0.51 | 0.55 | 0.61 | 0.67 | 0.73 | 0.73 | 0.77 | 0.79 | 0.82 |
| 21 | 58-62 | 0.44 | 0.51 | 0.55 | 0.56 | 0.67 | 0.69 | 0.73 | 0.79 | 0.80 |
| 21 | 63-67 | 0.44 | 0.45 | 0.56 | 0.58 | 0.63 | 0.69 | 0.75 | 0.79 | 0.81 |
| 31 | 18-22 | 0.73 | 0.77 | 0.98 | 0.98 | 0.98 | 1.03 | 1.22 | 1.28 | 1.31 |
| 31 | 23-27 | 0.73 | 0.77 | 0.98 | 0.98 | 1.00 | 1.11 | 1.28 | 1.28 | 1.32 |
| 31 | 28-32 | 0.73 | 0.73 | 0.87 | 0.98 | 0.98 | 1.00 | 1.23 | 1.28 | 1.31 |
| 31 | 33-37 | 0.73 | 0.73 | 0.77 | 0.98 | 0.98 | 1.00 | 1.11 | 1.28 | 1.28 |
| 31 | 38-42 | 0.69 | 0.73 | 0.73 | 0.75 | 0.98 | 0.98 | 1.00 | 1.11 | 1.28 |
| 31 | 43-47 | 0.64 | 0.68 | 0.73 | 0.75 | 0.79 | 0.98 | 0.98 | 1.00 | 1.06 |
| 31 | 48-52 | 0.55 | 0.58 | 0.62 | 0.69 | 0.73 | 0.76 | 0.80 | 0.98 | 1.07 |
| 31 | 53-57 | 0.55 | 0.56 | 0.67 | 0.71 | 0.75 | 0.79 | 0.82 | 0.98 | 1.05 |
| 31 | 58-62 | 0.52 | 0.55 | 0.61 | 0.67 | 0.73 | 0.76 | 0.82 | 0.90 | 0.99 |
| 31 | 63-67 | 0.44 | 0.55 | 0.59 | 0.66 | 0.69 | 0.73 | 0.82 | 0.87 | 1.01 |
| 64 | 18-22 | 0.83 | 0.98 | 1.03 | 1.28 | 1.28 | 1.28 | 1.35 | 1.49 | 1.49 |
| 64 | 23-27 | 0.98 | 0.98 | 1.00 | 1.28 | 1.28 | 1.28 | 1.32 | 1.45 | 1.49 |
| 64 | 28-32 | 0.98 | 0.98 | 1.00 | 1.27 | 1.28 | 1.28 | 1.32 | 1.38 | 1.44 |
| 64 | 33-37 | 0.79 | 0.98 | 0.98 | 1.00 | 1.11 | 1.28 | 1.28 | 1.35 | 1.38 |
| 64 | 38-42 | 0.73 | 0.73 | 0.98 | 0.98 | 1.03 | 1.28 | 1.28 | 1.32 | 1.35 |
| 64 | 43-47 | 0.73 | 0.73 | 0.79 | 0.98 | 1.00 | 1.27 | 1.28 | 1.32 | 1.32 |
| 64 | 48-52 | 0.63 | 0.68 | 0.73 | 0.77 | 0.80 | 0.98 | 1.04 | 1.11 | 1.23 |
| 64 | 53-57 | 0.67 | 0.69 | 0.73 | 0.77 | 0.90 | 0.98 | 1.05 | 1.11 | 1.31 |
| 64 | 58-62 | 0.58 | 0.69 | 0.73 | 0.76 | 0.86 | 1.00 | 1.06 | 1.16 | 1.30 |
| 64 | 63-67 | 0.57 | 0.63 | 0.72 | 0.75 | 0.81 | 0.86 | 0.99 | 1.06 | 1.11 |
| 90 | 18-22 | 1.01 | 1.28 | 1.28 | 1.28 | 1.32 | 1.38 | 1.49 | 1.49 | 1.49 |
| 90 | 23-27 | 1.00 | 1.08 | 1.28 | 1.28 | 1.32 | 1.35 | 1.49 | 1.49 | 1.49 |
| 90 | 28-32 | 0.98 | 1.03 | 1.28 | 1.28 | 1.28 | 1.32 | 1.38 | 1.49 | 1.49 |
| 90 | 33-37 | 0.98 | 0.98 | 1.19 | 1.28 | 1.28 | 1.32 | 1.35 | 1.42 | 1.49 |
| 90 | 38-42 | 0.96 | 0.98 | 1.11 | 1.28 | 1.28 | 1.32 | 1.32 | 1.45 | 1.49 |
| 90 | 43-47 | 0.73 | 0.76 | 0.98 | 1.04 | 1.28 | 1.28 | 1.32 | 1.38 | 1.45 |
| 90 | 48-52 | 0.73 | 0.75 | 0.78 | 0.83 | 1.00 | 1.06 | 1.28 | 1.35 | 1.38 |
| 90 | 53-57 | 0.69 | 0.75 | 0.81 | 0.98 | 1.00 | 1.08 | 1.28 | 1.38 | 1.38 |
| 90 | 58-62 | 0.69 | 0.73 | 0.76 | 0.86 | 1.00 | 1.08 | 1.32 | 1.38 | 1.45 |
| 90 | 63-67 | 0.67 | 0.73 | 0.75 | 0.82 | 1.00 | 1.06 | 1.12 | 1.28 | 1.36 |

Table 4.2. Visual acuities for various population percentiles under 1000 lx (289 cd/$m^2$). Data have been binned into five year (y) age groups. Landolt ring contrast (C) is reported in percent.

| | | Percentile | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| C | Age, y | 15% | 20% | 30% | 40% | 50% | 60% | 70% | 80% | 85% |
| 8 | 18-22 | 0.56 | 0.67 | 0.73 | 0.73 | 0.75 | 0.82 | 0.98 | 1.00 | 1.05 |
| 8 | 23-27 | 0.67 | 0.69 | 0.73 | 0.73 | 0.73 | 0.75 | 0.98 | 1.00 | 1.03 |
| 8 | 28-32 | 0.67 | 0.67 | 0.71 | 0.73 | 0.74 | 0.77 | 0.98 | 0.98 | 0.98 |
| 8 | 33-37 | 0.55 | 0.57 | 0.67 | 0.69 | 0.73 | 0.75 | 0.80 | 0.98 | 0.98 |
| 8 | 38-42 | 0.51 | 0.55 | 0.67 | 0.69 | 0.73 | 0.73 | 0.79 | 0.98 | 0.98 |
| 8 | 43-47 | 0.49 | 0.56 | 0.64 | 0.67 | 0.69 | 0.73 | 0.73 | 0.77 | 0.82 |
| 8 | 48-52 | 0.38 | 0.42 | 0.51 | 0.57 | 0.67 | 0.73 | 0.73 | 0.78 | 0.82 |
| 8 | 53-57 | 0.38 | 0.41 | 0.45 | 0.55 | 0.60 | 0.67 | 0.73 | 0.77 | 0.79 |
| 8 | 58-62 | 0.41 | 0.47 | 0.51 | 0.55 | 0.57 | 0.60 | 0.69 | 0.76 | 0.77 |
| 8 | 63-67 | 0.31 | 0.35 | 0.42 | 0.47 | 0.53 | 0.57 | 0.63 | 0.71 | 0.71 |
| 12 | 18-22 | 0.73 | 0.73 | 0.98 | 0.98 | 1.00 | 1.06 | 1.28 | 1.28 | 1.28 |
| 12 | 23-27 | 0.73 | 0.75 | 0.98 | 0.98 | 0.98 | 1.00 | 1.21 | 1.28 | 1.32 |
| 12 | 28-32 | 0.73 | 0.73 | 0.79 | 0.98 | 0.98 | 1.00 | 1.05 | 1.28 | 1.28 |
| 12 | 33-37 | 0.73 | 0.73 | 0.75 | 0.81 | 0.98 | 0.98 | 1.03 | 1.11 | 1.28 |
| 12 | 38-42 | 0.69 | 0.73 | 0.75 | 0.82 | 0.98 | 0.98 | 0.98 | 1.06 | 1.28 |
| 12 | 43-47 | 0.62 | 0.67 | 0.73 | 0.75 | 0.77 | 0.98 | 0.98 | 1.01 | 1.06 |
| 12 | 48-52 | 0.52 | 0.55 | 0.63 | 0.69 | 0.73 | 0.79 | 0.86 | 1.00 | 1.04 |
| 12 | 53-57 | 0.51 | 0.55 | 0.61 | 0.69 | 0.73 | 0.76 | 0.79 | 0.98 | 1.00 |
| 12 | 58-62 | 0.52 | 0.55 | 0.58 | 0.67 | 0.69 | 0.77 | 0.79 | 0.86 | 0.86 |
| 12 | 63-67 | 0.44 | 0.45 | 0.56 | 0.60 | 0.67 | 0.73 | 0.76 | 0.82 | 0.83 |
| 21 | 18-22 | 0.98 | 0.98 | 1.06 | 1.28 | 1.28 | 1.28 | 1.32 | 1.35 | 1.38 |
| 21 | 23-27 | 0.98 | 0.98 | 1.06 | 1.28 | 1.28 | 1.28 | 1.32 | 1.35 | 1.45 |
| 21 | 28-32 | 0.98 | 0.98 | 0.99 | 1.03 | 1.27 | 1.28 | 1.28 | 1.32 | 1.32 |
| 21 | 33-37 | 0.76 | 0.98 | 0.98 | 1.01 | 1.28 | 1.28 | 1.28 | 1.32 | 1.35 |
| 21 | 38-42 | 0.75 | 0.84 | 0.98 | 1.00 | 1.06 | 1.28 | 1.28 | 1.32 | 1.35 |
| 21 | 43-47 | 0.73 | 0.75 | 0.92 | 1.00 | 1.00 | 1.11 | 1.28 | 1.28 | 1.32 |
| 21 | 48-52 | 0.62 | 0.69 | 0.74 | 0.77 | 0.88 | 1.00 | 1.06 | 1.19 | 1.28 |
| 21 | 53-57 | 0.57 | 0.63 | 0.73 | 0.77 | 0.82 | 0.90 | 1.00 | 1.06 | 1.06 |
| 21 | 58-62 | 0.63 | 0.67 | 0.73 | 0.75 | 0.82 | 0.98 | 1.00 | 1.11 | 1.19 |
| 21 | 63-67 | 0.55 | 0.57 | 0.64 | 0.73 | 0.75 | 0.82 | 0.99 | 1.03 | 1.07 |
| 31 | 18-22 | 0.98 | 1.03 | 1.28 | 1.28 | 1.28 | 1.35 | 1.49 | 1.49 | 1.49 |
| 31 | 23-27 | 1.00 | 1.28 | 1.28 | 1.28 | 1.28 | 1.32 | 1.38 | 1.49 | 1.49 |
| 31 | 28-32 | 1.03 | 1.06 | 1.28 | 1.28 | 1.28 | 1.32 | 1.38 | 1.49 | 1.49 |
| 31 | 33-37 | 0.98 | 0.98 | 1.11 | 1.28 | 1.28 | 1.32 | 1.35 | 1.49 | 1.49 |
| 31 | 38-42 | 0.84 | 0.98 | 1.00 | 1.28 | 1.28 | 1.32 | 1.35 | 1.49 | 1.49 |
| 31 | 43-47 | 0.73 | 0.78 | 0.98 | 1.00 | 1.28 | 1.28 | 1.28 | 1.32 | 1.38 |
| 31 | 48-52 | 0.64 | 0.72 | 0.76 | 0.82 | 0.98 | 1.06 | 1.28 | 1.34 | 1.38 |
| 31 | 53-57 | 0.68 | 0.69 | 0.75 | 0.87 | 1.00 | 1.06 | 1.11 | 1.22 | 1.31 |
| 31 | 58-62 | 0.72 | 0.73 | 0.77 | 0.82 | 1.00 | 1.03 | 1.11 | 1.28 | 1.35 |
| 31 | 63-67 | 0.58 | 0.64 | 0.75 | 0.79 | 0.87 | 1.00 | 1.11 | 1.32 | 1.35 |
| 64 | 18-22 | 1.28 | 1.28 | 1.30 | 1.38 | 1.49 | 1.49 | 1.49 | 1.49 | 1.52 |
| 64 | 23-27 | 1.28 | 1.28 | 1.28 | 1.32 | 1.49 | 1.49 | 1.49 | 1.53 | 1.53 |
| 64 | 28-32 | 1.27 | 1.28 | 1.28 | 1.32 | 1.35 | 1.49 | 1.49 | 1.49 | 1.49 |
| 64 | 33-37 | 1.00 | 1.23 | 1.28 | 1.29 | 1.35 | 1.45 | 1.49 | 1.49 | 1.49 |
| 64 | 38-42 | 0.98 | 1.06 | 1.28 | 1.28 | 1.32 | 1.38 | 1.49 | 1.49 | 1.49 |
| 64 | 43-47 | 0.82 | 0.98 | 1.08 | 1.28 | 1.32 | 1.32 | 1.38 | 1.49 | 1.49 |
| 64 | 48-52 | 0.73 | 0.75 | 0.82 | 1.03 | 1.22 | 1.32 | 1.38 | 1.48 | 1.50 |
| 64 | 53-57 | 0.73 | 0.75 | 0.93 | 1.01 | 1.11 | 1.21 | 1.35 | 1.38 | 1.38 |
| 64 | 58-62 | 0.73 | 0.76 | 0.82 | 1.00 | 1.03 | 1.11 | 1.32 | 1.45 | 1.52 |
| 64 | 63-67 | 0.70 | 0.73 | 0.76 | 0.81 | 1.00 | 1.06 | 1.27 | 1.35 | 1.40 |
| 90 | 18-22 | 1.28 | 1.28 | 1.35 | 1.49 | 1.49 | 1.49 | 1.49 | 1.53 | 1.53 |
| 90 | 23-27 | 1.28 | 1.28 | 1.35 | 1.49 | 1.49 | 1.49 | 1.49 | 1.53 | 1.58 |
| 90 | 28-32 | 1.28 | 1.28 | 1.32 | 1.40 | 1.49 | 1.49 | 1.49 | 1.53 | 1.53 |
| 90 | 33-37 | 1.28 | 1.28 | 1.31 | 1.32 | 1.45 | 1.49 | 1.49 | 1.49 | 1.53 |
| 90 | 38-42 | 1.28 | 1.28 | 1.28 | 1.32 | 1.38 | 1.49 | 1.49 | 1.49 | 1.53 |
| 90 | 43-47 | 1.00 | 1.11 | 1.28 | 1.29 | 1.32 | 1.38 | 1.49 | 1.49 | 1.49 |
| 90 | 48-52 | 0.77 | 0.86 | 1.03 | 1.15 | 1.28 | 1.36 | 1.45 | 1.51 | 1.54 |
| 90 | 53-57 | 0.82 | 0.95 | 0.98 | 1.06 | 1.22 | 1.32 | 1.38 | 1.43 | 1.45 |
| 90 | 58-62 | 0.73 | 0.82 | 0.98 | 1.03 | 1.28 | 1.35 | 1.45 | 1.52 | 1.52 |
| 90 | 63-67 | 0.74 | 0.76 | 0.98 | 1.00 | 1.07 | 1.32 | 1.38 | 1.45 | 1.52 |

Table 5. Parameter values for linear equations in Figure 3 and r, the correlation index between visual acuity (VA), from equation 1, and volunteer age in years (Y). Contrast is defined in equation 2. The linear equations are all in the form: VA = I + SY

100 lx

| Contrast | I | S x $10^{-3}$ | r |
|---|---|---|---|
| 0.08 | 0.82 | -7.5 | 0.98 |
| 0.12 | 0.88 | -5.8 | 0.95 |
| 0.21 | 1.14 | -8.1 | 0.94 |
| 0.31 | 1.20 | -8.0 | 0.92 |
| 0.64 | 1.55 | -12.1 | 0.94 |
| 0.90 | 1.55 | -8.7 | 0.88 |

1000 lx

| Contrast | I | S x $10^{-3}$ | r |
|---|---|---|---|
| 0.08 | 0.87 | -4.7 | 0.92 |
| 0.12 | 1.22 | -8.7 | 0.93 |
| 0.21 | 1.64 | -13.9 | 0.96 |
| 0.31 | 1.56 | -9.6 | 0.87 |
| 0.64 | 1.75 | -11.2 | 0.97 |
| 0.90 | 1.72 | -8.8 | 0.94 |

Table 6. Observed number of rings missed per page for each age group and population percentile.

| | Percentile | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | upper | | | | | | | | lower | | | | |
| Age | 12.5 | 15 | 20 | 25 | 30 | 40 | 50 | 40 | 30 | 25 | 20 | 15 | 12.5 |
| 18-22 | 12 | 12 | 14 | 15 | 16 | 18 | 21 | 24 | 27 | 28 | 31 | 36 | 40 |
| 23-27 | 13 | 13 | 15 | 16 | 17 | 19 | 21 | 23 | 27 | 30 | 32 | 37 | 40 |
| 28-32 | 15 | 15 | 16 | 17 | 18 | 21 | 23 | 27 | 30 | 32 | 35 | 37 | 38 |
| 33-37 | 15 | 16 | 18 | 20 | 21 | 23 | 26 | 29 | 31 | 35 | 38 | 41 | 44 |
| 38-42 | 17 | 17 | 18 | 21 | 23 | 25 | 27 | 31 | 35 | 37 | 42 | 48 | 52 |
| 43-47 | 19 | 20 | 21 | 23 | 25 | 28 | 31 | 37 | 41 | 42 | 47 | 54 | 55 |
| 48-52 | 26 | 27 | 30 | 32 | 33 | 36 | 41 | 49 | 56 | 58 | 64 | 70 | 74 |
| 53-57 | 26 | 29 | 32 | 33 | 35 | 41 | 46 | 50 | 55 | 60 | 64 | 69 | 71 |
| 58-62 | 26 | 28 | 30 | 32 | 35 | 39 | 44 | 49 | 54 | 56 | 58 | 65 | 69 |
| 63-67 | 29 | 31 | 31 | 35 | 37 | 41 | 44 | 53 | 61 | 64 | 69 | 71 | 77 |

Table 7. Number of rings missed per page for each age group and population percentile. The data has been smoothed by linear regression (Figure 8) to remove slight intransitivities.

| | Percentile | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | upper | | | | | | | lower | | | | | |
| Age | 12.5 | 15 | 20 | 25 | 30 | 40 | 50 | 40 | 30 | 25 | 20 | 15 | 12.5 |
| 18-22 | 11 | 11 | 12 | 13 | 14 | 16 | 18 | 20 | 23 | 25 | 27 | 32 | 34 |
| 23-27 | 13 | 13 | 15 | 16 | 17 | 19 | 21 | 24 | 27 | 29 | 32 | 37 | 39 |
| 28-32 | 15 | 15 | 17 | 18 | 19 | 22 | 24 | 28 | 31 | 33 | 37 | 41 | 44 |
| 33-37 | 17 | 17 | 19 | 21 | 22 | 25 | 28 | 31 | 35 | 38 | 41 | 46 | 49 |
| 38-42 | 19 | 20 | 21 | 23 | 25 | 28 | 31 | 35 | 40 | 42 | 46 | 51 | 53 |
| 43-47 | 21 | 22 | 24 | 26 | 27 | 31 | 34 | 39 | 44 | 46 | 50 | 55 | 58 |
| 48-52 | 23 | 24 | 26 | 28 | 30 | 34 | 37 | 43 | 48 | 51 | 55 | 60 | 63 |
| 53-57 | 25 | 27 | 28 | 31 | 32 | 37 | 40 | 47 | 52 | 55 | 59 | 64 | 68 |
| 58-62 | 27 | 29 | 31 | 33 | 35 | 40 | 44 | 50 | 56 | 60 | 64 | 69 | 73 |
| 63-67 | 29 | 31 | 33 | 36 | 38 | 43 | 47 | 54 | 61 | 64 | 69 | 74 | 78 |

Appendix 1. Procedure for calculating visual acuity from threshold ring number and viewing distance.

1) Take the gap width, w, from Table 1.

2) Calculate minimum resolvable angle, A, in degrees.
$A = \tan^{-1}(w/d)$
where d is the viewing distance in inches.

3) Convert A from radians to degrees, if necessary, by multiplying by $180/\pi$

4) Calculate viewing angle, T, in minutes of arc.
$T = 60(A)$

5) Calculate visual acuity, VA.
$VA = 1/T$

Appendix 2. Procedure for predicting visual acuity.

1) Select observer age, Y, in years (from 20 to 65).

2) Select task contrast, C, in percent (from 8 to 90).

3) Calculate X, the common logarithm of task contrast.
$X = Log_{10}(C)$

4) Calculate the intercept coefficient, b.

| 100 lx | 1000 lx |
|---|---|
| $b = 0.105 + 0.760(X)$ | $b = 0.388 + 0.753(X)$ |

5) Calculate the slope coefficient, m.
$m = -0.00417 - 0.00334(X)$

6) Calculate the predicted visual acuity, VA'.
$VA' = b + mY$

**ACKNOWLEDGEMENTS**

The author is most grateful to Mrs. Nicole Normandin for collecting the data and assisting in the development of the equipment used in this study. Thanks go to Mr. Michael Ouellette who, as always, was most helpful in analyzing the data and reviewing earlier manuscripts. Thanks also go to Mr. Ralston Jaekel who was instrumental in helping orchestrate the project to completion. Final thanks go to Mr. Ivan Pasini of Public Works Canada who supported this work from the beginning.

This paper was supported, in part, by Public Works Canada through a Financial Encumbrance to the National Research Council Canada, Institute for Research in Construction.

**FIGURE CAPTIONS**

Figure 1: The Vision and Lighting Diagnostic (VALiD) Kit.

Figure 2: The NRCC Standard Task.

Figure 3: Visual acuity as a function of volunteer age. Circles are the median acuity values for the different age groups in Table 3. Dashed and broken lines demarkate the middle 40% (median ± 20%) and 70% (median ± 35%) of the population, respectively. The solid line shows the best fitting linear equation through the median acuity values (Table 5). Figures 3.1 and 3.2 are the data at 100 and 1000 lx, respectively.

Figure 4: Parameter estimates for the empirical model of visual acuity plotted as a function of percent contrast of the Landolt rings. Open and solid symbols are associated with 100 and 1000 lx, respectively. Solid lines show the best fitting linear equations through the different parameter estimates. Figure 4.1 and 4.2 are the intercept and slope parameter estimates, respectively, from Table 5.

Figure 5. Prediction of the empirical model of visual acuity with the median acuity values from Figure 3. Appendix 2 describes the model used to generate the solid lines. Figure 5.1 and 5.2 are the model predictions of median acuity values at 100 and 1000 lx, respectively.

Figure 6. An example of the acuity data scores sheet for one volunteer. The circled letters correspond to the smallest ring gap discerned under 100 lx by this subject. The letters with squares around them correspond to the smallest ring gap discerned under 1000 lx.

Figure 7: The relationship between visual acuity and the number of ring gaps missed on a given row of the NRCC standard task. Circles represent the median visual acuities observed for the those trails producing from one to twelve ring gaps missed per row. The solid line is the best fitting experimental function relating visual acuity to ring gaps missed per row. The equation describing the line is in the upper right corner of the figure, where Y = median visual acuity and X is the number of ring gaps missed per row.

Figure 8: The relationship between the number of ring gaps missed per page as a function of volunteer age for different percentages of the sample population. Solid lines were the best fitting linear equations through the data for the different sample population percentages and used to produce the smoothed value in Table 7.

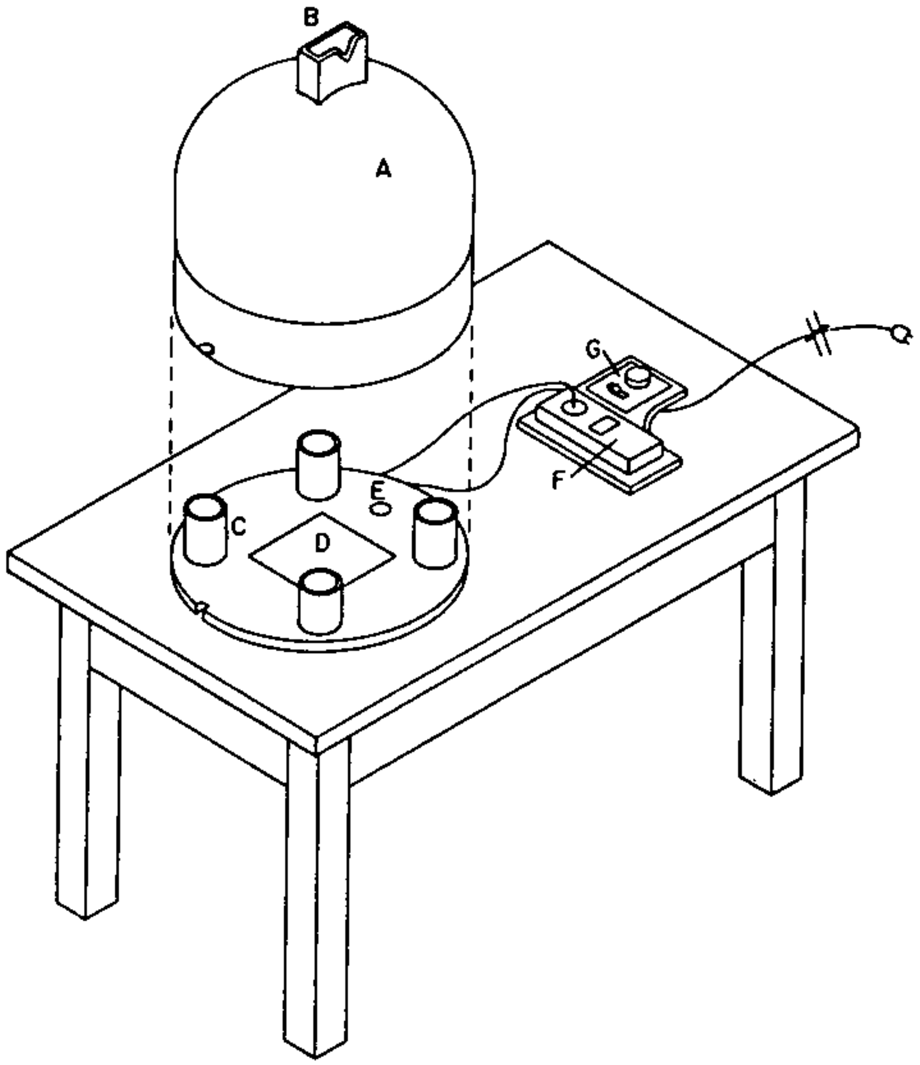


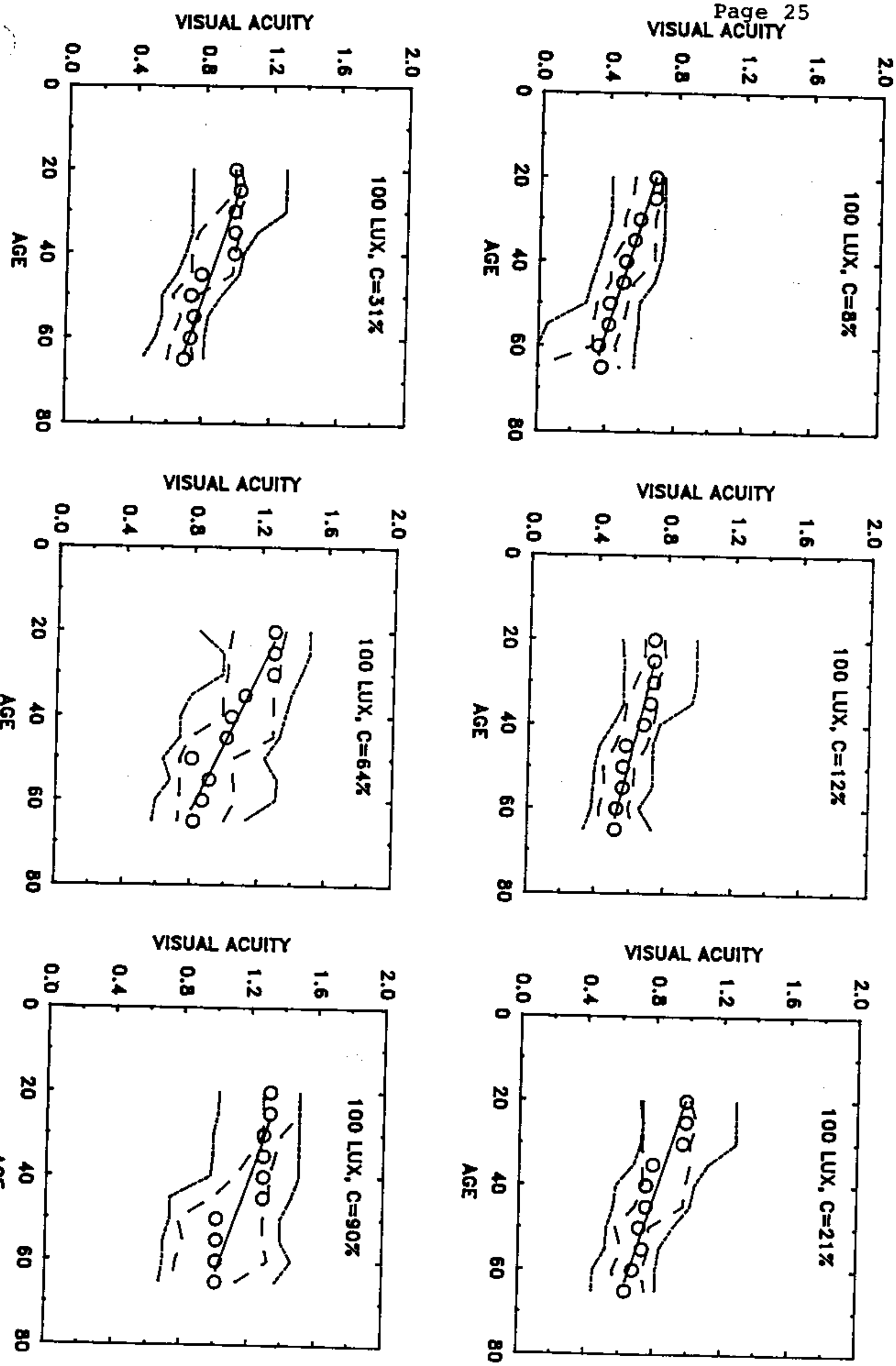

FIGURE 1

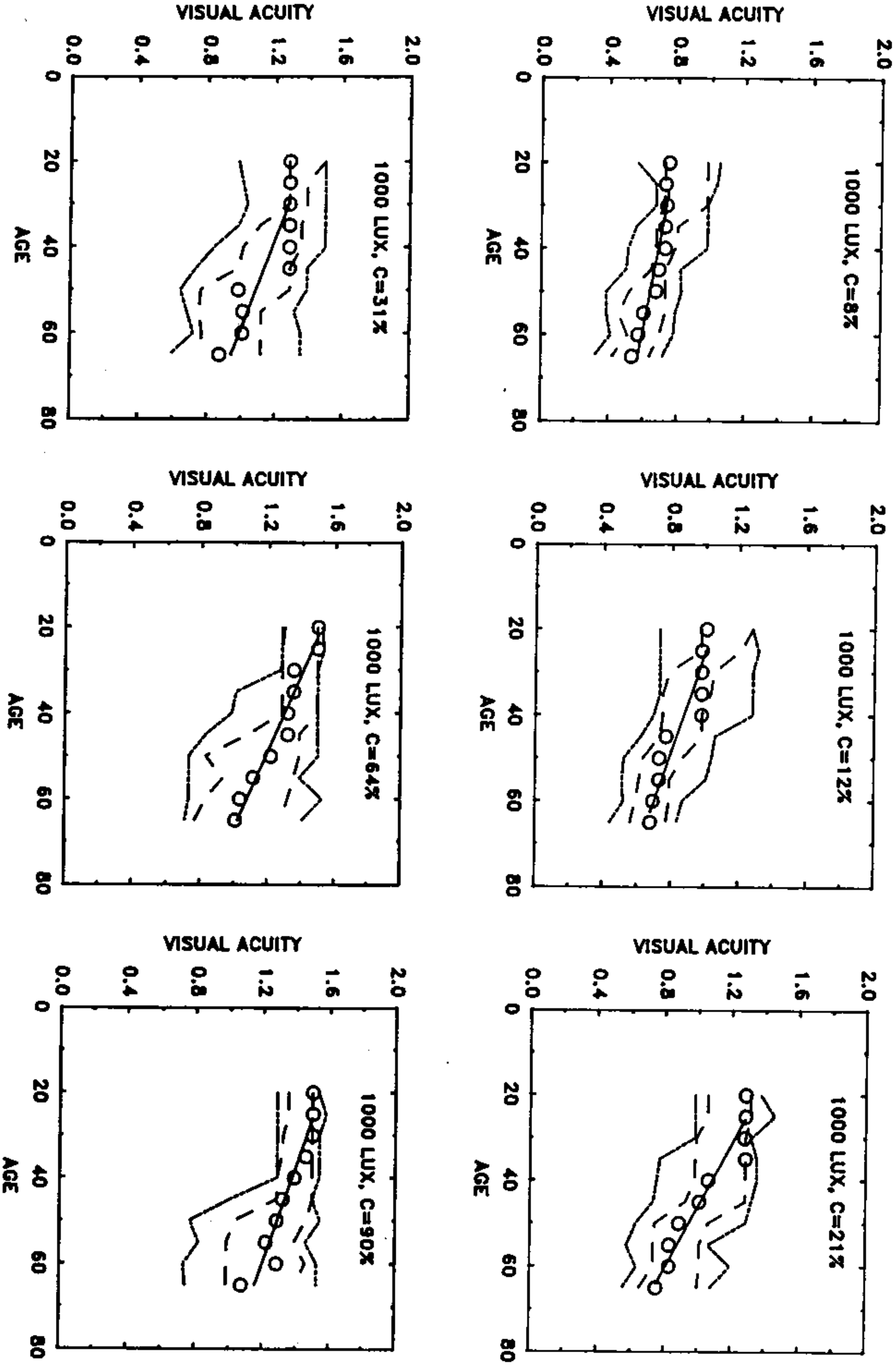
A - HEMISPHERE (DOME)
B - VIEWING PORT
C - CYLINDERS COVERING LIGHT SOURCES
D - NRC STANDARD VISABILITY TASK
E - ILLUMINANCE METER PROBE
F - ILLUMINANCE METER
G - LAMP SELECTOR AND FINE ADJUSTMENT SWITCHES

FIGURE 2

Figure 3.1




VISUAL ACUITY
AGE
100 LUX, C=8%
100 LUX, C=31%
100 LUX, C=12%
100 LUX, C=64%
100 LUX, C=21%
100 LUX, C=90%
0.0
0.4
0.8
1.2
1.6
2.0
0
20
40
60
80


VISUAL ACUITY
AGE
1000 LUX, C=8%
1000 LUX, C=31%
1000 LUX, C=12%
1000 LUX, C=64%
1000 LUX, C=21%
1000 LUX, C=90%
0.0
0.4
0.8
1.2
1.6
2.0
0
20
40
60
80

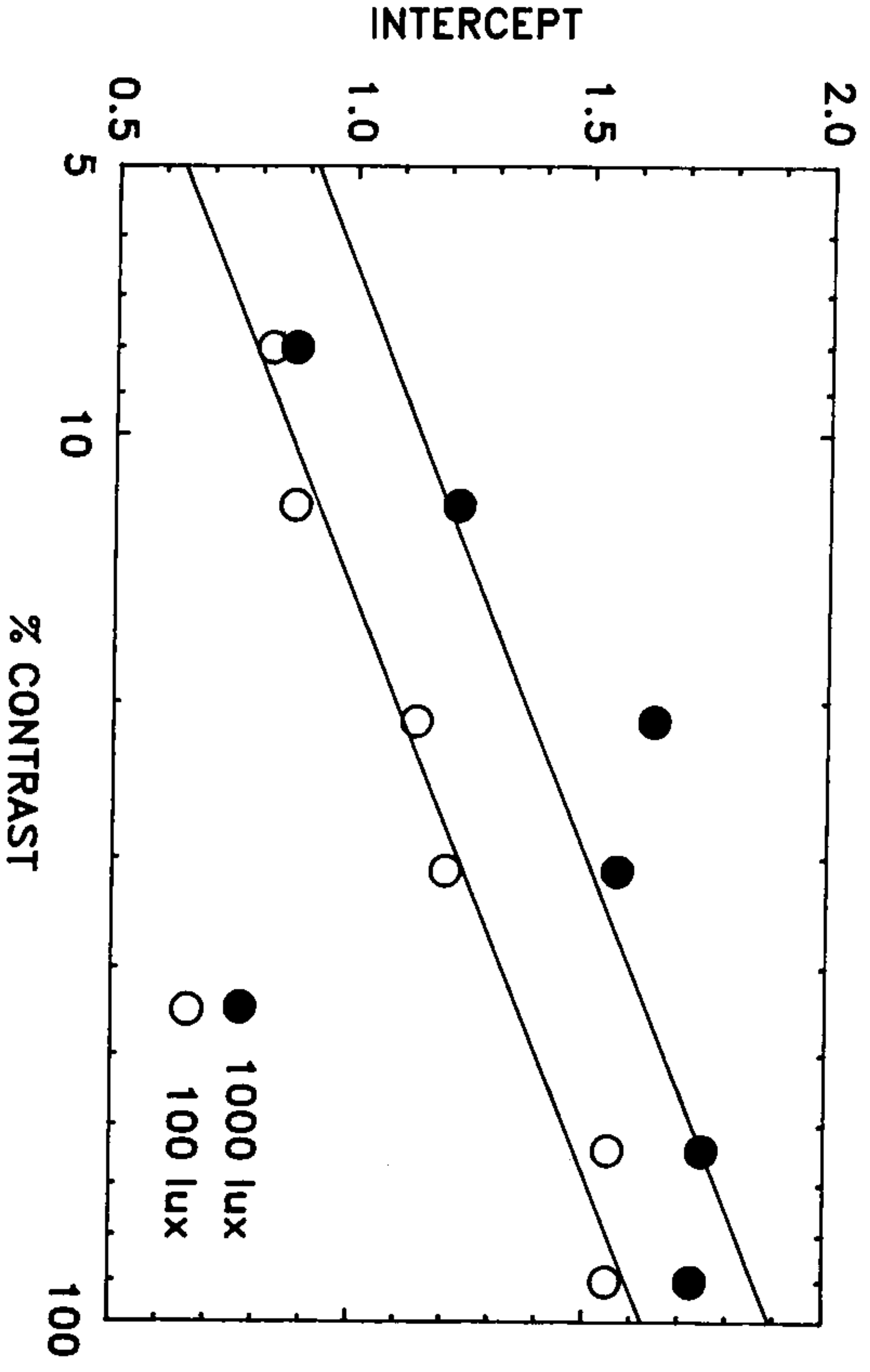
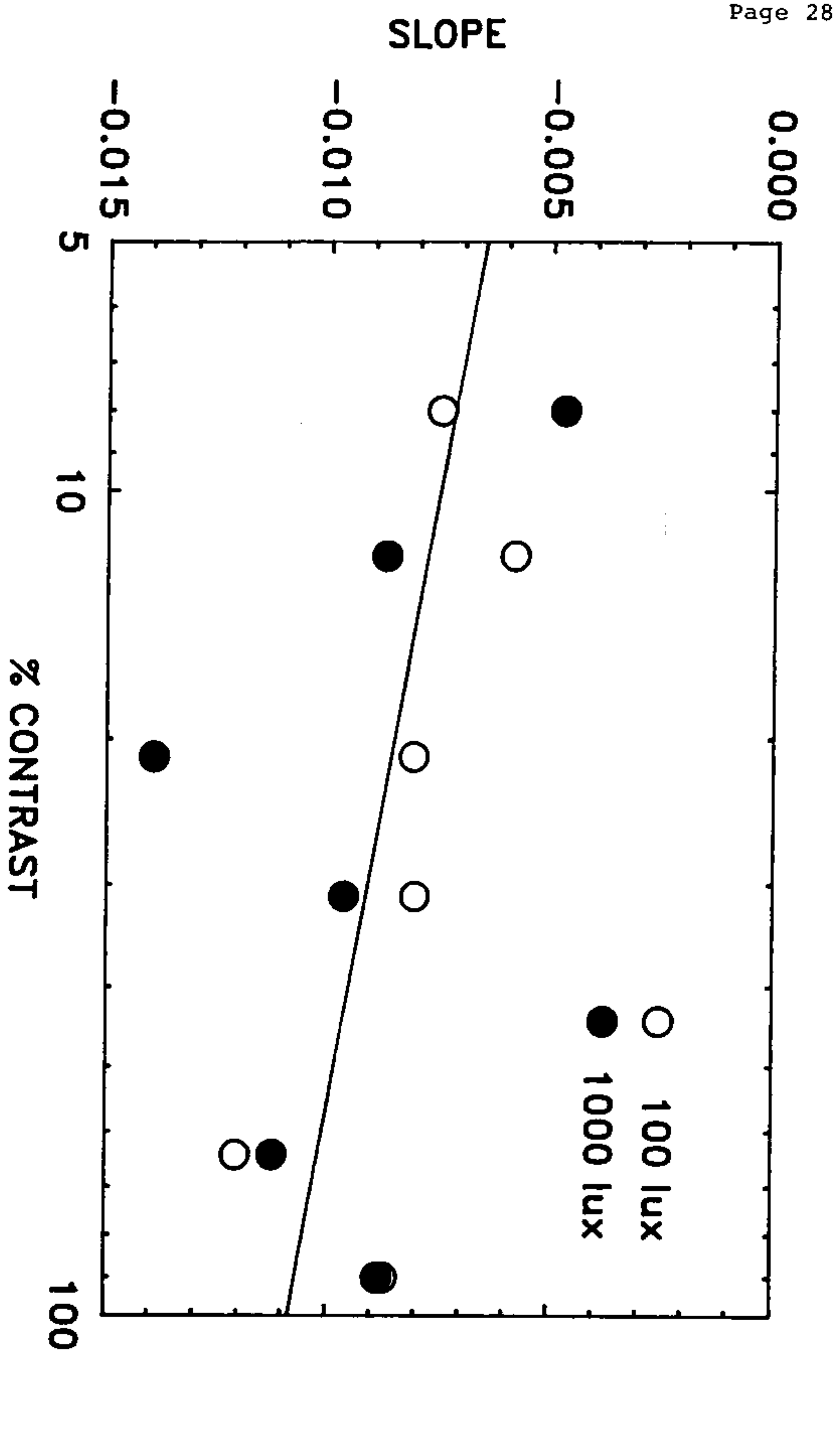
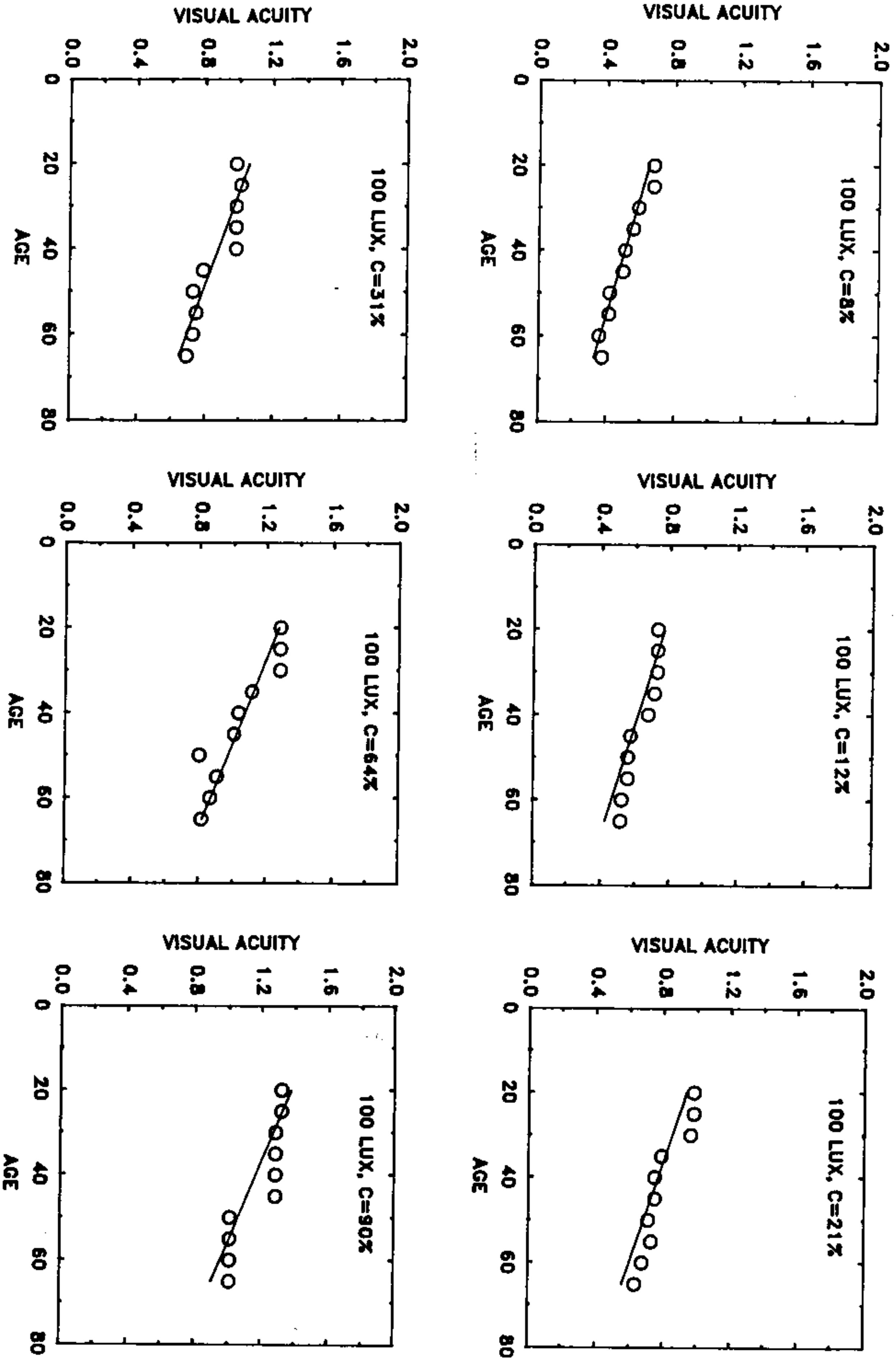
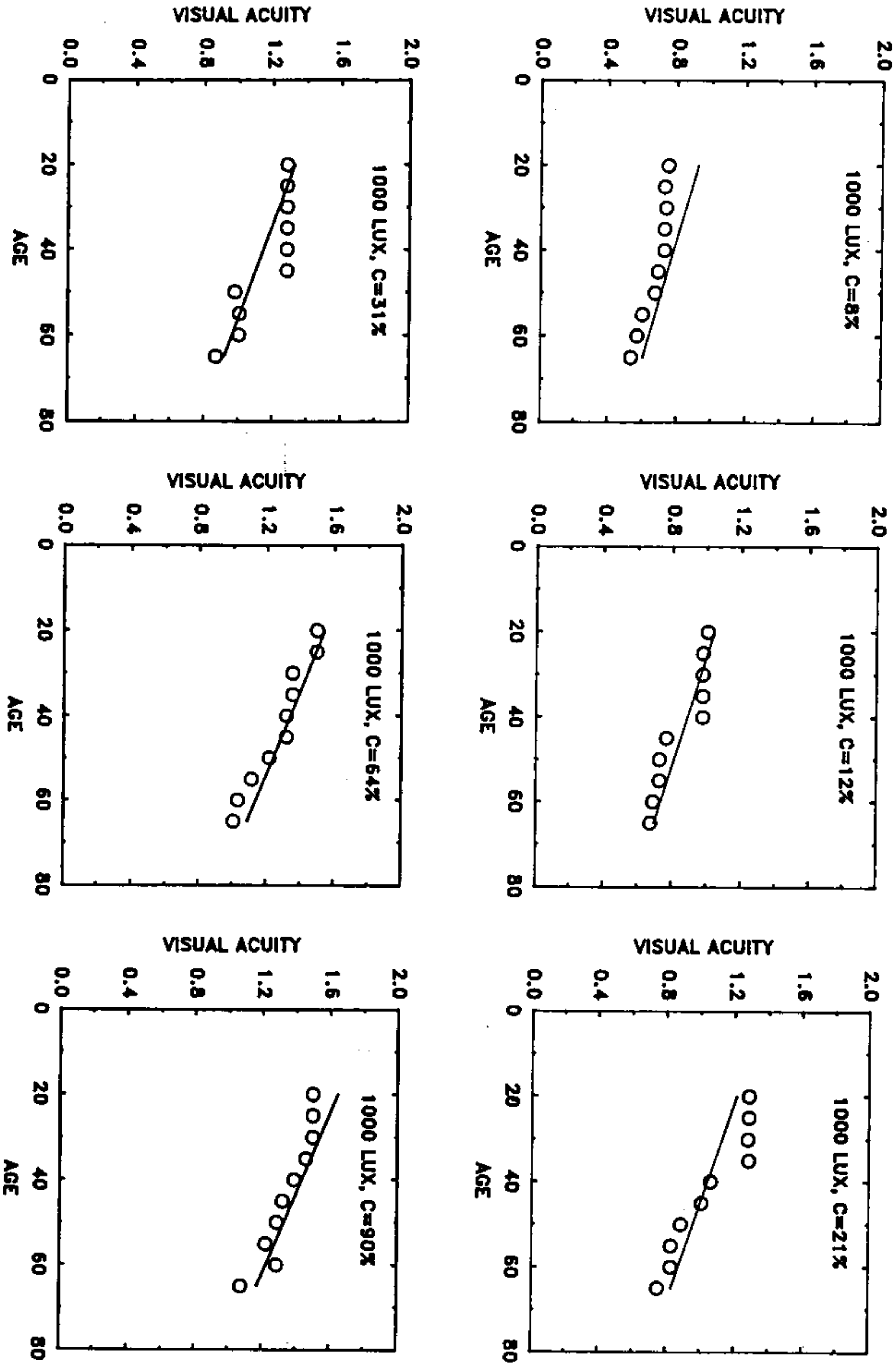

INTERCEPT
0.5
1.0
1.5
2.0
5
10
100
% CONTRAST
1000 lux
100 lux

Figure 4.2




VISUAL ACUITY
AGE
100 LUX, C=8%
100 LUX, C=31%
100 LUX, C=12%
100 LUX, C=64%
100 LUX, C=21%
100 LUX, C=90%


VISUAL ACUITY
AGE
1000 LUX, C=8%
1000 LUX, C=31%
1000 LUX, C=12%
1000 LUX, C=64%
1000 LUX, C=21%
1000 LUX, C=90%
0.0
0.4
0.8
1.2
1.6
2.0
0
20
40
60
80

**Location** *Prom. Outaouais* **Date** *6-Nov-87*

**Viewing distance** *26"* **Experimenter** *NN*

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | Contrast |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A | L | D | U | R | D | R | L | U | D | D | R | L | D | 0.90 |
| B | R | U | D | L | U | D | R | D | U | U | D | L | R | |
| C | D | R | U | L | R | U | D | R | D | D | U | L | D | 0.64 |
| D | L | L | R | R | L | L | D | [illegible] | R | L | L | U | R | |
| E | L | R | D | D | D | U | L | L | U | D | R | U | U | 0.31 |
| F | U | D | D | R | U | U | D | R | D | L | U | R | R | |
| G | D | U | U | R | L | R | D | R | D | R | U | L | D | 0.21 |
| H | D | L | R | D | R | D | [illegible] | L | L | R | U | L | L | |
| I | R | U | R | U | L | D | U | D | U | D | L | U | R | 0.12 |
| J | R | L | U | U | D | D | R | U | L | R | L | D | U | |
| K | U | R | D | L | L | D | [illegible] | D | L | R | D | L | R | 0.08 |
| L | L | D | U | L | R | L | U | D | R | U | R | R | U | |

1 2 3 4 5 6 7 8 9 10 11 12 13

**Acuity**

**Age** *54*

**Sex**
M ✓
F ___

**Vision Correction**
none
contacts ___

**Eyeglasses**
half ___
single ___
bifocal ✓
trifocal ___
no line ___

**Other Factors**
diabetes ___
cataracts ___
glaucoma ___
high blood pressure ___
*none*

**Eye Color**
brown ___
blue ___
hazel ✓
green ___

**Other Info**

Figure 7

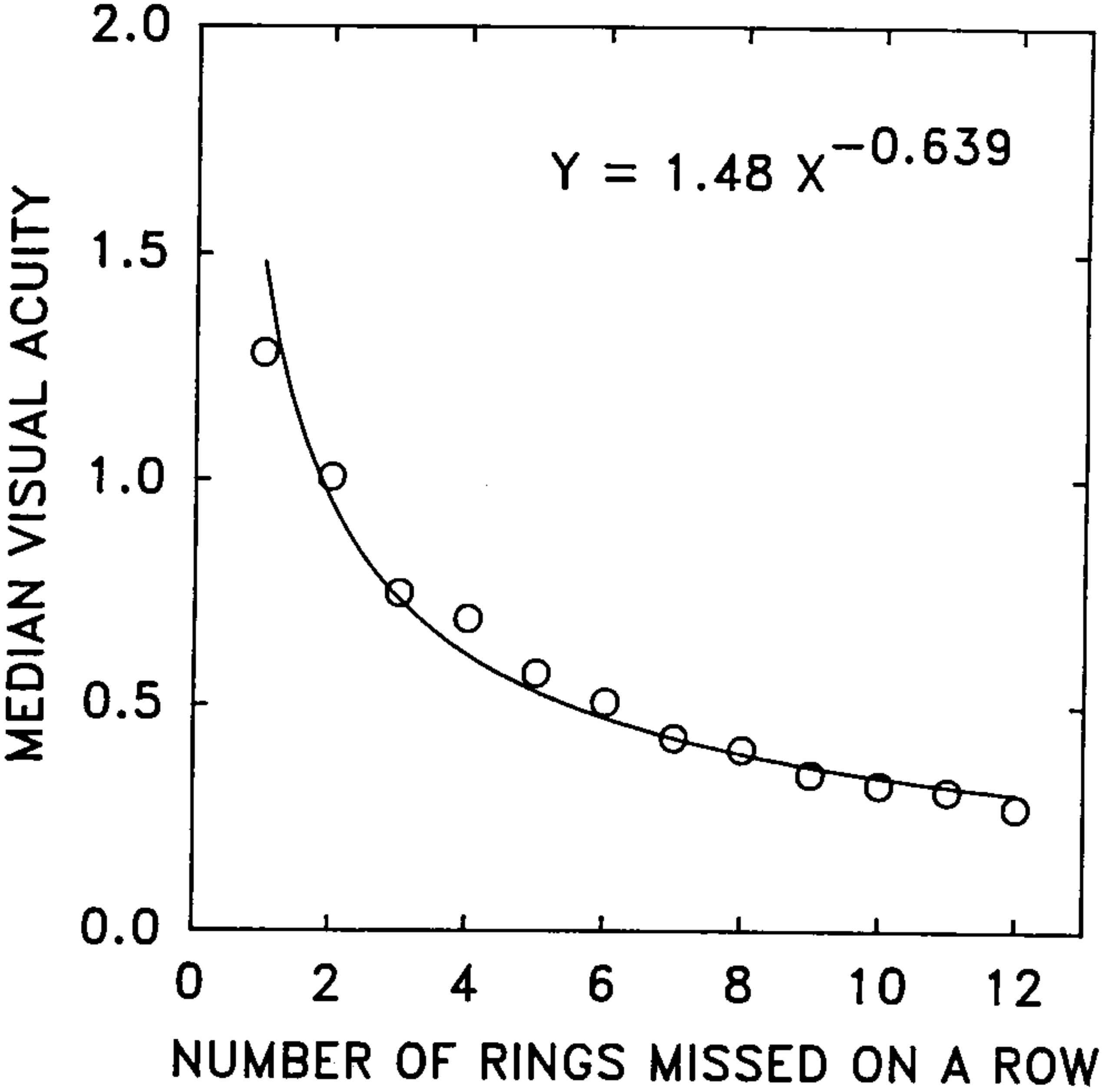
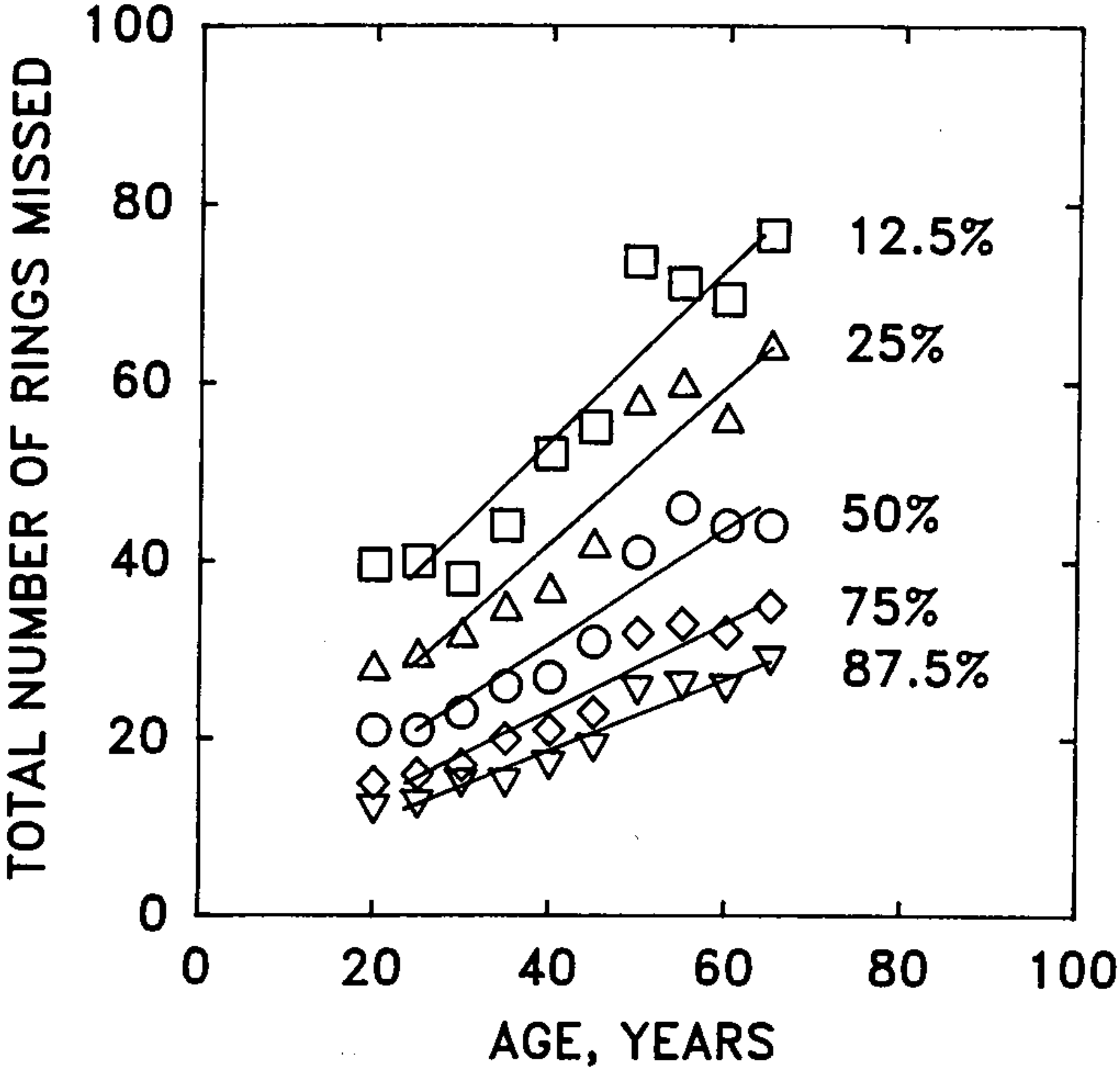

2.0
1.5
1.0
0.5
0.0
MEDIAN VISUAL ACUITY
Y = 1.48 X$^{-0.639}$
0
2
4
6
8
10
12
NUMBER OF RINGS MISSED ON A ROW

Figure 8






NRC·CNRC