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Visual Survey of Infantry Troops, Part I: Visual Acuity, Refractive Status, Interpupillary Distance, and Visual Skills

By

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The primary objective of the study was to establish a database characterizing the current visual status of infantrymen. Individuals selected as participants for this study were active duty personnel undergoing training to receive Military Occupational Specialty (MOS) 11B20, Infantryman. The visual survey test battery included measurements of visual acuity (high and low contrast), refractive error, interpupillary distance, color vision, distance lateral phoria, stereopsis, contrast sensitivity, isoluminance resolution, and sighting dominance. This report presents data collected from the following tests/measurements: High contrast visual acuity, refractive error, interpupillary distance, depth perception, distance lateral phoria, and color vision. Of the 828 participants, 95.6 percent rated an E-1 (highest classification) in the vision category of the physical profile serial. Among entry-level infantrymen, 33 percent were spectacle wearers. Distributions of the various visual parameters are presented for the test population and for selected subpopulations. Implications for selection/retention standards and for equipment design are discussed.

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Introduction

New technology is an important source for the weapons and equipment needed to counter the technological advances of threat forces. The effectiveness and efficiency of military hardware depend on the man-machine interface. The equipment must be designed around the capabilities of the user.

While much of military hardware development centers around the firepower needed to defeat the opposition, even the most effective weapon system requires soldiers to acquire the targets. Thus, the equipment which enhances the individual's ability to "see" the enemy is critical to the overall system. Target acquisition sensors, whether remotely operated or integrated into the weapon system, must be usable by the operator. In some cases, the operator interprets information from a sensor provided on a video screen. Other devices permit direct view of the target. With these latter devices, the ultimate sensor is the human eye.

A visually coupled system (VCS) is a device containing optical components designed to provide input to the human eye. Binoculars, weapon sights, and electro-optical viewing devices are examples of VCSs. VCSs must be matched to the visual system of the user. For example, if a VCS is not compatible with spectacles, the optical components must provide the refractive correction. For systems which are expected to be in general use, the range of visual capabilities of the entire population of soldiers must be considered. On the other hand, when the effectiveness of limited-use or specialized equipment relies heavily on the visual capabilities of the user, selection of operators from a given population pool may be required. In either case, the visual capabilities of the population of potential users must be known and considered when developing VCSs.

The primary objective of this study was to establish a database characterizing the current visual status of infantrymen. This information is needed to answer the following basic question: How might the population pool of Advanced Antitank Weapon System-Medium (AAWS-M) gunner eligibles be affected if the vision profile was more stringent than for the predecessor Dragon system? This suggestion resulted from the assumption that selecting visually superior soldiers would enhance overall effectiveness of the AAWS-M, and from the desire to select as gunners for AAWS-M those soldiers with the best visual status. The study approach was a limited-scope epidemiological study among current antitank gunner eligibles, i.e., infantry trainees undergoing One-Station Unit Training at Fort Benning, Georgia.

In addition to answering the primary question, the results of this study will have broad usage by specifying the visual characteristics of the infantrymen. The epidemiological data will be available for estimating materiel and personnel requirements of the optical laboratories supplying prescription eye wear and mask inserts, for estimating required numbers and types of eye protective devices, e.g., ballistic laser eye protection, for specifying the range of dioptric adjustments in optical and electro-optical devices, for developing selection criteria for other systems, and for similar applications based on visual characteristics.

This report summarizes only a portion of the data collected in the study. The data discussed here answer specific questions concerning the visual status of infantrymen. Subsequent reports will address the remaining data.

Background

There is an ongoing development program for a medium antitank missile to replace the Dragon missile. The new system, AAWS-M, is expected to be fielded in the early 1990s. The Dragon was found to be effective only in the hands of a soldier with superior marksmanship skills. Attempting to use this experience constructively, the Request For Proposal (RFP) for the AAWS-M includes a requirement to minimize human performance skills needed to effectively operate the system. This supports the intent of the Manpower and Personnel Integration (MANPRINT) program. MANPRINT emphasizes designing systems to match soldiers' capabilities to obtain maximum performance. In the case of the AAWS-M, a weapon system could be designed to be less dependent on gunners' marksmanship skills. Thus, the system should maintain its effectiveness when in the hands of a larger population of users.

Beyond hardware considerations, MANPRINT considers other capabilities of the soldier to attain maximum system effectiveness. Since antitank gunners first must be able to "acquire" the target, selection of gunners with superior target acquisition skills might enhance the overall system effectiveness. Target acquisition is a multifaceted task which includes detection, classification, recognition, and identification. Intuitively, these tasks depend heavily on the soldiers' visual capabilities. While vision, as measured in an acuity task, has been demonstrated as important, the role of visual skills (other than acuity) and other aspects of visual perception remains undetermined. Both laboratory and field studies (Berbaum et al., 1985 and Kabala, 1986) suggest that, at a minimum, acuity, color vision, contrast sensitivity, and cognitive factors may influence target acquisition performance.

This study will complement the Target Acquisition Predictor Study (TAPS) being conducted by the U.S. Army Aeromedical Research Laboratory (USAARL). TAPS is designed to obtain operational data which can be correlated to visual attributes. This study, by providing a database of the attributes in the current population pool, will provide information with which to develop/modify a selection model consistent with the population pool.

Vision requirements for the 11B infantryman

For an individual to be assigned a Military Occupational Specialty (MOS), the requirements contained in AR 40-501, Standards of Medical Fitness (for enlistment) and AR 611-201, Enlisted Career Management Fields and Military Occupational Specialties must be met. In the case of vision requirements, the enlistee undergoes minimum vision testing at the Military Enlistment Processing Station (MEPS). The initial physical requires only measurements of visual acuity and color vision. If the uncorrected visual acuity is less than 20/20, an evaluation to determine the refractive error is required. Based on this information, a "profile" is assigned.

The physical profile serial (AR 40-501) is a classification of physical abilities in terms of six factors designated by the letters P-U-L-H-E-S (P - physical capacity or stamina; U - upper extremities; L - lower extremities; H - hearing and ear; E - eyes; and S - psychiatric). The serial indicates the functional capacity of particular organs or bodily systems, which in turn should relate to performance of military duties. The physical profile serial is used in AR 611-201 to designate minimum standards for enlisted specialties.

In using the physical profile system, each of the six factors is given a numerical designation of 1 to 4, with 1 indicating a high level of medical fitness and not medically limiting military assignments. For factor "E" - eyes, the regulation specifies an E2 profile as minimum requirement for enlistment. Thus, the population of enlistees (pool from which 11B infantrymen will be selected) normally will be composed of individuals possessing an E1 or E2 profile. For an E1 profile, the enlistee must have an uncorrected visual acuity of 20/200 or better, and must have vision correctable to 20/20 in each eye. The E2 must have distant visual acuity correctable to 20/40 in the better eye and 20/70 in the worse eye, or similar combinations of 20/30-20/100 and 20/20-20/400.

AR 611-201 imposes additional requirements for correctable visual acuity as a selection criterion for the 11B MOS (infantryman). The minimum corrected acuity must be 20/20 in one eye and 20/100 in the other eye. Thus, while E2 profiles can be found among infantrymen, not all individuals with E2 profiles will qualify.

The establishment of an E1 visual standard potentially could impact AAWS-M gunner selection by effectively reducing the size of the qualified manpower pool. However, the data from which to assess the effects of establishing an E1 visual qualification on personnel eligibility are nonexistent.

Literature review

A review of the literature of visual epidemiology studies provides no information concerning infantrymen in particular. Most military surveys have been conducted on specialized groups (e.g., aviators and submariners) in other services. Of the few associated with the Army, the majority are linked to the aviation community (Kim, 1982).

Studies in the civilian community do not consider uncorrected visual acuity to be as important a factor as correctable visual acuity and refractive error. There are many reasons for this. One is the lack of repeatability of a visual acuity measurement over time when the spectacles are not worn. With time, there is an increase in the measured acuity level as the individual adapts to the blurred environment and learns to better interpret a blurred retinal image.

The existing studies, although limited, provide descriptions of the visual status of the general population in terms of spectacle wear, refractive error, and color vision. For the age group of 18-30-year-old males, 30-35 percent are expected to be spectacle wearers (Grosvenor, 1976). For this age group, the types of refractive errors found are myopia (35-38 percent), hyperopia (25-27 percent), and astigmatism (10-15 percent). Approximately 30-40 percent do not meet the criteria for having a refractive error. However, there is no consistency among studies in the specification of refractive errors.

Approximately 8 percent of males possess some form of color vision deficiency. Two percent have dichromatic vision (serious); the remainder have anomalous trichromacy (less serious; varying grades) (Borish, 1970). AR 611-201 does not require normal color vision for the 11B MOS. The infantryman only has to be able to distinguish between red and green. If the population of enlistees mirrors the civilian population, only 1-2 percent would be ineligible due to a color vision deficiency.

While selection for the 11B MOS is based on visual acuity and color vision, other visual attributes and visual skills are ignored. These attributes include the ability of the two eyes to work together (heterophoria, stereopsis), the type of refractive error (myopia, hyperopia, astigmatism, anisometropia), and the ability to see under degraded conditions (contrast sensitivity, low contrast visual acuity).

For visual characteristics other than visual acuity, the relationship to performance, such as target acquisition, has not been defined clearly. Recent reports, based on literature reviews (Berbaum et al., 1985 and Kabala, 1986), have failed to discover studies where visual predictors have been used successfully to select individuals for target acquisition skills. However, these reports have recommended a number of visual tests be included in screening for target acquisition skills. While some of the tests are common to the standard military physical examination, others were identified based on theoretical considerations and on the results of laboratory findings. Certain recommended tests do not lend themselves to the screening type environment. Making selections from large populations necessitates the apparatus be simple to operate and provide rapid, reliable measurements in a clinical setting.

Methods

Participants

The individuals selected as participants for this study were active duty personnel undergoing training to receive MOS 11B20. All were males, since females are not eligible for this combat MOS. The participants were in the population pool from which candidates for Dragon training are selected. The participants were tested during Infantry One-Station Unit Training (OSUT) at Fort Benning, Georgia.

The participants for this epidemiological study were selected on a quasi-random basis. Based on the training schedule, only one company normally was available for testing on a given day. Individuals were selected among eligible candidates using computer generated random number tables. Lists of selected participants were supplied to the training companies tasked to provide participants. For most companies, at least some of the selectees were not made available for the testing. When this situation occurred, company cadre "randomly" selected trainees. Trainees selected by cadre not meeting the study criteria were not tested.

The total number of participants tested was 843. Data for 15 trainees screened were eliminated for the following reasons: 12 were National Guard, 1 was training for an 11H MOS, and 2 did not complete training. The database contains data from the remaining 828. Of this group, 85 participants who had been prescribed spectacles did not have their correction with them. Another seven participants arrived for testing wearing contact lenses. While complete data sets were not obtained from these subgroups, available data will be presented either combined or separately, as appropriate. The remaining 736 participants made up the main population. This group provided data for the best corrected condition, i.e., nonspectacle wearers and spectacle wearers wearing their spectacles.

The ages of the trainees ranged from 17 to 35 years, with a mean of 19.3 years. Both the median and mode for the group were 18.0 years.

Test materials and procedures

The testing was divided into two phases -- questionnaire and vision tests. A self-administered paper-and-pencil questionnaire was used to obtain self-report information on demographics, spectacle and contact lens history, laterality, and smoking history. Only those portions of the results pertaining to spectacle and contact lens wear are reported here.

In the visual assessment portion of the study, each participant was tested for: standard visual acuity, refractive error, color vision, depth perception (including stereopsis), distance lateral phoria, contrast sensitivity, low contrast visual acuity, isoluminance detection threshold, and sighting dominance. Related measurements included neutralization of the optical corrections of spectacle wearers and measurement of the interpupillary distance. Table 1 shows the tests used and measurements made.

This report covers only a portion of the data collected. Subsequent reports will include methodology and data for contrast sensitivity, low contrast visual acuity, isoluminance detection threshold, and sighting dominance tests.

Standard visual acuity testing

The visual acuity test used the Goodlite professional eye cabinet*. The 10 inch by 18 inch retro-illuminated chart was elevated to the approximate standing eye height of the observers. The illumination was between 25 and 30 foot lamberts with a color temperature equivalent to Illuminant C. The test chart consisted of 11 lines of Sloan letters with 100 percent horizontal spacing between letters. The letters on each line subtend the same visual angle; the size of the letters decreases from top to bottom. The sizes range from 20/160 to 20/16. The test distance for these charts was 10 feet. The walk-up method was used to measure acuities less than 20/160. The short test distance was dictated by space limitations in the mobile van.

A standard sequence of testing, similar to that employed in routine screening, was employed. A single chart was used for all measurements. Acuities of the right eye, left eye, and then both eyes were measured. For spectacle wearers, uncorrected visual acuity was measured before corrected acuity.

Objective refractive error

For this survey, the Humphrey 520 autorefractor* was used. Besides an objective assessment of refractive error, this instrument provided a means to measure uncorrected and corrected visual acuity. Testing was accomplished in subdued, ambient room illumination. To obtain maximum accuracy, the instrument was set to provide readings to the nearest 0.12 diopters. To determine refractive error, the participant simply fixated a target in the instrument.

Spectacle correction

For the spectacle wearers, the power of the habitual prescription was measured with the Model 322 Humphrey laboratory

* See Appendix C.

Table 1.

Visual survey tests

Instrument/test	Measures
Humphrey autolensometer	*Sphere power, cylinder power and axis, distance between optical centers of spectacle lenses
Silor pupillometer	*Distant monocular and binocular IPDs, near IPD
Sighting dominance test battery (point, hole-in-card, Miles ABC, alignment and Asher tests)	Sighting dominance score
Humphrey autorefractor	Uncorrected and corrected monocular visual acuity
	*Refractive sphere power and cylinder power and axis
Armed Forces Vision Tester	*Depth perception and distant lateral phoria
Ishihara pseudo-isochromatic plates	*Color vision
Titmus stereotest	Stereopsis
Randot stereotest	Stereopsis
Standard visual acuity	*Uncorrected and corrected monocular and binocular visual acuity
Regan low contrast letter charts	Low contrast visual acuity
Vistech contrast sensitivity charts	Contrast sensitivity
Isoluminance detection task	Isoluminance score

* Data summarized in this report.

lens analyzer*. As with the Humphrey autorefractor, this instrument provided an objective measurement and was set for an accuracy of 0.12 diopters. The lensometer provided scales for measuring the distance between optical centers of the spectacles.

Interpupillary distance

Distance and near interpupillary distances and monocular pupillary distances were measured using the Silor corneal reflection pupillometer*. This pupillometer optically simulates viewing distances from 35 centimeters to infinity. The distance measurement was made at the infinity setting, and the near measurement was made with the instrument set for 40 centimeters.

The instrument was positioned with the nose pads resting on the bridge of the participant's nose. With the participant viewing an illuminated target, the technician moved a vertical graticule to align it with the corneal reflections. The measurements were read from the scales on the instrument to the nearest millimeter.

Color vision

The Ishihara color 14 plate book* was used to test color discrimination. This test falls into the category of pseudoisochromatic plate tests (PIP) and is designed to discriminate color normals from color defectives in a screening environment. The Ishihara PIP was selected because it is less sensitive than other tests to variations in viewing distance, viewing duration, and stimulus blur (Long et al., 1984). During mass screenings under less than ideal conditions, these factors become important.

The test plates were illuminated by a Macbeth easel lamp*. The observer was positioned 30 inches (75 cm) from the plates. The task on each plate was to identify a one- or two-digit number or trace a winding path with a brush.

Depth perception and distant lateral phoria

Depth perception and distant lateral phoria were measured using the Armed Forces Vision Tester (AFVT)*. The AFVT is a stereoscope-type instrument incorporating test slides on an illuminated surface. This instrument optically simulates distant and near viewing. The fusion and depth perception (#71-21-18) and far lateral phoria (#71-21-12) slides were mounted in positions 1 and 2, respectively. The instrument was fixed in the distance viewing position.

The depth perception slide contains six blocks (A-F) with three rows in each block and five rings on each row. For those participants appreciating stereopsis, one of the rings in each row should appear slightly nearer than the other four. Within each block, the disparity, or measure of depth perception, is the same. The participant's task was to identify the ring which appeared closer.

The distant lateral phoria test consisted of an alignment task. With an arrow visible to one eye and a horizontal row of numbered dots to the other, the participant identified the dot nearest to the arrow point.

General procedures

Each participant was provided with a volunteer briefing form, which briefly described the test procedures. The questionnaire then was completed in the classroom. As the questionnaires were completed, data collection forms (Appendix A) were provided to each participant. The trainees carried these forms from station to station.

Eight data collectors manned six test stations. At three of the stations, the numbers of tests administered required two data collectors. A single data collector manned two stations. For each test, standardized procedures were developed. Data collectors were trained and evaluated during in-house workshops and during a pilot study at Fort Rucker, Alabama.

Results

Most of the figures presented here are interval histograms. In an effort to increase clarity and to reduce clutter, only the midpoints of the intervals are listed along the horizontal axes. Failure to record test results or subjects not completing all tests has resulted in missing data. All available data are included in each analysis.

Visual acuity

Visual acuity (VA) is specified by a variety of notations. These include Snellen, decimal, minimum angle of resolution (MAR), and logarithm of MAR (log MAR). Snellen notation is most common in military documents. However, because letter size difference between lines is not consistent, the use of Snellen notation results in a nonlinear spread of data. For example, if an individual reads all the letters on one line and several letters on the next line, there is no accurate way to credit these extra letters for statistical analysis. The decimal and MAR scales suffer the same deficiency. Log MAR, on the other hand, provides a nearly linear function with a logarithmic letter size progression (Bailey and Lovie, 1976). Using this method, each line read subtracts about 0.10 units from the log MAR; extra letters read receive credit as a fraction of 0.10.

VA data were recorded using Snellen notation and then converted to log MAR for data analysis. As an example, if a participant read all the letters on the 20/20 line and three of the ten letters on the 20/16 line, the log MAR score would be recorded as -0.03. Log MARs of 20/20 and 20/16 are 0.00 and -0.10, respectively. Credit for extra letters is 3 times 0.01 or 0.03. This value is subtracted from 0.00. For presentation purposes, summary acuities were converted back to standard Snellen notation.

Populations

The visual acuity requirement for infantrymen is 20/20 in the better eye and 20/100 in the worse eye. Figures 1 through 5 show the distributions of uncorrected and corrected visual acuity for the total participant population and subgroups within the total. The term "best visual acuity" describes data collected from non-spectacle wearers and spectacle wearers with current correction. Table 2 provides the corresponding means, medians, modes, and ranges. Since each of the ranges included a maximum acuity of 20/16, only the minimum acuity of the range is listed.

Based on this standard acuity measurement, only two individuals obtained acuity scores below the requirement for the MOS. In one case, another acuity measurement, made with the Humphrey autorefractor, showed an acceptable level. In the other

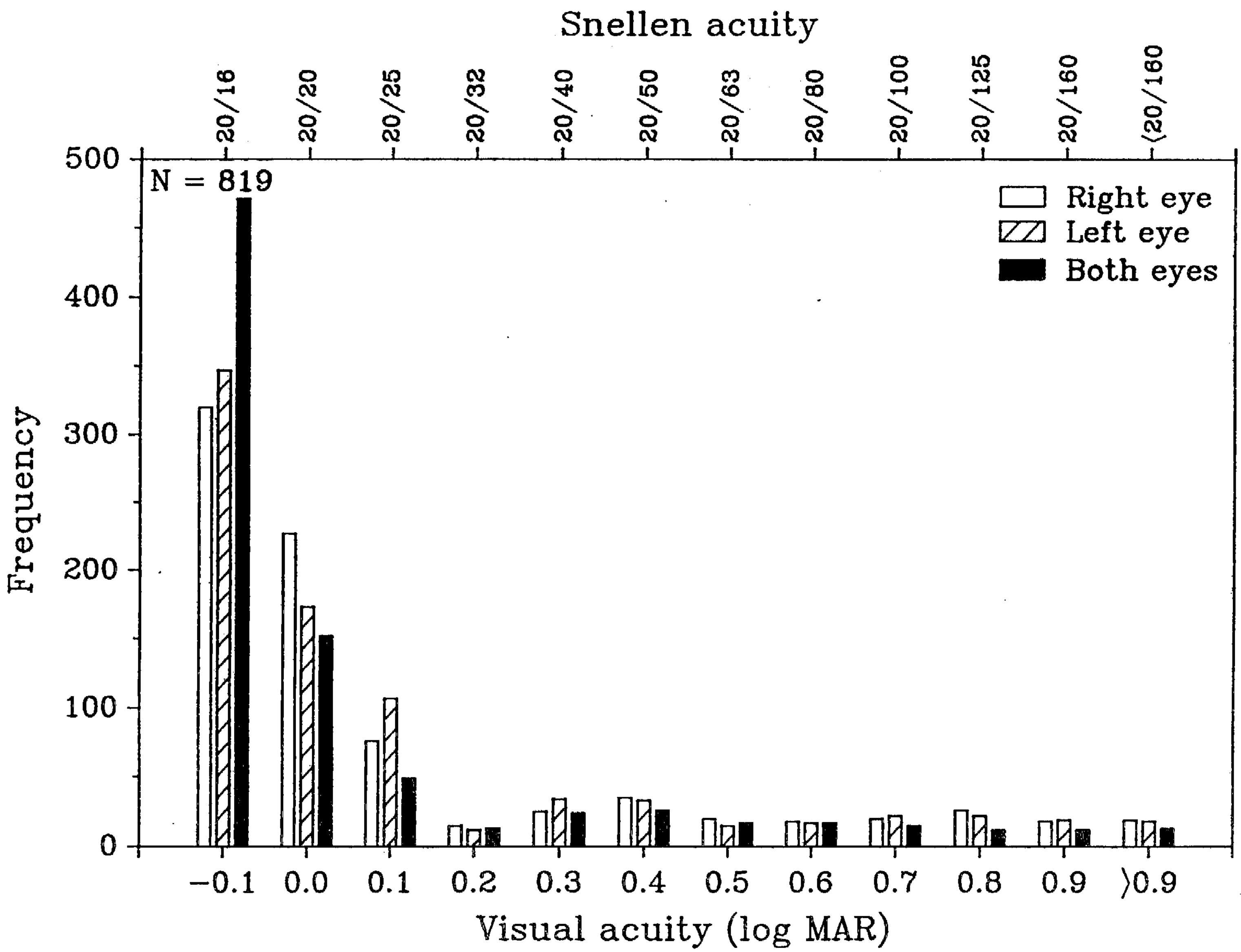

Figure 1. Uncorrected visual acuity of infantrymen.

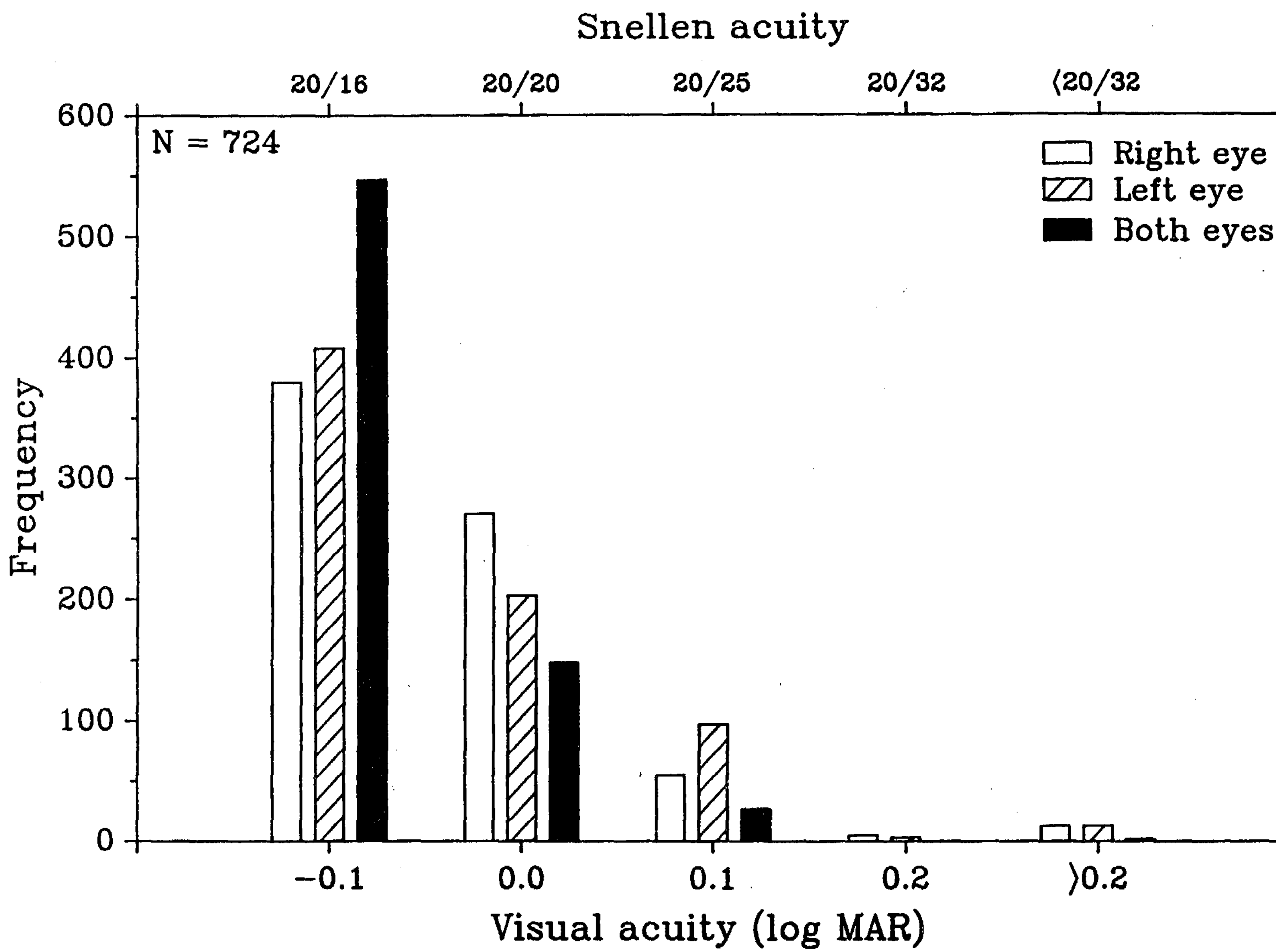

Figure 2. Best visual acuity of infantrymen.

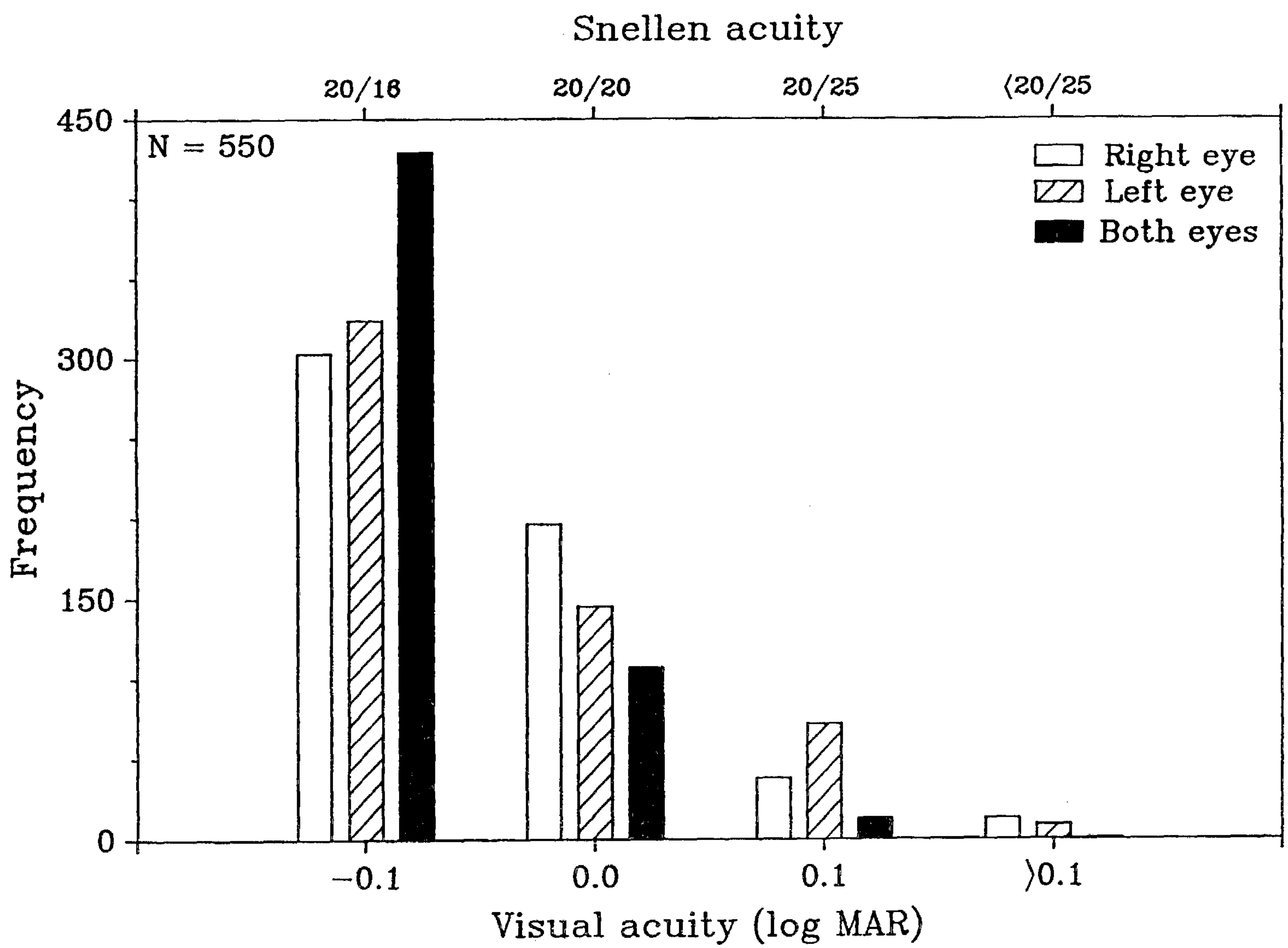

Figure 3. Visual acuity of nonspectacle wearers.

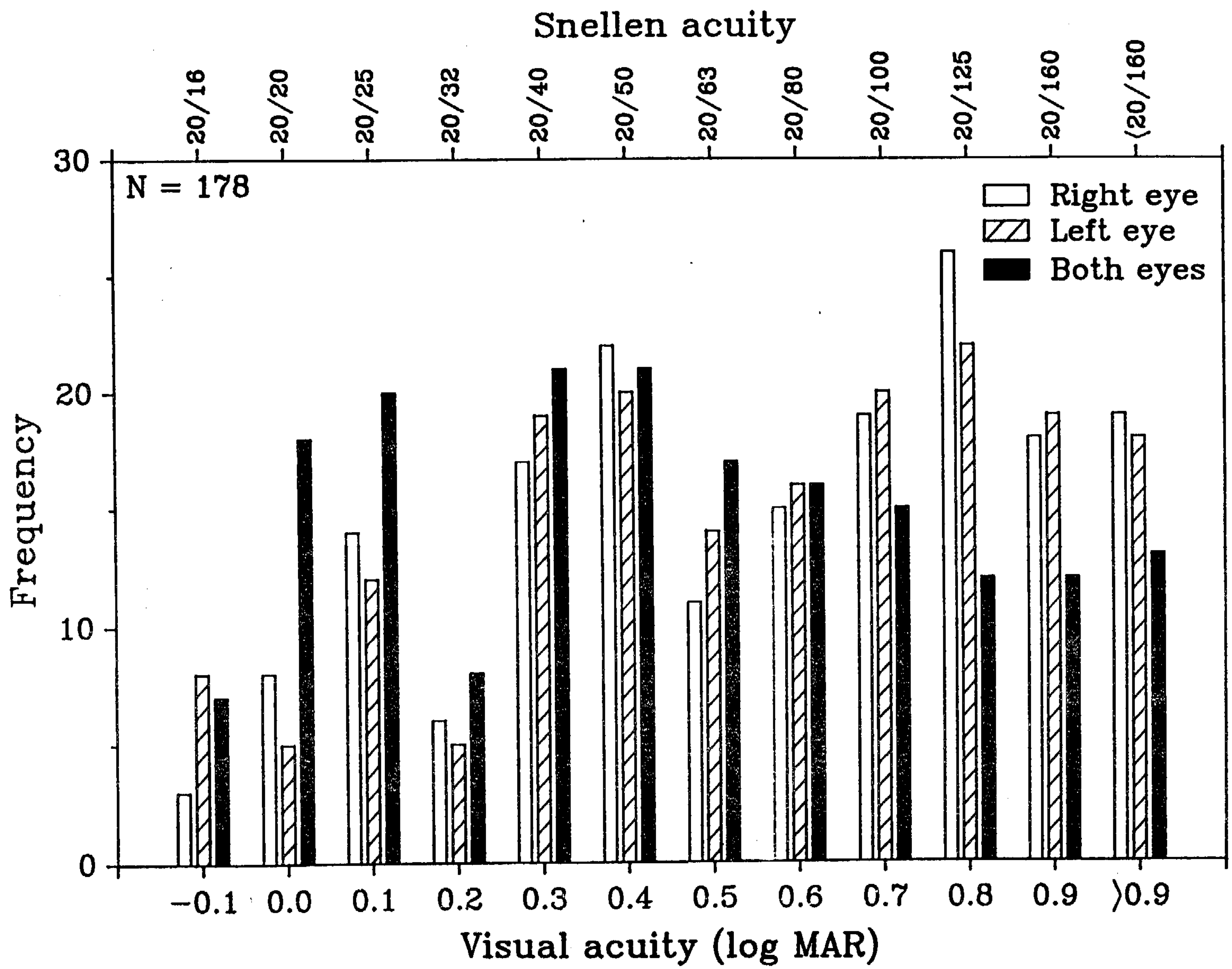

Figure 4. Uncorrected acuity of spectacle wearers.

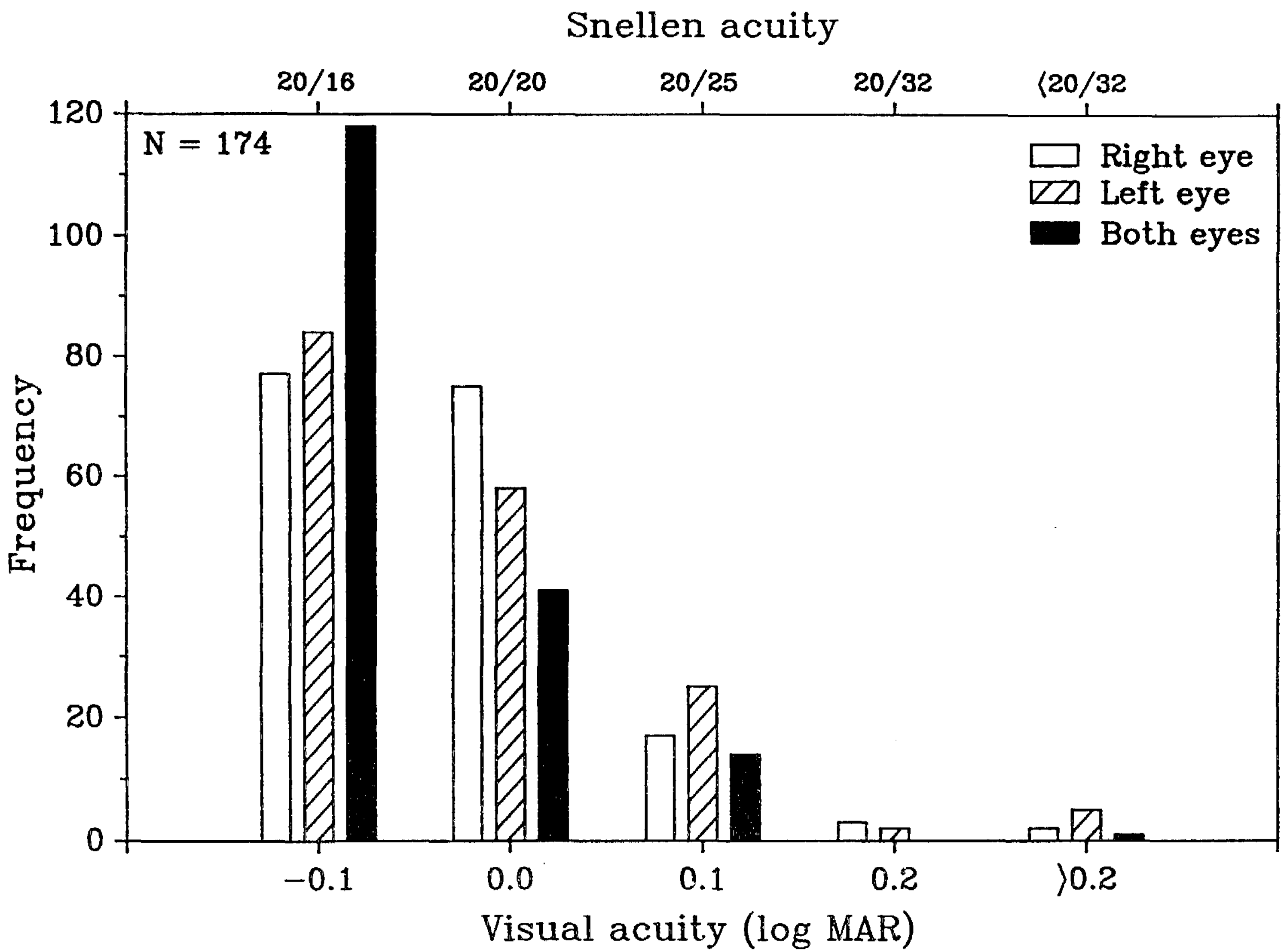

Figure 5. Corrected acuity of spectacle wearers.

case, a soft contact lens wearer's acuity fell outside the limits on all acuity measurements made during the survey. Thus, of the 828 participants, all but 1 met the acuity standard for 11B infantrymen.

Table 2.

Visual acuity of infantrymen

	Mean	Median	Mode	Range (minimum)
All participants (N=819) uncorrected acuity:				
Right eye	20/40	20/19	20/16	20/582
Left eye	20/39	20/18	20/16	20/800
Both eyes	20/32	20/16	20/16	20/582
Best acuity (N=724):				
Right eye	20/19	20/17	20/16	20/127
Left eye	20/19	20/16	20/16	20/94
Both eyes	20/17	20/16	20/16	20/48
Nonspectacle wearers (N=550) uncorrected acuity:				
Right eye	20/18	20/16	20/16	20/64
Left eye	20/18	20/16	20/16	20/48
Both eyes	20/17	20/16	20/16	20/48
Spectacle wearers:				
Uncorrected (N=178):				
Right eye	20/111	20/82	20/125	20/582
Left eye	20/107	20/80	20/125	20/800
Both eyes	20/83	20/51	20/100	20/582
Corrected (N=174):				
Right eye	20/19	20/18	20/16	20/127
Left eye	20/20	20/18	20/16	20/94
Both eyes	20/18	20/16	20/16	20/38

A number of the participants did not have their optical correction available during the testing. Table 3 and Figure 6 show the uncorrected acuity information for this group. Of these 85 trainees, 29 (34 percent) had binocular visual acuity worse than 20/20. Without their spectacles, 35 (41 percent) did not meet the minimum visual acuity requirement for 11B.

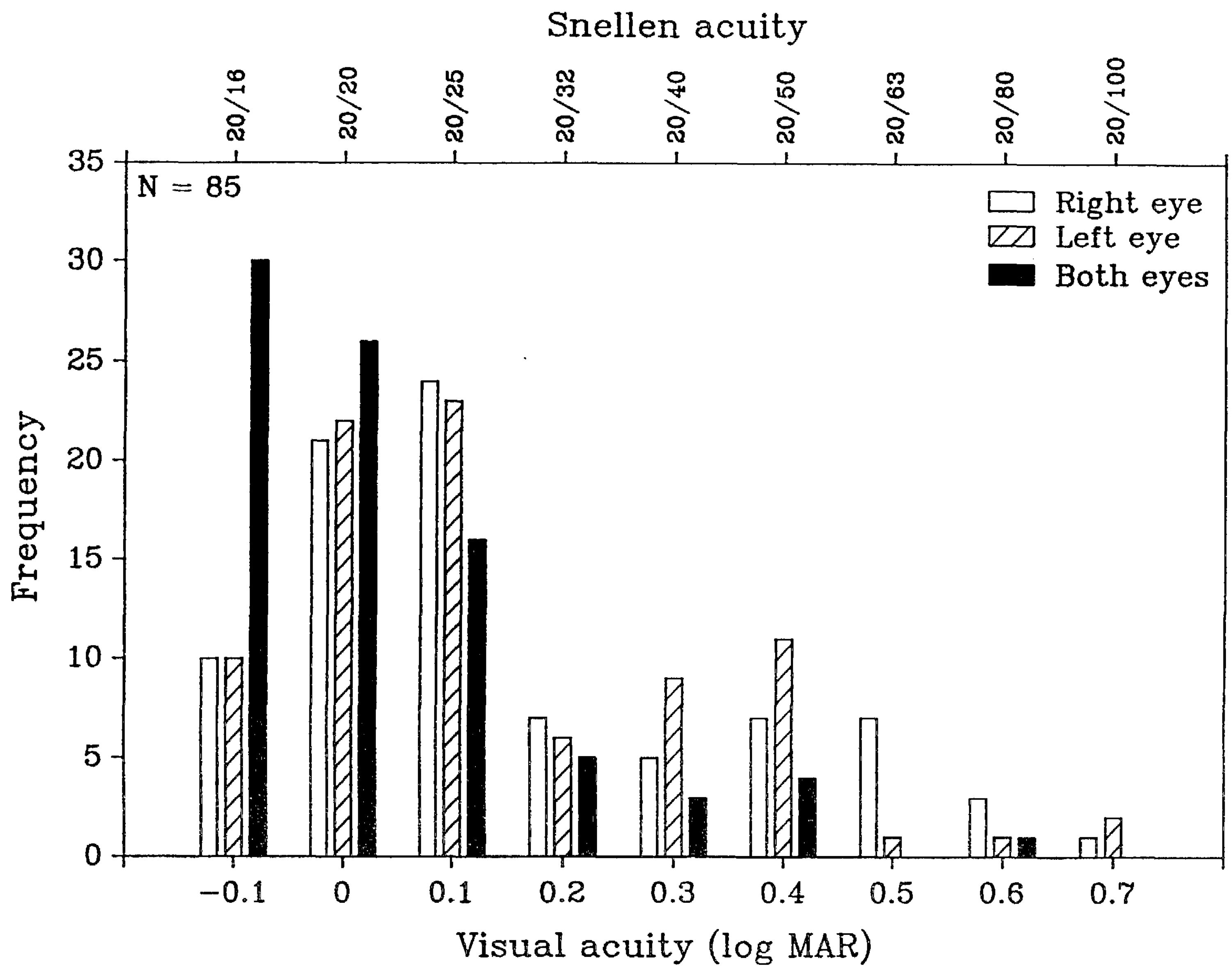

Figure 6. Uncorrected acuity of spectacle wearers without spectacles available.

Table 3.

Uncorrected acuity of infantrymen without spectacles (N=85)

	Mean	Median	Mode	Range (minimum)
Right eye	20/32	20/25	20/25	20/100
Left eye	20/30	20/23	20/25	20/100
Both eyes	20/23	20/20	20/16	20/89

Contact lens wearers

Another group of participants (N=7) was wearing contact lenses. This number is not an indication of the normal frequency of contact lens wear among this group to be expected following training. Most training companies tell enlistees not to wear their contact lenses during training. The rationale for this is based on the varying environmental conditions encountered, extended training hours, and lack of routine professional care. The visual correction provided by their contact lenses as a group appears adequate for their training (Table 4). Based on standard acuity and acuity from other testing, only one individual had a binocular acuity less than 20/20.

Table 4.

Corrected acuity of contact lens wearers (N=6)

	Mean	Median	Mode	Range (minimum)
Right eye	20/27	20/22	20/16	20/60
Left eye	20/35	20/17	20/16	20/125
Both eyes	20/18	20/17	20/16	20/23

Spectacle wear pattern

Of 273 spectacle wearers completing questionnaire responses, there were 119 (44 percent) full-time wearers and 154 (56 percent) part-time wearers (Table 5). Table 6 shows the usage of spectacles by part-time wearers.

Table 7 shows the uncorrected visual acuities for full-time vs. part-time spectacle wearers. These data demonstrate the relative need for constant visual correction by the full-time wearers. Figure 7 shows the distributions of uncorrected visual acuity for full-time (upper panel) and part-time (lower panel) spectacle wearers.

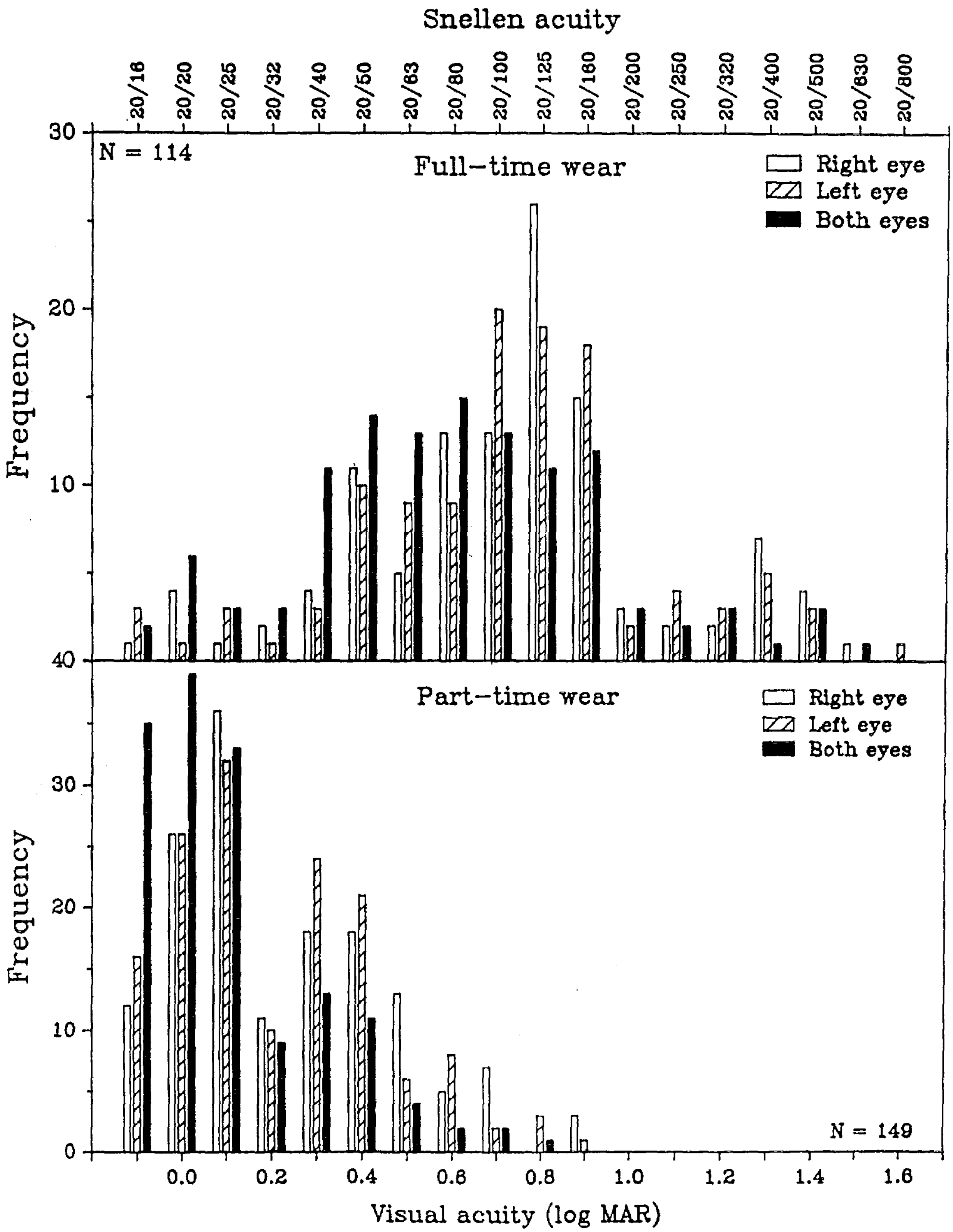

Figure 7. Uncorrected acuity of full-time spectacle wearers and of part-time spectacle wearers.

Table 5.

Spectacle wear pattern

Time worn	Freq (%)
Full-time spectacle wear	119 (44)
Part-time spectacle wear	154 (56)

Table 6.

Usage by part-time spectacle wearers

Activity	Response frequency
Reading	58
Day driving	33
Night driving	48
TV	31
Rifle range	61
Hunting	2
Distant viewing	9
Contact lenses out	2
Other	15
No response	14

Table 7.

Uncorrected visual acuity for full-time and part-time spectacle wearers

	Mean	Median	Mode	Range (minimum)
Full-time (N=114):				
Right eye	20/144	20/124	20/125	20/582
Left eye	20/141	20/104	20/160	20/800
Both eyes	20/109	20/80	20/100	20/582
Part-time (N=149):				
Right eye	20/40	20/29	20/25	20/160
Left eye	20/38	20/29	20/25	20/160
Both eyes	20/28	20/23	20/16	20/116

Among the part-time spectacle wearers, 103 (69 percent) would not meet the entry VA requirement for 11B without their spectacles.

Uncorrected visual acuity

Occasionally, questions arise concerning the capability of spectacle wearers to perform duties without their spectacles. This situation could arise when spectacles are damaged, lost, fogged, made unusable by rain, mud, etc., or are incompatible with equipment. Table 8 provides percentages of spectacle wearers who would meet progressive minimums which might be required to complete an acuity-limited task. The percentages are based on uncorrected visual acuity using a binocular viewing condition.

Table 8.

Percentages of spectacle wearers meeting progressive binocular acuity minimums

Uncorrected acuity limit (binocular)	Group with spectacles N=178 (in %)	Group without spectacles N=85 (in %)	Total N=263 (in %)
20/20	14.0	65.9	30.8
20/30	29.8	90.6	49.4
20/40	41.6	94.1	58.6
20/50	53.4	98.8	68.1
20/60	62.9	98.8	74.5
20/80	71.9	100.0	81.0
20/100	80.0		86.3
20/125	86.5		90.9
20/160	92.7		95.1

While there are no direct relationships between uncorrected visual acuity and many infantry tasks, there are tasks with an established minimum acuity level. For example, vehicle operator licensing requires a minimum VA. There are other tasks which have a limiting acuity established indirectly. For example, since night vision devices limit visual acuity, tasks that can be performed with these devices also could be performed by an individual with reduced acuity during the day.

To obtain a military driver's license, the requirement is binocular acuity of 20/40 (AR 611-125). Approximately 59 percent of spectacle wearers had sufficient acuity without spectacles to meet the licensing standard.

With the requirement for infantry to be able to fight at night comes the increased use of night vision goggles (NVGs). These electro-optical devices have limited resolution capabilities. The maximum visual acuity obtainable with NVGs is in the 20/50 to 20/60 range. The use of these devices to perform essential duties implies a minimum acuity level for tasks. Using 20/60 as limiting acuity, 75 percent of spectacle wearers can achieve this acuity without their spectacles. While the individuals may be effective in performing the tasks, the efficiency will be reduced, yet comparable to that obtainable with NVGs.

Monocular versus binocular acuity

The high cost of binocular optical and electro-optical devices makes monocular systems attractive. Since binocular acuity is usually better than monocular acuity, monocular optical systems reduce maximum obtainable acuity. Table 9 contains population percentages achieving specific "best visual acuity" levels for binocular and monocular viewing conditions. If a particular task required 20/16 visual acuity, although unlikely, about 75 percent of the best corrected population would be able to complete the task with a binocular system compared to about half with a monocular system. However, when the acuity requirement is decreased to a more realistic level (e.g., 20/30) the advantage of binocular over monocular is reduced greatly.

Table 9.

Population percentages meeting progressive acuity minimums (N=724)

Acuity	Binocular	Right eye	Left eye
20/16	75.5%	52.5%	56.4%
20/20	96.0%	89.9%	84.4%
20/25	99.7%	97.5%	97.8%
20/30	99.7%	98.2%	98.2%

Refractive error

The refractive error was determined objectively using the Humphrey autorefractor. The data, formatted in minus-cylinder notation, were measured to the nearest one-eighth diopter. Since the accuracy of objective data from automated instruments is a concern, a comparison between Humphrey data and the participants' spectacle prescriptions was made. The results, contained in Appendix B, show, on average, no difference in the spherical component and a 0.25 diopter difference in the cylindrical component. The autorefractor read more cylinder than subjectively was prescribed.

Refractive status of infantrymen

Table 10 contains the descriptive statistics of the objective refractive error components of infantrymen. Figures 8-11 show the frequency distributions for sphere power, cylinder power, type of astigmatism, and spherical equivalent, respectively.

Table 10.

Spherical and cylindrical refractive error components (diopters)

	N	Mean	Median	Mode	Range
Spherical component					
Right eye	826	-0.29	0.00	+0.25	-7.62 to +6.12
Left eye	826	-0.28	+0.12	+0.25	-7.50 to +8.00
Cylindrical component					
Right eye	828	0.56	0.50	0.50	0.00 to 6.62
Left eye	828	0.57	0.50	0.50	0.00 to 4.50
Spherical equivalent	1652	-0.56	-0.25	-0.25	-8.43 to +7.25

The spherical component of the refractive error ranged from 7.62 diopters of myopia to 8.00 diopters of hyperopia. The mean is slightly myopic. However, the skew of the distribution makes the median and mode more meaningful than the mean. The median is plano and the mode is hyperopic. There was no notable difference between the right and left eyes.

Two components describing the correction for astigmatism are the power and axis orientation. The cylinder power is the difference in power between the two major meridia of the lens. The orientation of astigmatism is the axis of the meridian with the greatest plus or weakest minus power. The cylindrical power component ranged from 0 to 6.62 diopters. The mean cylindrical

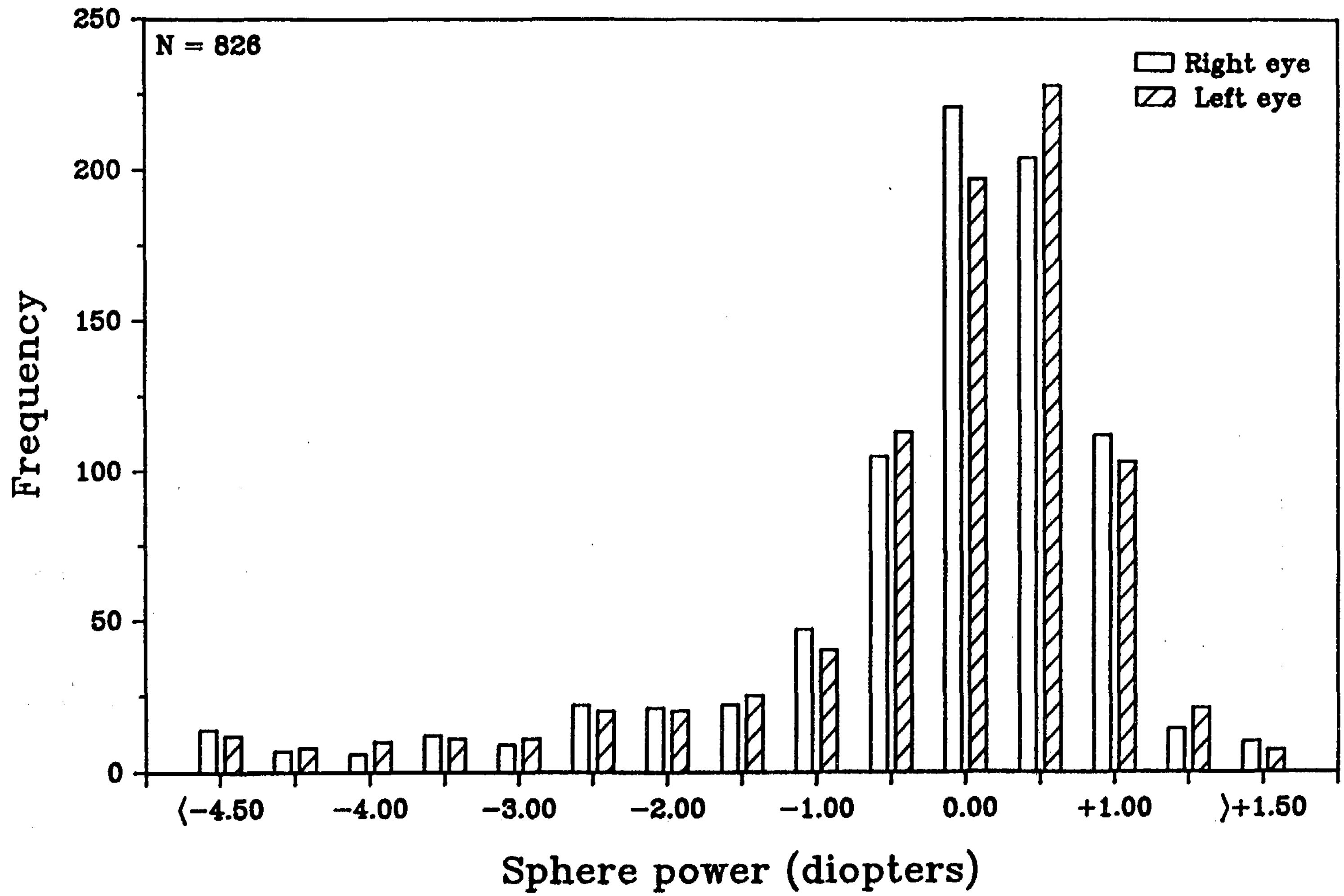

Figure 8. Distribution of refractive sphere power.

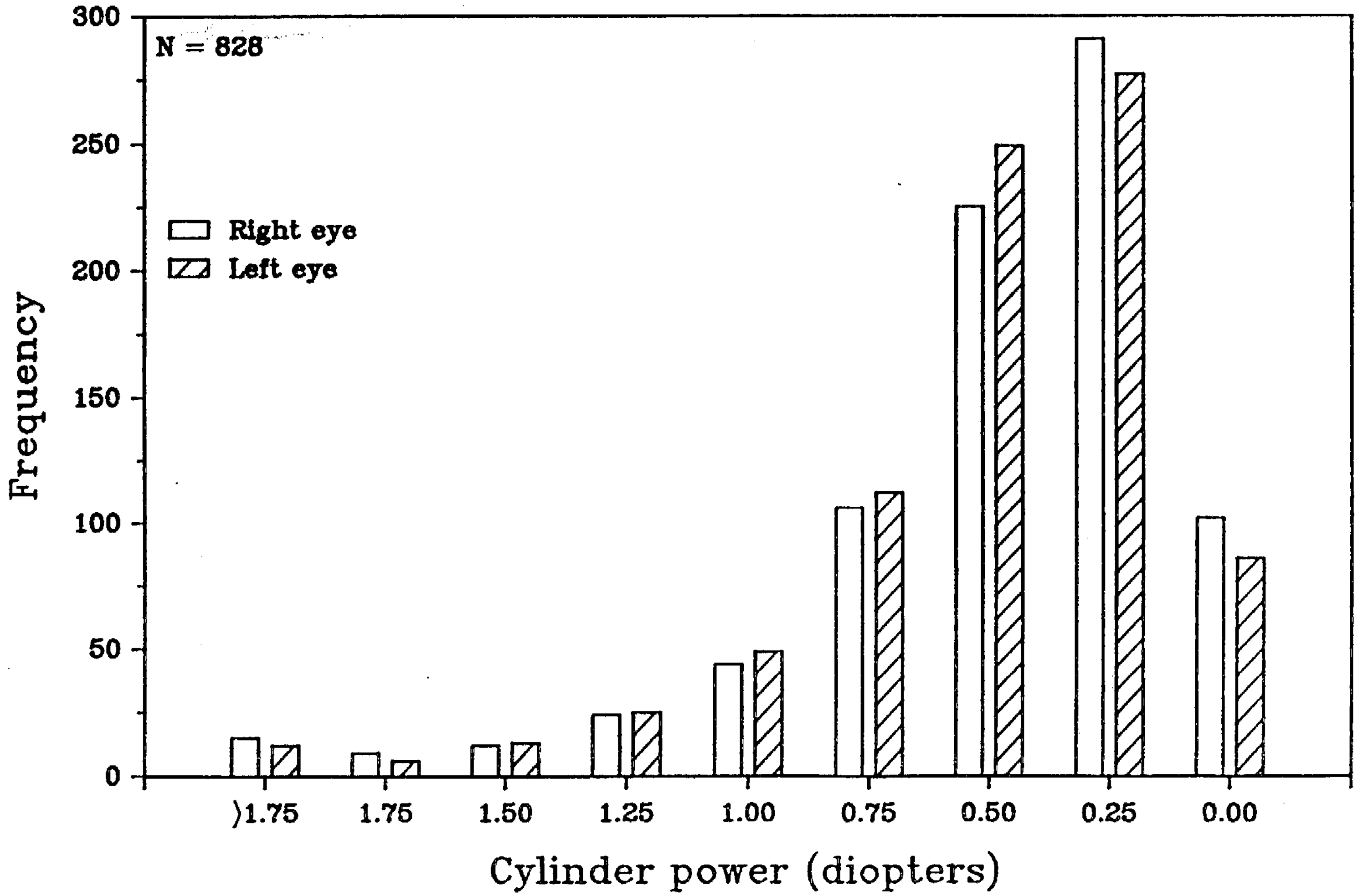

Figure 9. Distribution of refractive cylinder power.

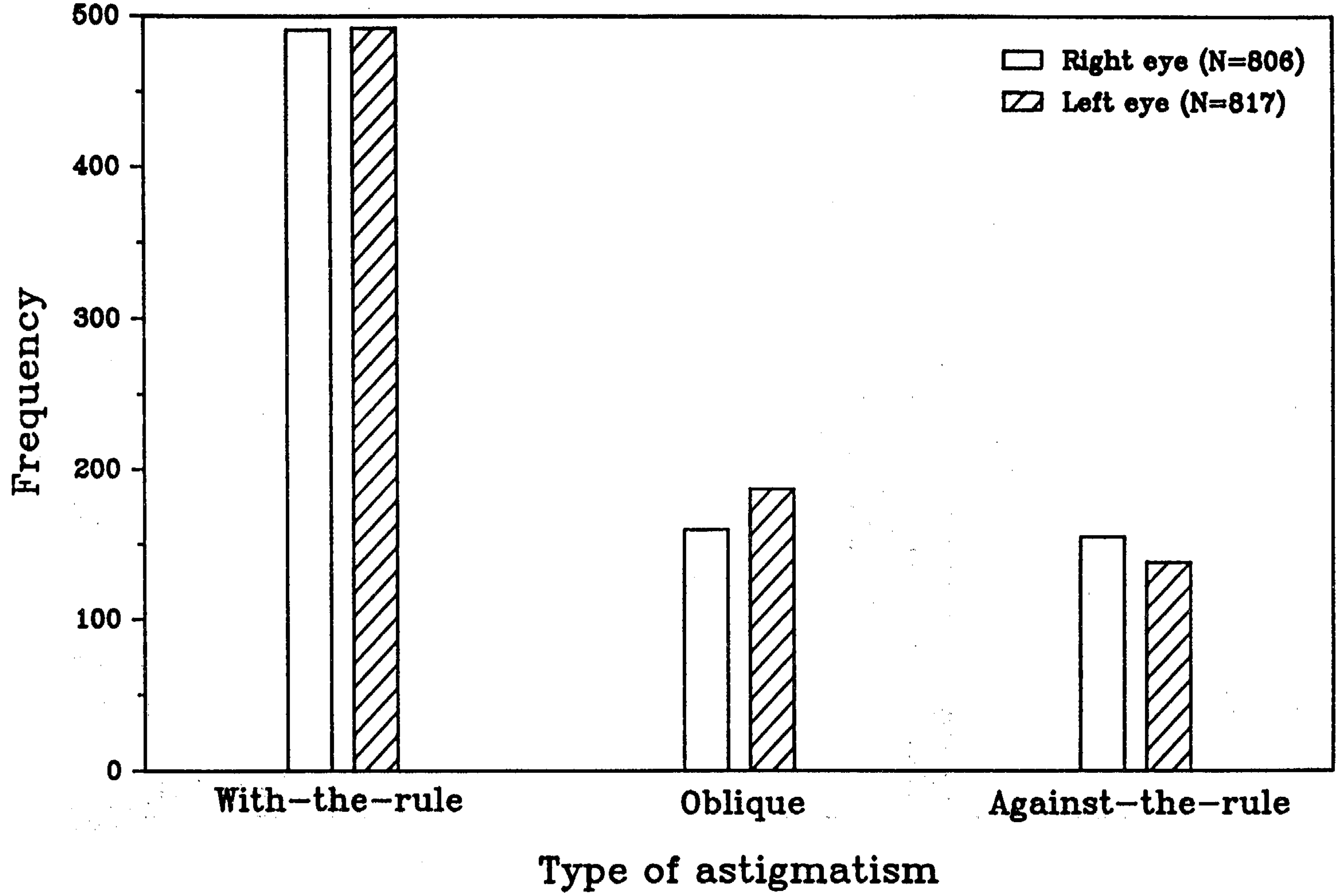

Figure 10. Distribution of astigmatism type.

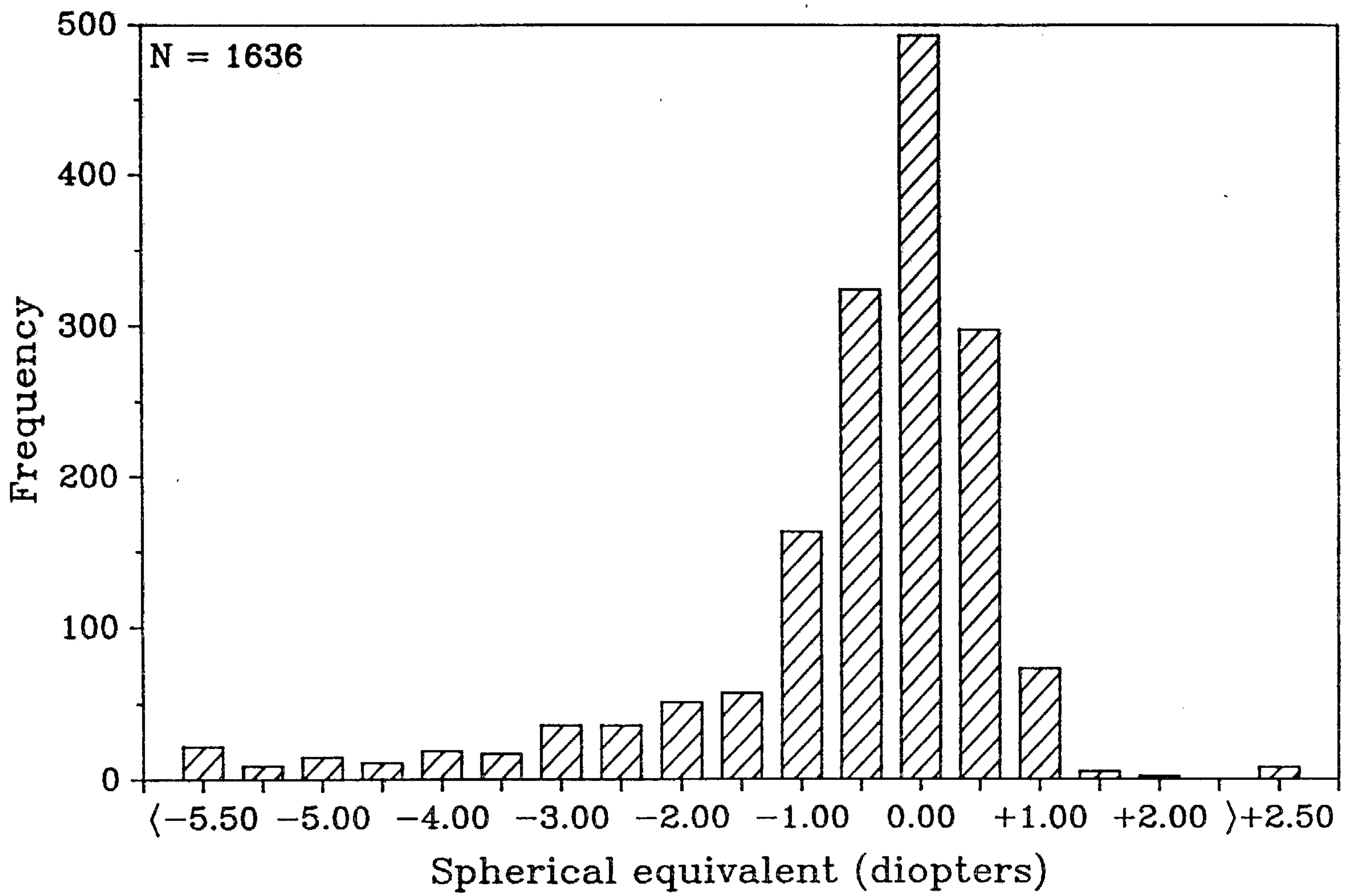

Figure 11. Distribution of spherical equivalents.

power was 0.56 diopters overall. The median and mode both show 0.50 diopters. Since the Humphrey data show 0.25 diopter more astigmatism when the autorefraction results are compared to spectacles (Appendix B), the cylinder power values in Table 10 probably provide a better indication of astigmatism when reduced by 0.25. There was no appreciable difference between the two eyes.

The axes of the astigmatism extend from 1 to 180 degrees. Based on axis orientation, the three broad categories of astigmatism are with-the-rule (W/R), oblique (OBL), and against-the-rule (A/R) (Table 11). The frequencies of the three types of astigmatism, Figure 10, show a predominance of W/R astigmatism. These data show a 3-to-1 ratio of W/R over either OBL or A/R. However, data from the Humphrey-spectacle comparison (Appendix B) indicate the Humphrey's accuracy in determining the axis of cylinder orientation is questionable.

Table 11.

Categories of astigmatism

Type	Axis orientations (degrees)
W/R	1 - 29 and 151 - 180
OBL	30 - 60 and 120 - 150
A/R	61 - 119

Table 10 also contains data for the spherical equivalent of refractive error. The spherical equivalent is a value derived by combining the spherical power with one-half the cylinder power. Vision standards for Army enlistment require a spherical equivalent of refractive error less than or equal to 8.00 diopters (AR 40-501). Based on the objective refraction, all but one participant met this requirement. The spherical equivalent of this participant's spectacles did meet the requirement. Figure 11 shows the distribution of spherical equivalents.

Nonspectacle wearers

Table 12 contains the descriptive statistics for nonspectacle wearers. Based on these refractive error data, about 30 percent of the eyes (N=1102) of nonspectacle wearers showed some myopia (-0.12 diopter or more). Of this group, 1/3 (N=108) demonstrated an increase in visual acuity when measured through the spectacle prescription determined by the autorefractor. Thus, about 10 percent of the 1102 eyes tested may not be fully corrected.

Table 12.

Objective refractive error of nonspectacle wearers (diopters)

	N	Mean	Median	Mode	Range
Spherical component					
Right eye	551	+0.19	+0.25	+0.25	-1.62 to +1.62
Left eye	551	+0.23	+0.25	+0.25	-1.87 to +2.37
Cylindrical component					
Right eye	535	-0.47	-0.37	-0.25	0.00 to -1.87
Left eye	542	-0.49	-0.50	-0.50	0.00 to -4.25

Spectacle wearers

The group of spectacle wearers includes individuals who consider themselves current spectacle wearers. Of the total population of 828, 273 (33 percent) were spectacle wearers, based on self-reported questionnaire responses. Comparing spherical error data for nonspectacle wearers (Table 12) and spectacle wearers (Table 13), central tendencies for the latter show a greater degree of myopia, as expected. However, for the cylindrical component, the spectacle wearers show only a slightly greater central tendency of astigmatism.

Table 13.

Objective refractive error of spectacle wearers (diopters)

	N	Mean	Median	Mode	Range
Spherical component					
Right eye	271	-1.27	-1.00	-0.75	-7.62 to +6.12
Left eye	271	-1.30	-1.00	-0.62	-7.50 to +8.00
Cylindrical component					
Right eye	268	-0.80	-0.50	-0.50	0.00 to -6.62
Left eye	271	-0.76	-0.62	-0.37	0.00 to -4.50

Classification of refractive error

Classifications of refractive error are somewhat arbitrary. In some studies, the power of the sphere is the determining factor. In others, visual acuity or spherical equivalent of refractive error is the key factor. Table 14 presents a classification based on the ranges of sphere powers and cylinder powers from autorefraction. The corresponding percentages of the population are listed. The selection of the classification range for astigmatism takes into account the tendency of the autorefractor to measure a greater degree and the practice of not prescribing for a minimum amount.

Table 14.

Classification and prevalence of refractive error types among infantrymen

Refractive status	Classification range	Prevalence (N=1638)
Myopia	< -0.12 D sphere	38.2%
Emmetropia	-0.12 to +0.37 D sphere	34.4%
Hyperopia	> +0.37 D sphere	27.4%
Astigmatism	≥ -0.75 D cylinder	17.0%

While most refractive error categorizations are based on the spherical and cylindrical components individually, there may be interest in the breakdown of the participant population by sphere and cylinder combination. Figure 12 shows the distribution of sphere and cylinder refractive error for three categories of cylindrical error. The three categories are 0.00 to 0.25, 0.50 to 0.75, and greater than 0.75 diopters of cylinder.

From these data, it appears strictly spherical refractions (0.00 to -0.25 diopters of cylinder on the autorefractor) are more likely to be found at emmetropia and low myopia. And, as refractive error increases beyond this range, the likelihood of more substantial amounts of astigmatism (over -0.75 diopters) is increased. These trends are more evident when data are converted to percentages for each category (Table 15 and Figure 13). This has an implication for the development of optical devices which provide a means to correct refractive error, e.g., night vision goggles. Unless the adjustment range is very narrow, the system will have to be compatible with spectacles or suffer losses in visual performance due to uncorrected astigmatism.

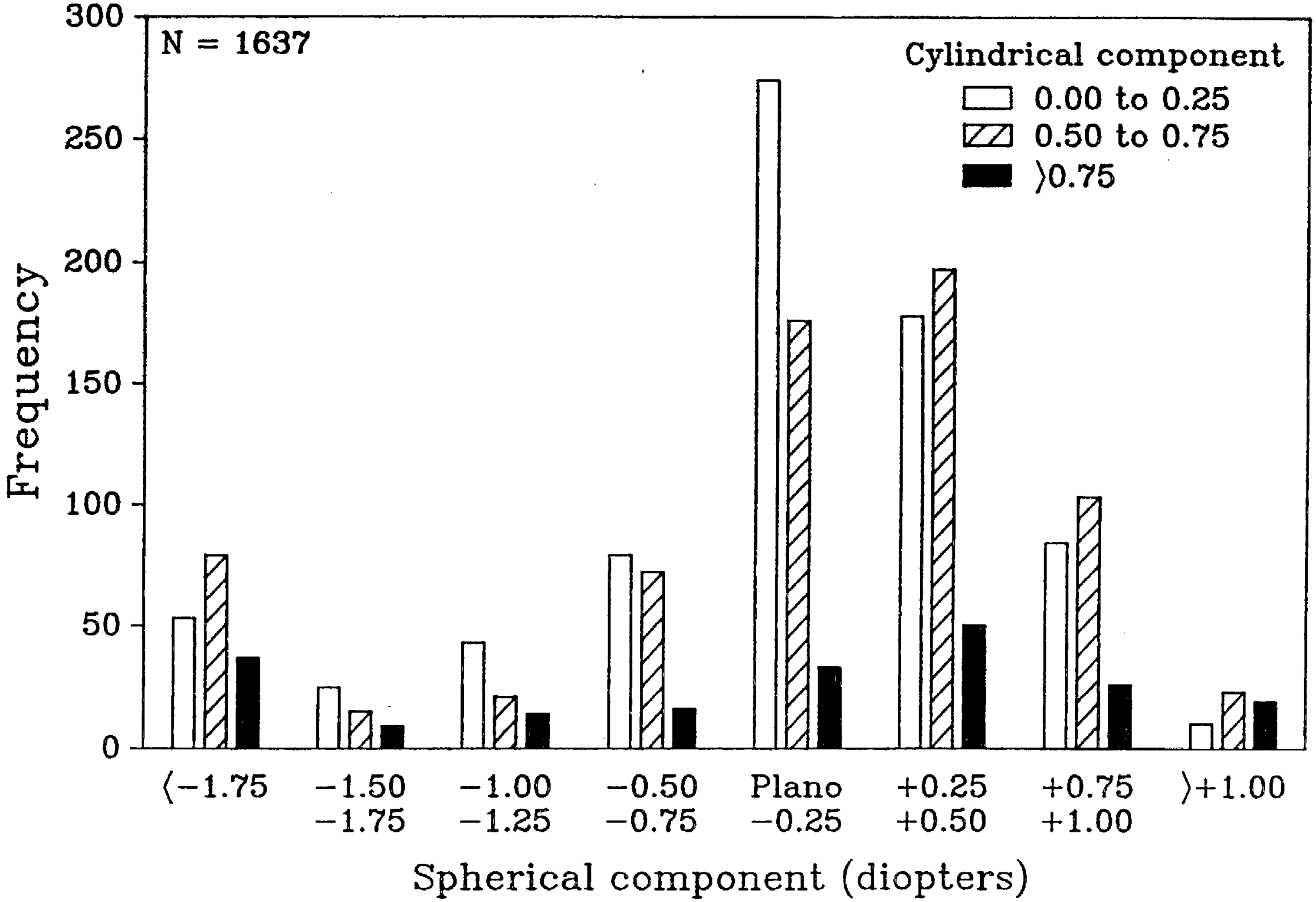

Figure 12. Distribution of cylindrical components across refractive error categories.

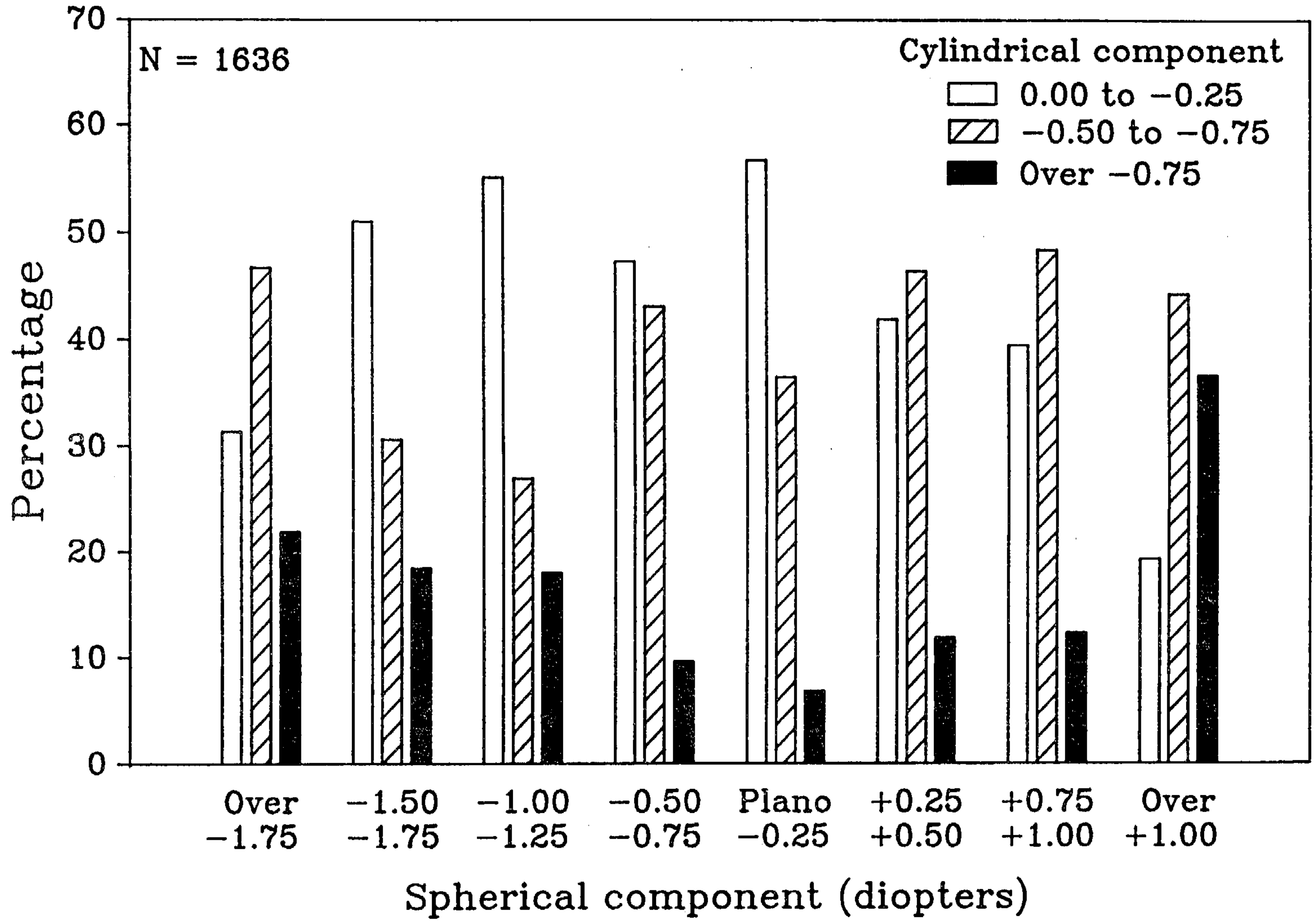

Figure 13. Relative distribution of cylindrical components across refractive error categories.

Table 15.

Percentages of refractive errors by sphere and cylinder (N=1636)

Sphere range	Cylinder range 0.00-0.25 D	0.50-0.75 D	>0.75 D	Totals
>+1.00	0.6	1.4	1.2	3.2
+0.75 to +1.00	5.1	6.3	1.6	13.0
+0.25 to +0.50	10.9	12.0	3.1	26.0
Plano to -0.25	16.7	10.8	2.0	29.5
-0.50 to -0.75	4.8	4.4	1.0	10.2
-1.00 to -1.25	2.6	1.3	0.9	4.8
-1.50 to -1.75	1.5	0.9	0.6	3.0
<-1.75	3.2	4.8	2.3	10.3
Totals	45.4	41.9	12.7	100.0

<u>Spherical equivalent percentiles</u>

Certain optical devices incorporate user-adjustable eyepieces which correct spherical refractive error because the devices prohibit spectacle wear. An example is the AN/PVS-5 series night vision goggles (NVGs). The NVGs use eyepieces which correct from -6.00 to +2.00 diopters. Since the eyepieces cannot correct for astigmatism, the spherical equivalent is the most appropriate measure of refractive error. Figure 11 shows the distribution of spherical equivalents and Table 16 lists the percentile breakdown. The range of adjustment of the NVGs eyepieces, for example, would correct the range of spherical equivalents for about 99 percent of the eyes of the population tested.

Table 16.

Spherical equivalent percentiles (N=1636)

Percentile	Refractive error
1	-7.00 D
5	-3.87 D
25	-0.87 D
50	-0.25 D
75	+0.25 D
95	+0.75 D
99	+1.12 D

Contact lens wearers

Since the field screening site did not have adequate facilities for contact lens care, contact lens wearers did not remove their lenses for any of the tests. An over-refraction produced the only refractive error data obtained. This is a refraction of the individual with contact lenses in place. The data from this measurement, Table 17, provide some information regarding the adequacy of the contact lenses to correct the refractive error. Ideally, the values for the spherical and cylindrical components should be plano or 0.00 diopters. This would show the contact lenses correct all the refractive error.

Table 17.

Objective over-refraction of contact lens wearers (diopters)

	N	Mean	Median	Range
Spherical component				
Right eye	6	+0.29	+0.50	-0.50 to +0.75
Left eye	6	+0.31	+0.31	-0.25 to +0.75
Cylindrical component				
Right eye	6	0.56	0.56	-0.12 to -1.00
Left eye	6	0.40	0.37	-0.25 to -0.50

Data for only six of the seven participants are presented in the table. The data for the remaining individual were questionable. For this individual, the autorefractor cylindrical component was over 2.00 diopters in each eye. In the right eye, both pre- and postrefraction acuity was 20/40, while in the left eye, the acuity improved from 20/200 to 20/80.

Before considering the implications of these data, two assumptions must be made. First, the contact lenses are correcting myopia. Second, the data provide a true picture of the refractive status. Based on these assumptions, there is a tendency for the contact lenses to overcorrect the spherical error and undercorrect the astigmatism. Both these findings are frequently encountered (Grosvenor, 1972).

Table 18 contains means and ranges for the spherical equivalent of the contact lens over-refractions. These data indicate that, on average, the contact lens correction is most appropriate for the residual astigmatism demonstrated.

Table 18.

Spherical equivalent of contact lens over-refraction (diopters)

	N	Mean	Range
Right eye	6	-0.01	-0.69 to +0.57
Left eye	6	-0.11	-0.44 to +0.50

Based on responses from the questionnaire, 76 (9.4 percent) of the trainees have worn contact lenses. Of these 31 (3.7 percent) consider themselves current contact lens wearers. Table 19 lists the types of contact lenses worn and Table 20 categorizes the current wearers as either part-time wearers (less than 6 hours a day) or full-time wearers (at least 6 hours daily). Table 21 provides a breakdown of the times the contact lenses are worn by the part-time wearers.

Table 19.

Types of contact lenses worn (N=76)

	Hard	Rigid gas permeable	Soft daily wear	Soft extended wear
Previous wearers	6	2	26	11
Current wearers	2	2	23	4

Table 20.

Contact lens wearing time

Daily wear	Number of Responses
Less than 6 hours	7
At least 6 hours	24

Table 21.

Part-time wearing of contact lenses

Responses	Number of Responses
Evenings and weekends	2
Weekends	2
Once a month	1
In spare time	1

Interpupillary Distance (IPD)

An important part of any spectacle prescription is the IPD of the individual. The distance between the optical centers of lenses in a spectacle frame, i.e., spectacle IPD, must correspond to the distance between the wearer's eyes. This assures that the optical centers of the lenses correspond with the visual axes of the eyes. The conventional unit of measure for IPDs is millimeters (mm).

The accuracy of measured IPDs depends on the method used. The Silor pupillometer* measures IPDs based on the location of the corneal reflection. The corneal reflection falls along the pupillary axis. Since the corneal reflection is not coincident with the visual axis of the eye, a slight discrepancy will result. The angular difference (angle lambda) between the pupillary and visual axes at the entrance pupil of the eye is about 1.6 degrees (Brooks and Borish, 1979). The IPD measured with a corneal reflection pupillometer is 0.92 mm less than an IPD measured along the visual axes. This report contains corrected IPD measurements, i.e., IPDs increased by 0.92 mm and monocular PDs increased by 0.46 mm.

Distant and near IPD

The IPD changes depending on the viewing distance. As an object moves closer, the eyes turn inward and the IPD decreases. Two commonly used measurements are the distant IPD and the near IPD. For the distant IPD, the eyes view objects at or beyond 20 feet, i.e., optical infinity. For the near IPD, the eyes view objects located at 16 inches. This distance corresponds to normal reading distance. Bifocal spectacles have the reading portion of the lens aligned using the near IPD.

Table 22 shows central tendencies for distant and near IPD measurements and the differences between measurements for an individual. Figure 14 displays the distribution of distant IPD measurements.

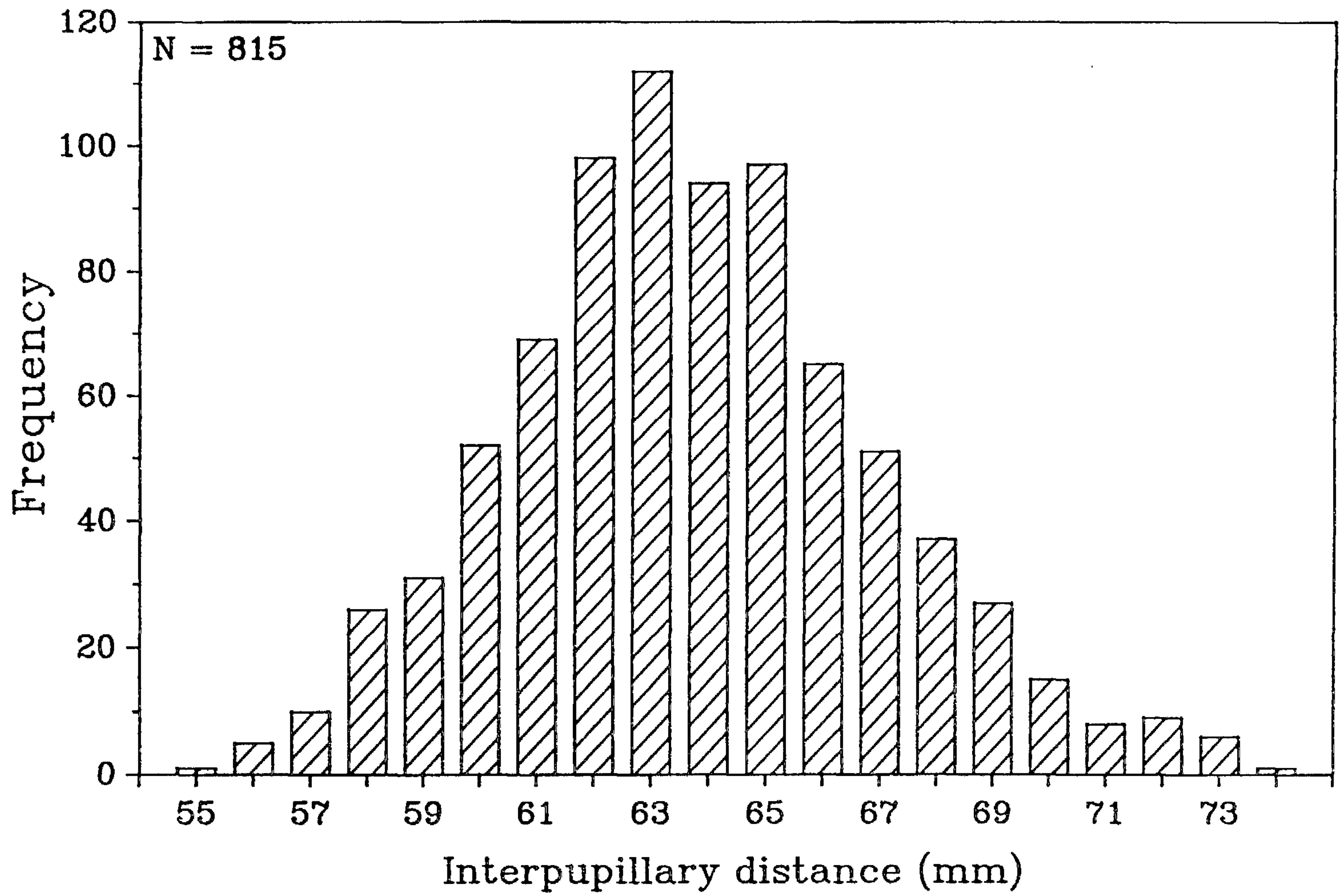

Figure 14. Distribution of distant interpupillary distances.

Table 22.

Distant and near IPD (mm) of infantrymen (N=815)

	Mean	Standard deviation	Median	Mode	Range
Distant IPD	63.7	3.27	64	63	55 - 74
Near IPD	59.1	3.04	59	58	53 - 70
Difference	4.6	0.76	5	5	2 - 7

There are many methods used to determine the near IPD. These range from the more sophisticated pupillometers to measurement with a millimeter ruler while the individual fixates a near target to the use of rules-of-thumb. One common method is the use of rules-of-thumb to determine the near IPD from the measured distant IPD. From the distant IPD, subtract 3 millimeters for midrange distant IPDs. Midrange is subjectively defined. For narrow IPDs, subtract 2 millimeters. Finally, for very wide distant IPDs, subtract 4 millimeters.

The central tendencies for differences between distant and near IPDs are contained in Table 22 and the distribution is shown in Figure 15. Based on this information, the rule-of-thumb's standard 3-millimeter difference becomes questionable. A probable reason for the discrepancy may be the use of the millimeter rule in developing the rules-of-thumb. Inherent measurement errors plague this method of measuring IPDs (Brooks and Borish, 1979).

Table 23 contains IPD differences for selected ranges of IPDs. While there is a slight tendency for the difference between distant and near IPDs to increase as the distant IPD increases, the trend found in this survey was not large.

Table 23.

Distant vs. near IPD differences (mm) for various IPD ranges

Distant IPD (mm)	N	Mean	Standard deviation	Median	Mode	Difference range
< 59	42	3.57	0.63	5	5	2 - 5
59 - 63	362	4.49	0.68	5	5	2 - 6
64 - 68	345	4.74	0.74	5	5	2 - 6
> 68	66	5.07	0.73	5	5	3 - 7

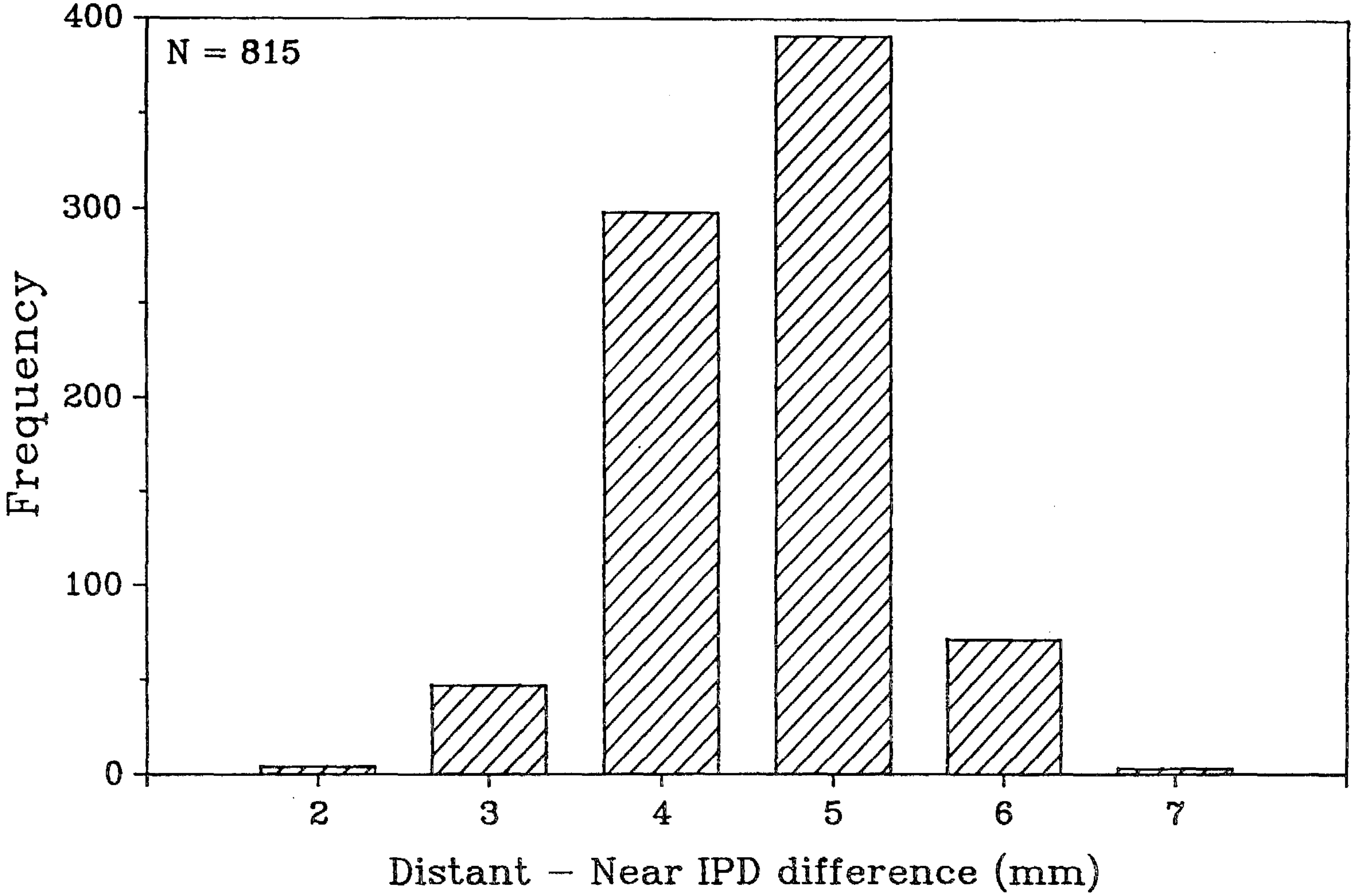

Figure 15. Differences between distant and near interpupillary distances.

Monocular pupillary distances

There normally is little attention paid to the asymmetry of eye position. Most binocular and biocular optical devices have symmetrical IPD adjustments. The control knob moves both eyepieces either inward or outward an equal amount. In a more common application, there normally is a symmetrical placement of spectacle lenses in the frames. This assumes symmetrical placement of the eyes relative to the bridge of the nose. Manufacturers of sophisticated variable focus lenses, e.g., invisible bifocals, have found that the eye position asymmetries are important. For successful fitting of their lenses, they recommend use of monocular PDs for mounting lenses in the spectacle frames.

The monocular pupillary distances (monocular PDs) were measured with the pupillometer while the eyes fixated a distant target. This device fits the bridge of the nose as would a spectacle frame. Table 24 shows the statistics for right and left monocular PD measurements and the absolute value of the differences between participants' monocular PD measurements. Figures 16 and 17 show the distribution of monocular PDs and the differences, respectively. Table 25 lists the frequencies of the differences. For about 10 percent of the population tested, there is a greater than 2 mm asymmetry. For high lens power optical systems, reduction in visual acuity and visual discomfort can occur when the visual axes of the eyes do not coincide with the axes of an optical system. This situation, however, is likely to occur only when the optical system is centered either on the nose or face. Spectacles are an example of a system centered on the nose, and night vision goggles are an example of a device centered on the head or face. The IPD adjustments of most NVGs are symmetrical.

Table 24.

Monocular PDs (mm) of infantrymen (N=814)

	Mean	Standard deviation	Median	Mode	Range
Right eye	31.8	1.78	31.5	31.5	26.5 - 38.5
Left eye	31.8	1.84	31.5	32.5	26.5 - 38.5
Difference	1.1	1.05	1	1	0 - 7

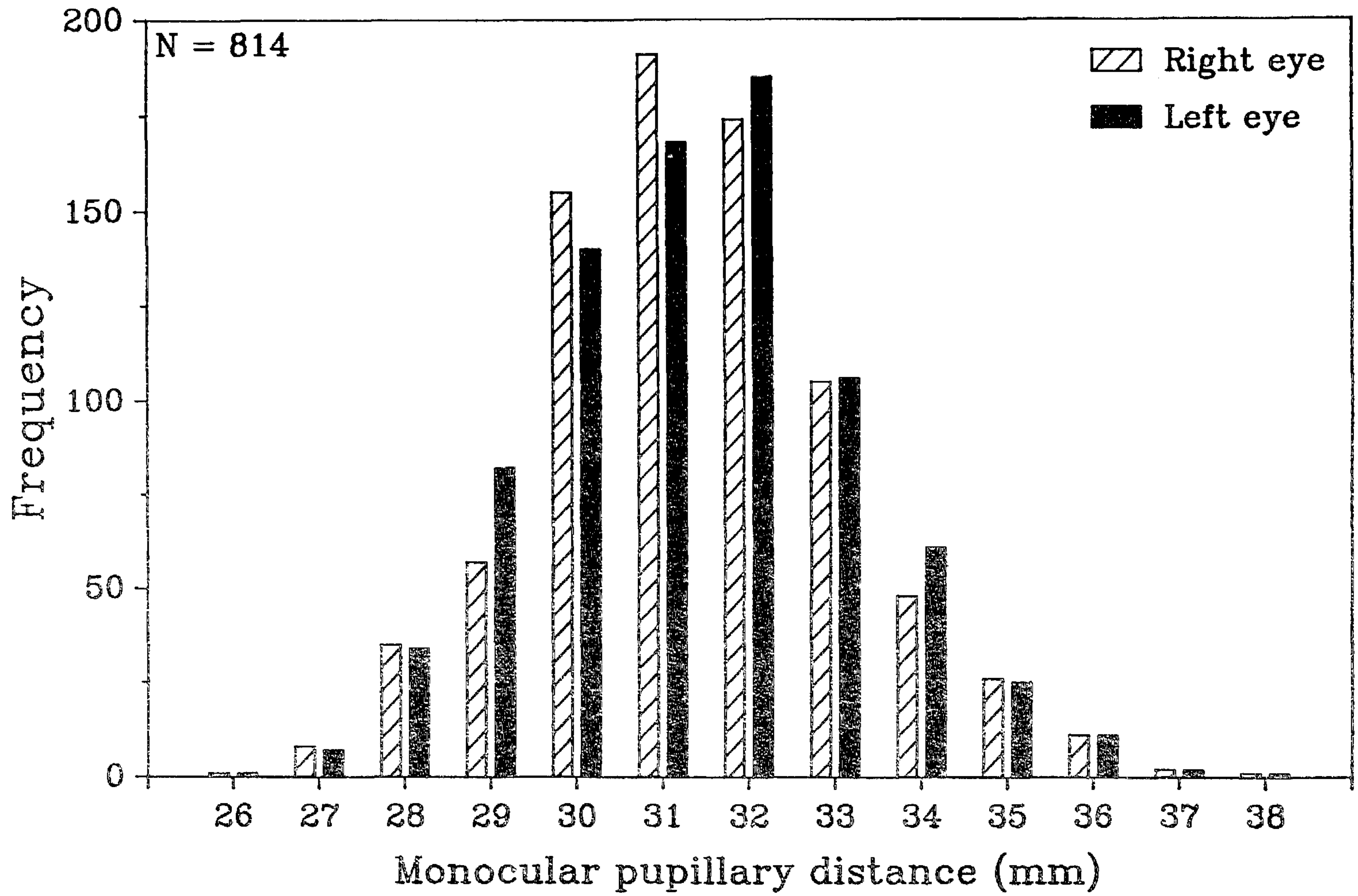

Figure 16. Monocular pupillary distances.

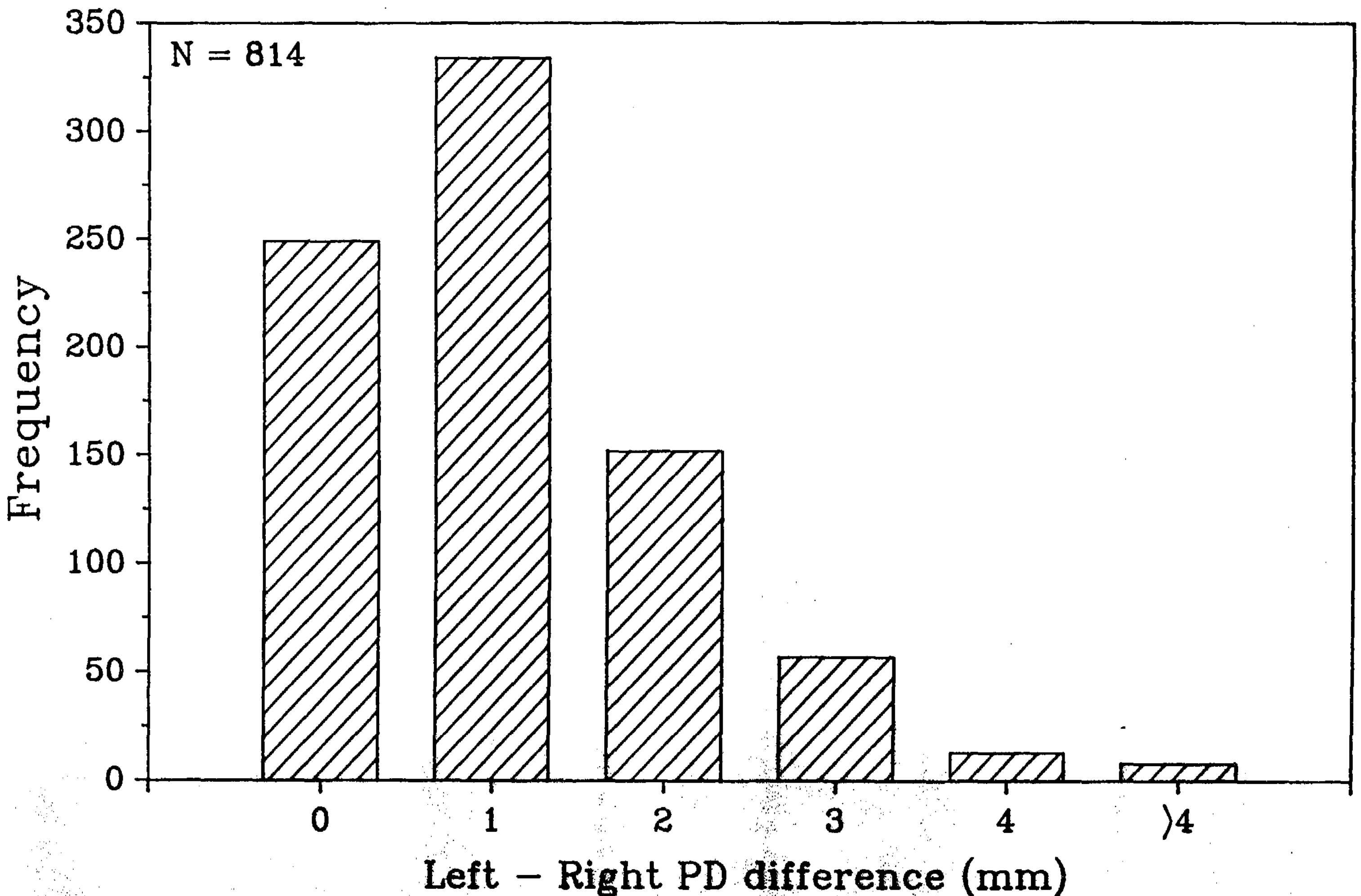

Figure 17. Differences between left and right monocular pupillary distances.

Table 25.

Distribution of monocular PD differences (left vs. right eye)

Difference (mm)	Frequency	Percent
0	250	30.7
1	334	41.0
2	152	18.7
>2	78	9.6

<u>Spectacle IPD</u>

Spectacle IPD, the distance between optical centers of the lenses mounted in spectacle frames, was measured on the Humphrey autolensometer. As mentioned above, it is important for the individual's IPD to match the spectacle IPD. This is necessary to achieve comfort and avoid inducing unnecessary lateral prism in the prescription. Table 26 provides statistics for IPDs of the spectacle wearers, the spectacle IPDs, and differences (absolute values) between the two measures. Figure 18 shows the distribution of differences. The median difference between the two measurements is 2 mm. Ideally, there should be no difference. Table 27 contains frequencies and percentages of IPD differences. About 34 percent had greater than 2 mm differences.

Table 26.

IPDs (mm) of spectacle wearers and their spectacles (N=176)

	Mean	Standard deviation	Median	Mode	Range
Spectacle wearers	63.7	2.79	63	63	57 - 73
Spectacles	63.2	3.15	63	64	55 - 72
Differences	2.0	1.63	2	1	0 - 10

The one individual with a 10 mm IPD difference was probably an accommodative esotrope. This five-plus diopter hyperope demonstrated left-eye amblyopia, 4 prism diopters of esophoria, and suppression on depth perception testing. In this case, the spectacle IPD was 56 mm while the individual's IPD measured 66 mm with the pupillometer. Assuming there was no error in the

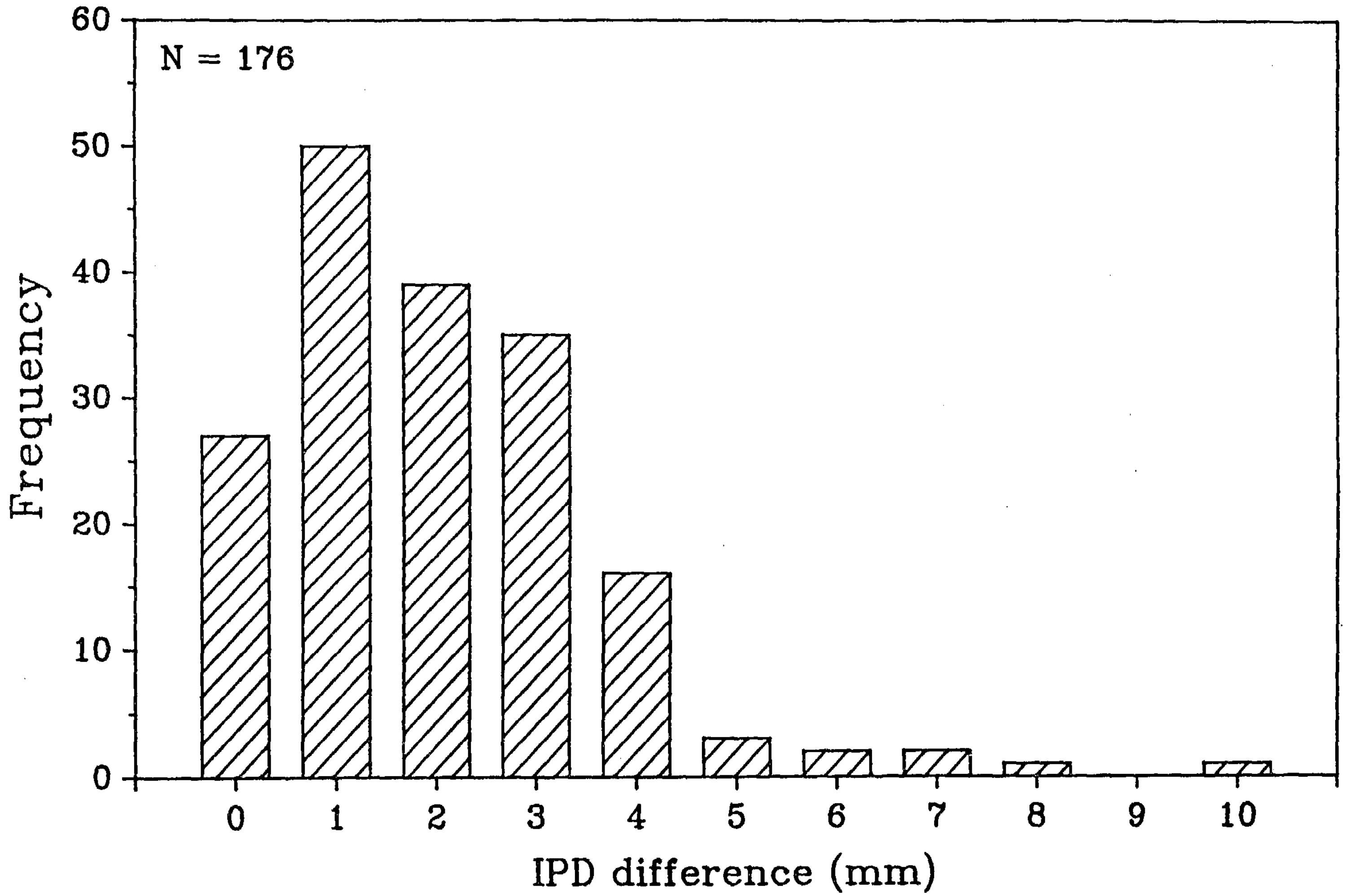

Figure 18. Differences between individual IPDs and spectacle IPDs.

written prescription and the spectacles were made correctly, it is likely that the IPD was measured with a ruler while the individual was not wearing the spectacles. The near point fixation required by the measurement would have induced accommodative convergence and narrowed the IPD.

Table 27.

Distribution of IPD differences between spectacle wearers and their spectacles

Difference(mm)	Frequency	Percent
0	27	15.3
1	50	28.4
2	39	22.2
3	35	19.9
>3	25	14.2

American National Standard Z80.1 for prescription spectacle lenses limits horizontal prism to one-third prism diopter for each lens or two-thirds prism diopter imbalance. The latter value represents the algebraic sum of the induced prism in each lens. While these standards apply to the deviation of spectacles from the spectacle prescription, the basis lies in the effect of the exceeded limits on the wearer. Considering only the group with greater than 2 mm difference (34 percent of spectacle wearers), Table 28 provides means and ranges of horizontal prism (in prism diopters) induced by the mismatch of spectacle lenses to these individuals. The means for monocular and binocular conditions match the Z80.1 standard. Greater than 30 percent exceed the standard. Of those participants with a 3 mm or larger IPD difference, greater than 50 percent exceeded the induced horizontal prism limit.

Table 28.

Horizontal prism (prism diopters) induced by IPD misalignment (N=59)

	Mean	Median	Range
Monocular mismatch			
Right eye	0.34	0.19	0.00 to 1.02
Left eye	0.33	0.19	0.00 to 1.05
Binocular imbalance	0.67	0.36	0.00 to 2.05

Anthropometric considerations

Because of its role in the alignment with optical devices, the IPD is an important anthropometric measurement. All binocular and biocular optical devices must have an IPD adjustment to fit a large percentage of the population of users. The National Aeronautics and Space Administration's Anthropometric source book (1978) contains the range of IPDs required for Army optical systems. A 1966 survey of 6682 male Army personnel is the source of these data. The population measured included basic trainees (39 percent), infantry (51 percent), armor personnel (7 percent), and aviation personnel (2 percent). Before using anthropometric data for development purposes, one must answer at least two questions. Are the data current? Are the data representative of the population which will use the device?

Anthropometric population parameters change over time. As individuals grow in stature, over generations, there will be accompanying increases in head and facial dimensions. However, since the IPD is small compared to other body dimensions, changes are likely to be small. If a measurable change occurs, the expected direction would be toward larger IPDs.

Half of the 1966 survey population served in noninfantry specialties. The results from the present study may be more appropriate for a strictly infantry population. Thus, an optical device developed for use by infantrymen exclusively may need a different range of IPD adjustment than indicated in the 1978 Anthropometric source book, to avoid design features resulting in compatibility problems.

Table 29 presents two sets of IPD measurements, broken down by percentile. The 1966 study measurements are those found in the Anthropometric source book. Based on the means, the infantrymen (1986) have slightly larger IPDs. Another feature is the narrower range for infantrymen.

Table 29.

Interpupillary distances (mm) by percentile for Army soldiers and infantrymen

Population		N	Mean	SD	Percentile 1	5	25	50	75	95	99
Soldiers	(1966)	6682	61.3	4.0	52	55	59	61	64	68	71
Infantrymen	(1986)	815	63.7	3.3	57	58	62	64	66	69	72

One application of this information is the range of adjustment of NVGs. The eyespan adjustment range for one device is 55-72 mm. Only seven infantrymen (less than 1 percent) fell outside this range, all seven being on the high end of the range. New developments should consider extending the upper limit of adjustment.

Visual Skills

Color vision

The PIP test used for this study was a 14 plate Ishihara test. The set in this study consists of a demonstration plate, 10 screening plates, and 3 diagnostic plates. The figures on these plates consist of single and double digit numerals or winding paths which must be traced. The three diagnostic plates were not used in evaluating the results of this test.

By design, administering and scoring this series of plates requires an extra step for one of the plates. On plate 9, the numeral "2" can be read by both color defectives and color normals. The scoring key indicates that color normals do not see a number on this plate. Under normal testing procedures, if the number "2" is read, this plate would be marked wrong. For this plate, however, the test administrator must determine whether the observer can read the plate 9 numeral easier than the numeral on plate 8. If this is the case, plate 9 is marked wrong.

The assessment of the results for defective color vision is not clear cut. While successfully reading at least 10 of the first 11 plates indicates normal color vision, reading less than 10 plates does not indicate deficient color vision. For this test, color vision is considered deficient if only seven or fewer plates are read correctly. The scoring instructions state that it is rare to find scores of eight or nine correct. For these cases, additional assessment is required. The recommendation is for other color vision tests including the anomaloscope.

Evaluation of the color vision of the survey population depends on both the testing/scoring methods and selection of the criteria used to categorize the resulting scores. In the military community, this test would be used as a quick screening device to identify color defectives. In keeping with the instructions for other PIP tests, e.g., Dvorine pseudo-isochromatic plates (1963), no special instructions were given regarding the scoring of plate 9. The expected result of this deviation is an increase in the number of errors on plate 9. Such an increase will push many color normals into the hazy area of nine plates read normally. Only a portion of those "rare" cases of eight correct would be pushed into the color defective category. These should not significantly affect the overall population percentages, if the 7-plate cutoff is used to identify color defectives.

The distribution of normally read color plates is shown in Figure 19. Using the 7 correct responses criterion, 62 (7.5 percent) of the population (N=828) failed the test. This is consistent with the eight percent of males in the general population reported to have color deficiencies (Borish, 1970). The percentages for those with 8 and 9 correct were 0.4 percent and 3.4 percent, respectively. Thus, using a 10 plate correct criterion would result in a larger number of failures - 11.3 percent. The larger percentage of individuals with nine correct responses was expected.

Phoria

The AFVT phoria test measures the tendency of the eyes to turn outward (exophoria) or inward (esophoria) while fixating an object at optical infinity. Figure 20 shows the distribution of the distant lateral phorias of infantrymen. Table 30 contains the central tendencies for the total population surveyed and two subpopulations. Although the mean and range are skewed toward esophoria, the population essentially is orthophoric. About 75 percent of the population falls at or within 1 prism diopter of orthophoria and about 93 percent at or within 2 prism diopters. Comparing the best corrected group with the uncorrected group of spectacle wearers revealed no significant differences.

Table 30.

Distant lateral phoria (prism diopters)

	N	Mean	Median	Mode	Range
Total population	826	0.2 es	0.0	0.0	11 es - 8 xo
Best corrected	734	0.2 es	0.0	0.0	11 es - 8 xo
Uncorrected	85	0.0	0.0	0.0	9 es - 4 xo

There are few standards against which the infantry population can be compared. The only military occupational specialties with a phoria standard are those associated with flying duties (Walsh and Levine, 1987). To pass a flight physical, the individual can have no more than eight prism diopters of either esophoria or exophoria. Using this standard as a basis of comparison, only 11 individuals (1.3 percent) could not meet the requirement.

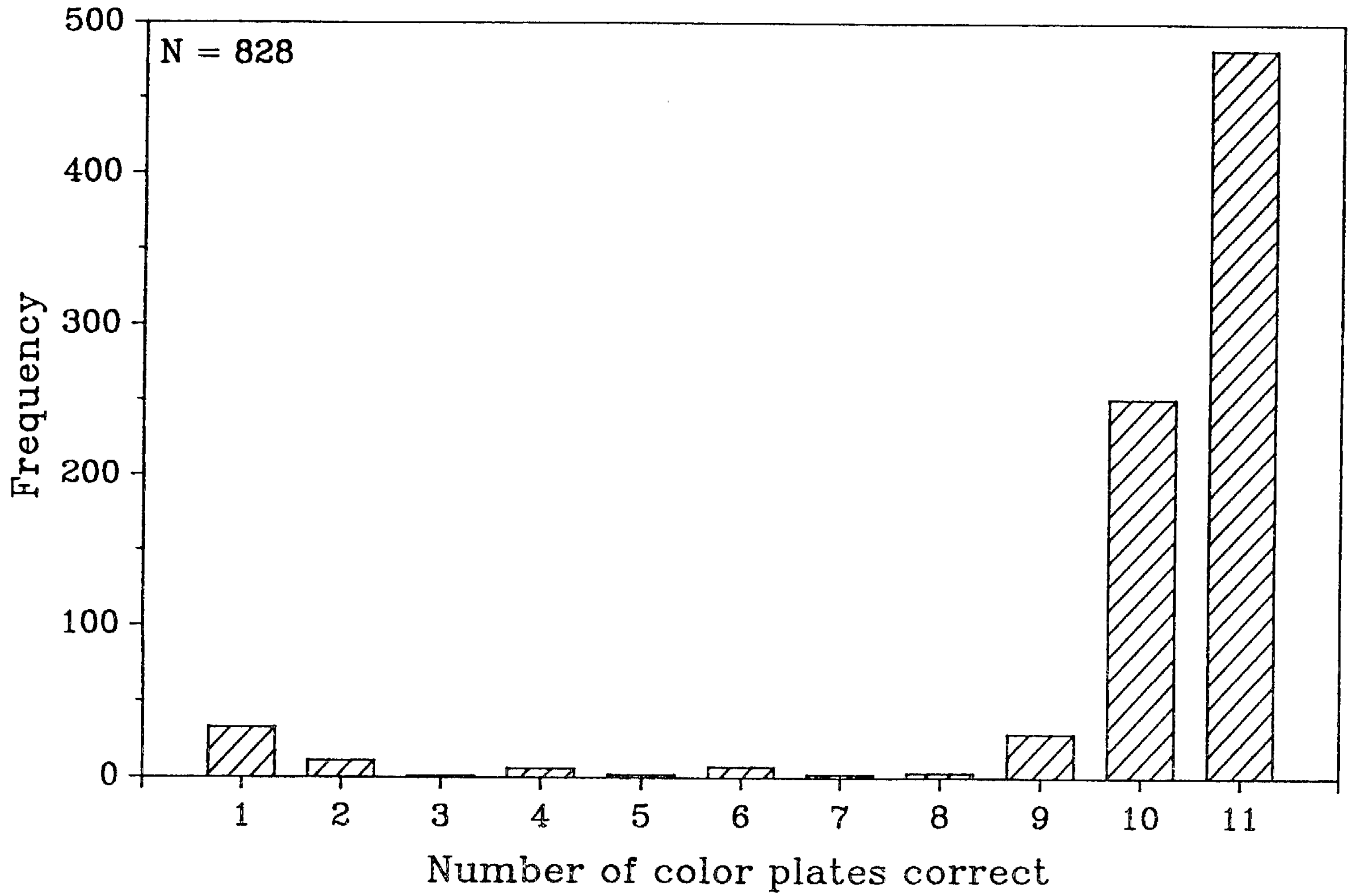

Figure 19. Distribution of color plate scores.

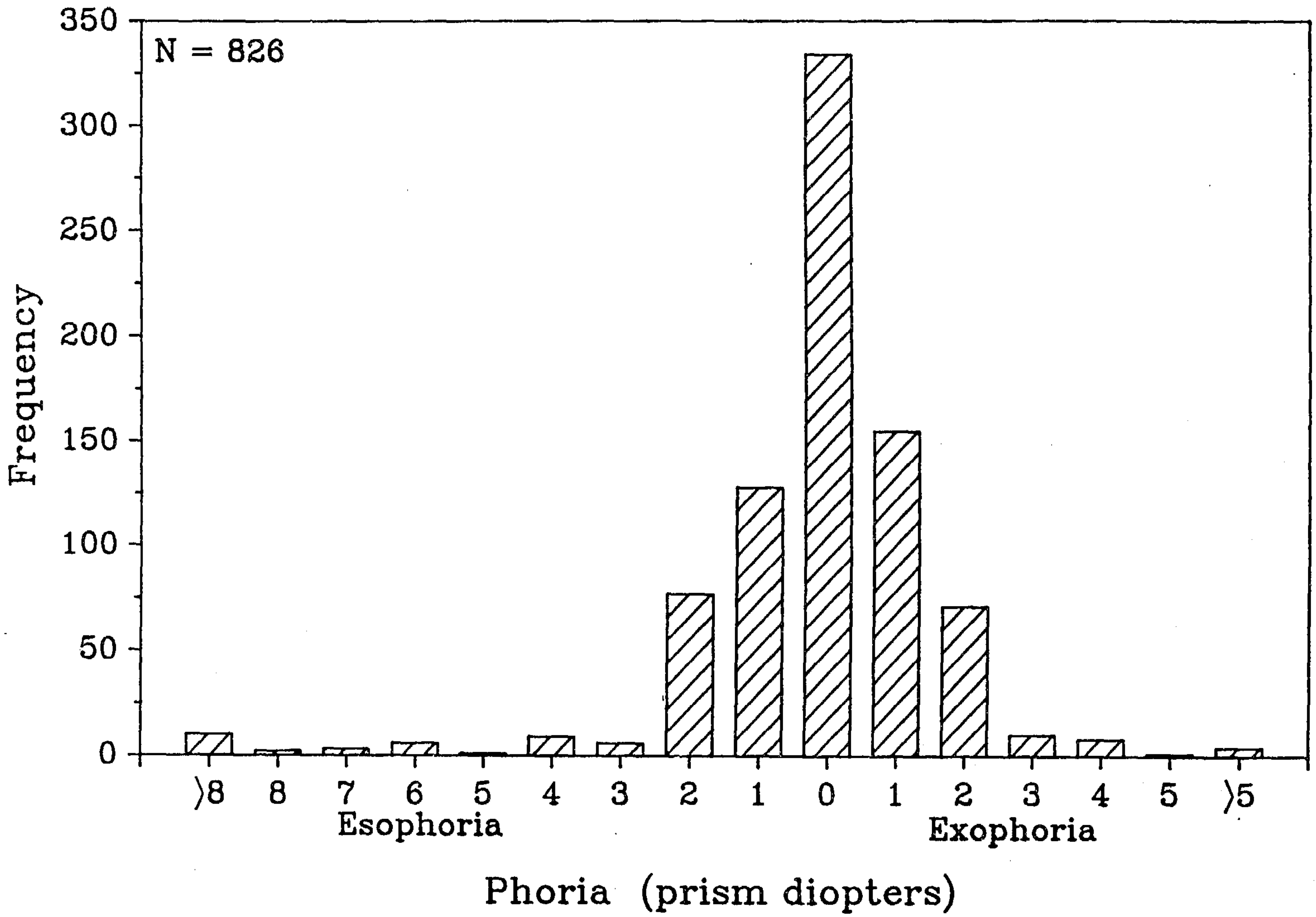

Figure 20. Distance lateral phoria measurements.

Stereopsis

The scores from the AFVT depth perception test, recorded as letters "A" through "F", were converted to stereopsis, in seconds of arc, using the values in Table 31. These values specify the magnitude of the disparity, or offset, of the two rings. The individuals who were unable to appreciate stereopsis at the largest disparity (83 seconds of arc) are grouped in the category ">83". This group includes individuals who are not able to appreciate stereopsis.

Table 31.

Depth perception disparities (seconds of arc)

Letter	Disparity	Letter	Disparity
A	83	D	27
B	43	E	19
C	32	F	13

The distribution of stereopsis scores is shown in Figure 21. Since the discrete disparity levels are nonlinear values, central tendencies would provide little information. Table 32 provides population percentages for selected disparity levels. The three groups are the total population, the best corrected subpopulation, and the subpopulation of spectacle wearers without their spectacles plus the contact lens wearers. The contact lens wearers are included with this group since these individuals also demonstrate reduced visual acuity and uncorrected refractive error.

Table 32.

Percentages of infantrymen demonstrating progressive levels of stereopsis

		Seconds of arc appreciated				
	N	<= 13	<= 27	<= 32	<= 43	<= 83
Total population	828	65.8%	76.8%	80.8%	84.7%	88.6%
Best corrected	736	69.0%	80.8%	84.2%	88.3%	91.2%
Uncorrected	92	40.2%	44.6%	53.3%	55.5%	67.5%

Only a limited number of specialties have a requirement for stereopsis (Walsh and Levine, 1987). For aviation specialties, candidates are required to achieve at least 27 seconds of arc,

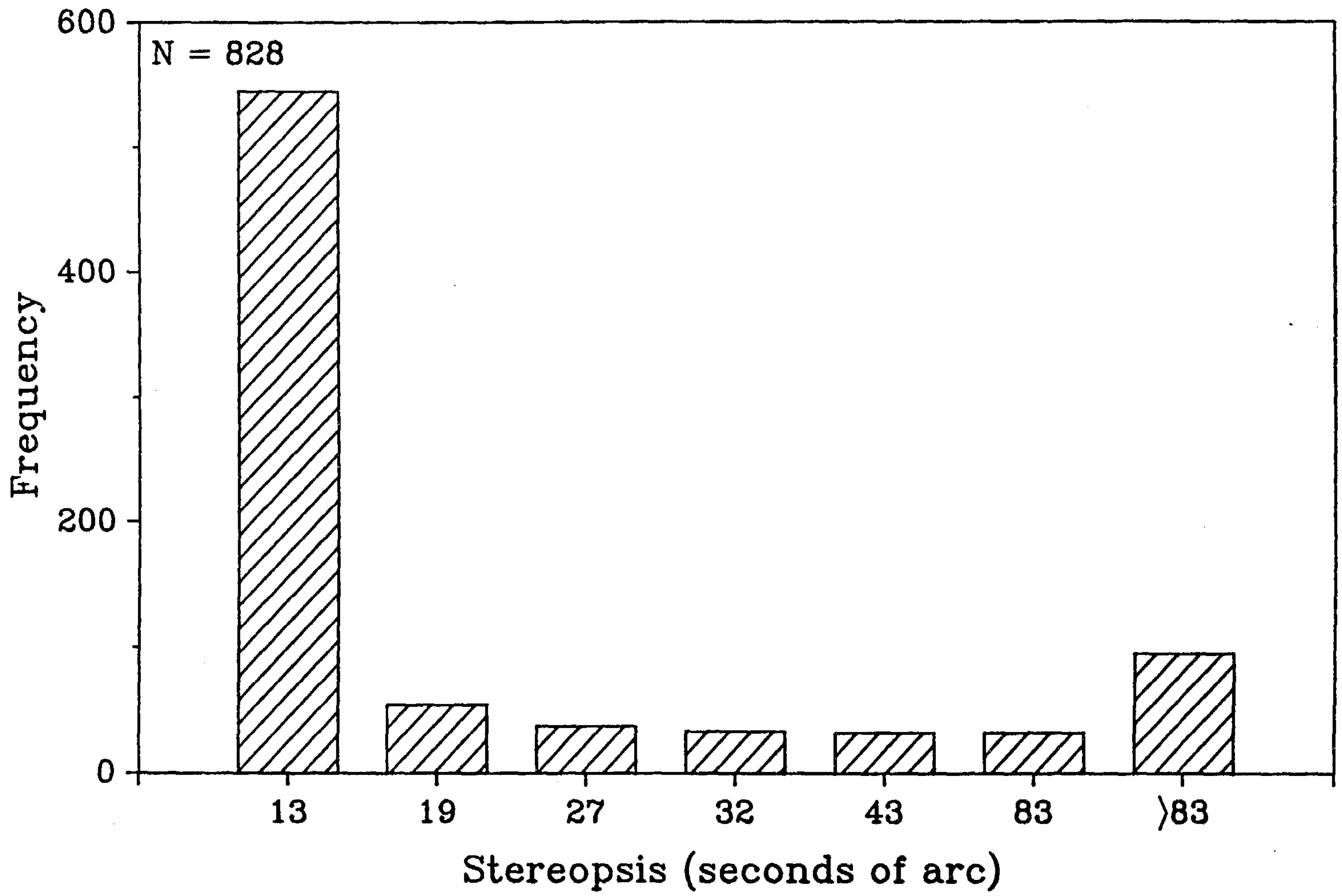

Figure 21. Distribution of stereopsis scores.

i.e., correct responses through block "D." Of the infantry population surveyed in this study, 76.8 percent achieved a score of 27 seconds of arc or better.

The effect of uncorrected refractive error on stereopsis can be seen in Table 32. The best corrected subpopulation outperformed the subpopulation of spectacle wearers without spectacles and contact lens wearers. Using the aviation standard (27 sec of arc), 80.8 percent of the best corrected achieved this level while only 44.6 percent of the "uncorrected" group achieved the same level.

Discussion

The initial purpose of this study was to answer the question: How might the population pool of Advanced Antitank Weapon System-Medium (AAWS-M) gunner eligibles be affected if the vision profile were changed to E1 from E2? To answer this, the uncorrected and corrected distance visual acuities are the only measurements required. Table 33 shows the percentage of participants falling into each of the profile categories. The categorization of the 85 participants who did not have their spectacles is based, in part, on corrected visual acuity measurements from the Humphrey autorefractor.

Table 33.

Vision profiles of participants (N=828)

Subpopulation	E1	E2
Best corrected	86.6%	2.3%
Without spectacles	8.9%	1.3%
Contact lens wearers	*	0.8%
Totals	95.5%	4.4%

* All contact lens wearers were arbitrarily categorized as E2.

Uncorrected visual acuity data were not available for the seven contact lens wearers. Since this group represents less than 1 percent of the population, the category percentages will not be influenced greatly. Since the intent of this analysis is to provide an estimate of those ineligible for selection, the more conservative approach is to classify the contact lens wearers E2.

The best estimate of the percentage of infantrymen with an E2 profile is 4.4 percent, leaving 95.6 percent of the population with an E1 profile.

Visual status profile

Based on central tendencies alone, the "typical" infantryman sees at least 20/20 with each eye, does not wear spectacles, has normal color vision, and has excellent stereopsis. However, most hardware developed for infantry must "fit" at least 90 percent of that population (5th to 95th percentile). For designing hardware, the central tendencies of the "typical" infantryman provide little information. More appropriate statistics are the ranges and percentiles.

The measured visual acuities met or exceeded the entry level standards for the 11B MOS in all but one case. While only 4 percent of the best corrected population did not achieve 20/20 acuity binocularly, 10 percent of the right eyes and 15 percent of the left eyes of this group did not attain that acuity level. This is a consideration when weighing the advantages of binocular versus monocular or right-eyed versus left-eyed VCS.

Among infantrymen, 33 percent were spectacle wearers. A VCS designed for unlimited use by this population must be compatible with spectacles, since built-in optical adjustments cannot correct astigmatism. Based on objective refractive error data, the infantry population was classified as 38.2 percent myopic, 27.4 percent hyperopic, and 34.4 percent emmetropic. Approximately 17 percent of infantrymen were classified as astigmats.

In addition to spectacle compatibility, the VCS should provide an eyepiece with dioptric correction for a minimal range of spherical refractive error. This correction will benefit non-spectacle wearers who are undiagnosed ametropes, e.g., whose visual acuity could be improved with spectacles, and the low level hyperopes and myopes who are less likely to have large amounts of astigmatism. A reasonable range of adjustment might be -2.00 to +2.00 diopters.

Published studies describe the visual status of the general population for spectacle wear and refractive error. Spectacle wearers include 30-35 percent of 18-30 year old males (Grosvenor, 1976). In this study, 33 percent had spectacles prescribed. The types of refractive errors found are myopia (35-38 percent), hyperopia (25-27 percent), and astigmatism (10-15 percent). The remaining 30-40 percent are classified as emmetropes. Based on the categorization of data from this study (Table 14), the population tested in this survey is not different from the general population of 18-30 year olds. However, selection of different criteria for each category certainly would yield much different results.

For type of astigmatism, one study (Borish, 1970) reported a population where 33 percent were with-the-rule (W/R), 20 percent against-the-rule (A/R), and 28 percent oblique. In the present study, the percentages found were 60, 22, and 18 percent, respectively. As mentioned previously, the autorefractor data for the axis measure are questionable.

The actual distribution of color vision capabilities does not vary significantly among different populations. Approximately eight percent of males are color defective (Borish, 1970). The effectiveness of screening tests to identify the defectives can vary. In this study, the 11 screening plates of the 14-plate Ishihara Pseudoisochromatic Plate Test were used. With a 7-plate pass criterion, approximately 7.5 percent of the participants were found to be color defective. Since this percentage coincides with the expected, the adopted criterion proved to be adequate for screening.

Approximately 77 percent of the participants passed the AFVT stereopsis test at the level required to pass a flight physical. More important was the finding that only 44.6 percent of the group who did not bring their spectacles and the contact lens wearers could pass the same test. For those tasks requiring excellent stereopsis, the importance of spectacle wear for the part-time wearer is evident.

Ideally, entry level evaluations should include a complete battery of vision tests and a complete evaluation of refractive error to optimize visual performance. However, the costs in time, equipment and manpower make such an endeavor improbable. Changes to the current system will occur only when performance based research is able to demonstrate a need for a specific level of a visual skill.

Conclusions

The visual acuity and refractive error data from infantrymen provide evidence of the effectiveness of the vision screening programs operated at the Military Enlistment Processing Stations (MEPS) and the Reception Station at Fort Benning. Only one surveyed participant failed to meet the entry requirements for the 11B MOS. The vision available to each individual, whether without spectacles or with spectacles, was adequate to complete OSUT training.

Based on visual acuity measurements, the infantrymen see very well. In a small number of cases, a change in spectacle prescription or spectacles for certain nonspectacle wearers would improve maximum visual acuity. Theoretically, these small improvements in acuity would only affect performance on a very limited number of tasks which require very detailed visual resolution. However, these changes may provide a greater benefit to the quality of vision. For example, an under-corrected individual may have to spend a greater amount of time and energy in attempting to identify a target than would be necessary if fully corrected.

Based on the results of this study, doctrine and materiel developers should promote visually coupled equipment which optically corrects for a narrow range of spherical refractive error and which is compatible with spectacle lenses.

The data collected during this study can be used by pertinent MOS proponency agencies in modifying existing selection standards and developing selection standards for new MOSs. For example, in the case of the AAWS-M gunner selection criteria, the results of the study show no serious decrement in the selection pool, should the vision profile requirement be set to the E1 standard.

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Appendix A

Data collection form

Station verification

1	2	3	4	5	6	7	8

DATA COLLECTION FORM

1. Name: ______________________ 2. Number: ____________

3. SSN: _____-_____-________ 4. Date (DD/MM/YY): ____ /____ /____

5. Lensometry:

   a. OD: _____ - _____ X _____
   Sph Cyl Axis

   b. OS: _____ - _____ X _____
   Sph Cyl Axis

   c. PD: _____ / _____ (dist/near)

   d. Prism: _____ @ _____
   Power Axis

6. Interpupillary Distance (Distance/near): _____ / _____ (mm)

   a. Monocular distance PD - right: _____ (mm)

   b. Monocular distance PD - left: _____ (mm)

7. Vertex Distance: ______ (mm)

Number: ______________

8. Tests of Sighting Dominance:

(Circle eye used. R = Right; L = Left; 0 = Indeterminant)

Test	Trial number	Response		
A. Point test	1.	R	0	L
	2.	R	0	L
	3.	R	0	L
	4.	R	0	L
B. Hole-in-card test	1.	R	0	L
	2.	R	0	L
	3.	R	0	L
	4.	R	0	L
C. Miles ABC test (Cone)	1.	R	0	L
	2.	R	0	L
	3.	R	0	L
	4.	R	0	L
D. Alignment test (Tube)	1.	R	0	L
	2.	R	0	L
	3.	R	0	L
	4.	R	0	L
E. Asher test (2-card)	1.	R	0	L
	2.	R	0	L
	3.	R	0	L
	4.	R	0	L

Scoring: No. right eye: ____ X (1) = _____ (A)

No. left eye: ____ X (-1) = _____ (B)

Final score: _____ (A) + _____ (B) = ___________ Final score

Number: ____________

9. Humphrey Autorefraction (Attach printout; enter results.):

   a. Initial visual acuity:

      (1) OD 20/_____

      (2) OS 20/_____

   b. OD: _____ - _____ X _____
      Sph Cyl Axis

   c. OS: _____ - _____ X _____
      Sph Cyl Axis

   d. Final visual acuity:

      (1) OD 20/_____

      (2) OS 20/_____

Warning: Measurements must be repeated if the following occur:

1. If "CONF" appears on printout.
2. If "REFLEX" is less than +1.50.
3. If difference between right and left eye "REFLEX" is > 15.0.

Number: ____________

10. AFVT:

a. Fusion and depth perception:

(1) AFVT Fusion (Enter Yes or No):

Depth perception ____ Diplopia ____ Suppression ____

(2) AFVT Depth Perception (Check correct answers; "X" errors.):

A:

L1	3
L2	2
L3	4

D:

L1	3
L2	2
L3	3

B:

L1	3
L2	4
L3	2

E:

L1	2
L2	3
L3	4

C:

L1	4
L2	2
L3	4

F:

L1	3
L2	2
L3	2

Depth perception results: _____

b. Far lateral phoria (Circle dot.):

Responses

1		3		5		7		9		11		13		15		17		19		21		
o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o
11	10	9	8	7	6	5	4	3	2	1	0	1	2	3	4	5	6	7	8	9	10	11

Esophoria (ES) <———|———> Exophoria (EX)

Far lateral phoria result: _____ _____
ES/EX

Number: ______________

11. Color vision:

Ishihara PIP - (Check, if correct; or record response):

Plate number	Normal response	OD	OS	OU	R/G defect response	
1	12				12	
2	8				3	
3	5				2	
4	29				70	
5	74				21	
6	7				X	
7	45				X	
8	2				X	
9	X				2	
10	16				X	
11	Traces				X	
12	35				5	3
13	96				6	9
14	Traces 2				PRP	RED

PIP (number correct): OD: ____/14 OS ____/14 OU: ____/14

Red/green (yes/no): OD: ____ OS: ____ OU: ____

Number: ____________

13. Standard VA (Record highest full line and number of additional letters read on the next smaller line.):

				D V						160
				N S H						125
			K	H	O	R				100
			C	K	D	V				80
		O	Z	N	H	V	C			60
	R	K	C	S	Z	H	V	D		50
	S	D	K	H	O	R	C	V		40
H	O	C	Z	R	K	D	S	V	N	30
N	Z	C	O	S	K	D	V	R	H	25
D	C	S	K	O	V	R	N	H	Z	20
Z	S	V	D	K	H	N	O	R	C	16

a. Without correction (Not applicable for contact lenses wearer):

OD 20/_____ + ___ OS 20/_____ + ___ OU 20/_____ + ___

b. With correction (Use for spectacle or contact lens wearer):

OD 20/_____ + ___ OS 20/_____ + ___ OU 20/_____ + ___

Number: ____________

14. Low contrast VA:

a. 95% Contrast:

								Line number
Z	R	D	O	V	C	N	S	1
H	R	V	C	O	S	K	Z	2
N	D	C	O	H	R	V	S	3
K	V	R	Z	C	O	H	S	4
Z	N	V	K	D	S	O	R	5
D	C	R	V	H	N	Z	K	6
O	S	K	C	V	R	Z	N	7
S	N	H	K	C	D	V	O	8
N	R	D	C	O	K	S	Z	9
V	H	C	O	R	Z	D	N	10
H	R	O	S	C	V	K	N	11

95% Contrast

	OD	OS	OU
A - Highest full line:	______	______	______
B - Extra letters:	______	______	______
Score = A + B/8*:	______	______	______

* B/8 conversions:

1/8 = .125	5/8 = .625
2/8 = .25	6/8 = .75
3/8 = .375	7/8 = .875
4/8 = .5	

Number: ____________

b. 9% Contrast:

N	R	V	C	D	S	O	H	1
Z	K	S	C	O	D	R	N	2
V	H	N	K	Z	C	S	O	3
K	R	D	H	V	Z	N	C	4
H	V	O	Z	S	D	R	K	5
S	K	C	D	V	H	O	R	6
Z	N	K	O	S	D	C	R	7
N	H	S	V	K	Z	C	R	8
Z	V	N	D	H	K	O	S	9
H	R	C	V	O	N	D	Z	10
V	Z	N	H	D	O	K	R	11

9% Contrast

	OD	OS	OU
A - Highest full line:	______	______	______
B - Extra letters:	______	______	______
Score = A + B/8*:	______	______	______

* B/8 conversions:

1/8 = .125	5/8 = .625
2/8 = .25	6/8 = .75
3/8 = .375	7/8 = .875
4/8 = .5	

Number: ____________

12. Stereopsis:

a. Titmus (Check correct; "X" errors or omissions.)

1	2	3
B	L	B
800	400	200

4	5	6
T	T	L
140	100	80

7	8	9
R	L	R
60	50	40

Titmus results: __________ Seconds

b. Randot (Check correct; "X" errors or omissions.):

1	2	3	4	5
L	R	L	M	R
400	200	140	100	70

6	7	8	9	10
M	L	R	M	R
50	40	30	25	20

Randot results: __________ seconds

Number: ____________

c. 3% Contrast:

S		O		Z		C		0
S	N	Z	K	C	V	D	R	1
K	O	H	S	C	R	V	N	2
N	D	Z	C	O	S	H	K	3
K	S	V	R	O	D	Z	C	4
K	N	R	O	Z	V	H	S	5
Z	H	N	C	D	O	V	R	6
K	Z	V	H	R	N	C	O	7
R	V	D	K	S	H	O	C	8
K	C	H	N	D	Z	S	O	9

3% Contrast

	OD	OS	OU
A - Highest full line:	______	______	______
B - Extra letters:	______	______	______
Score = A + B/8*:	______	______	______

* B/8 conversions:

1/8 = .125
2/8 = .25
3/8 = .375
4/8 = .5
5/8 = .625
6/8 = .75
7/8 = .875

Number: ____________

b. Chart configuration B (Indicate eye; circle response):

Eye tested (OD, OS, or OU): _________

	1	2	3	4	5	6	7	8
A:	**U** L R	U L **R**	U L **R**	**U** L R	U **L** R	**U** L R	U L **R**	U **L** R
	3	7	12	20	35	70	120	170

	1	2	3	4	5	6	7	8
B:	**U** L R	U L **R**	U **L** R	U **L** R	**U** L R	U L **R**	U **L** R	U L **R**
	4	9	15	24	44	85	170	220

	1	2	3	4	5	6	7	8
C:	**U** L R	U **L** R	**U** L R	**U** L R	U L **R**	U **L** R	U L **R**	**U** L R
	5	11	21	45	70	125	185	260

	1	2	3	4	5	6	7	8
D:	**U** L R	U **L** R	U **L** R	U L **R**	**U** L R	**U** L R	U **L** R	**U** L R
	5	8	15	32	55	88	125	170

	1	2	3	4	5	6	7	8
E:	**U** L R	**U** L R	U L **R**	**U** L R	U **L** R	**U** L R	U L **R**	**U** L R
	4	7	10	15	26	40	65	90

b. Chart configuration B - Score summary (Enter contrast sensitivity):

1.5 ______ 3 ______ 6 ______ 12 ______ 18 ______

Number: ____________

15. Contrast sensitivity:

a. Chart configuration A (Indicate eye; circle response):

Eye tested (OD, OS, or OU): __________

	1	2	3	4	5	6	7	8
A:	**U** L R	**U** L R	U L **R**	U L **R**	U **L** R	U **L** R	U **L** R	U L **R**
	3	7	12	20	35	70	120	170

	1	2	3	4	5	6	7	8
B:	**U** L R	U **L** R	U L **R**	**U** L R	**U** L R	U **L** R	U L **R**	**U** L R
	4	9	15	24	44	85	170	220

	1	2	3	4	5	6	7	8
C:	**U** L R	U L **R**	U **L** R	U **L** R	U L **R**	U L **R**	**U** L R	U **L** R
	5	11	21	45	70	125	185	260

	1	2	3	4	5	6	7	8
D:	**U** L R	**U** L R	U L **R**	**U** L R	U **L** R	U **L** R	**U** L R	U L **R**
	5	8	15	32	55	88	125	170

	1	2	3	4	5	6	7	8
E:	**U** L R	U **L** R	**U** L R	U **L** R	U L **R**	**U** L R	U L **R**	**U** L R
	4	7	10	15	26	40	65	90

a. Chart configuration A - Score summary (Enter contrast sensitivity):

1.5 ______ 3 ______ 6 ______ 12 ______ 18 ______

Number: ______________

c. Chart configuration C (Indicate eye; circle response):

Eye tested (OD, OS, or OU): __________

	1	2	3	4	5	6	7	8
A:	**U** L R	**U** L R	U **L** R	U L **R**	**U** L R	U **L** R	U **L** R	U **L** R
	3	7	12	20	35	70	120	170

	1	2	3	4	5	6	7	8
B:	**U** L R	U **L** R	U L **R**	**U** L R	U L **R**	U **L** R	**U** L R	**U** L R
	4	9	15	24	44	85	170	220

	1	2	3	4	5	6	7	8
C:	**U** L R	U **L** R	**U** L R	U L **R**	U **L** R	U L **R**	**U** L R	U L **R**
	5	11	21	45	70	125	185	260

	1	2	3	4	5	6	7	8
D:	**U** L R	**U** L R	**U** L R	U L **R**	U L **R**	U **L** R	**U** L R	U **L** R
	5	8	15	32	55	88	125	170

	1	2	3	4	5	6	7	8
E:	**U** L R	U L **R**	**U** L R	U **L** R	U L **R**	**U** L R	U L **R**	U L **R**
	4	7	10	15	26	40	65	90

c. Chart configuration C - Score summary (Enter contrast sensitivity):

1.5 ______ 3 ______ 6 ______ 12 ______ 18 ______

Number: ____________

16. Isoluminance test:

Plate #:	1	2	3	4	5
Gap position:	UL	LL / (UR)	D / (R)	UR / (LL)	LR / (LL)
Response:		/	/	/	/
Quality:		/	/	/	/

Plate #:	6	7	8	9	10
Gap position:	LR	LL	(D)	L	UL
Response:					
Quality:					

Plate #:	11	12	13	14
Gap position:	U	UL	LL	UR
Response:				
Quality:				

Quality: C = Correct recognition
A = Abnormal recognition
X = Nonrecognition (including errors)

Total (Cs + As): _____ / 18 (correct)

Appendix B

Humphrey autorefractor accuracy

To estimate the capability of the Humphrey autorefractor to provide an accurate estimate of refractive error, Humphrey data were compared to the spectacle prescriptions. Figures 22 and 23 show the distributions of the differences in sphere power and cylinder power, respectively.

Table 34 summarizes difference scores for the sphere and cylinder power data. If the refractive prescription (Humphrey data) exactly matched the spectacle prescription, the means would be 0.0. Based on the mean of the differences of the spherical components, the autorefractor provides accurate information across a population. For the cylindrical component, there is a tendency for the autorefractor to measure greater cylinder power (0.25 diopter). This is consistent with differences between objective and subjective measurements of this value.

Table 34.

Difference (in diopters) between spectacle prescriptions and objective refractive errors

	N	Mean	Median	Mode	Range
Spherical component	356	-0.08	0.00	0.00	-1.62 to +1.75
Cylindrical component	360	0.18	+0.25	+0.25	-3.12 to +1.62
Spherical equivalent	356	0.26	0.00	0.00	-1.26 to +2.06

The ranges of differences are relatively large. This alone makes the reliability of prescribing from autorefractor data questionable. However, as a screening device, the reliability is acceptable. For spectacle wearers, 78 percent of sphere differences and 81 percent of cylinder differences fell within a ± 0.50 diopter range.

The inherent assumption in this comparison is the spectacle prescriptions provide the individual with the most accurate refractive error correction. While this was the norm, there were exceptions. As an example, there were 15 cases with spherical equivalent differences of 1.00 diopters or more. Of these, four individuals obtained better visual acuity from the autorefractor prescriptions. In one case, acuity with spectacle lenses was better than that obtained with the autorefractor prescription. In the remaining cases, the autorefractor acuity was 20/20 or better.

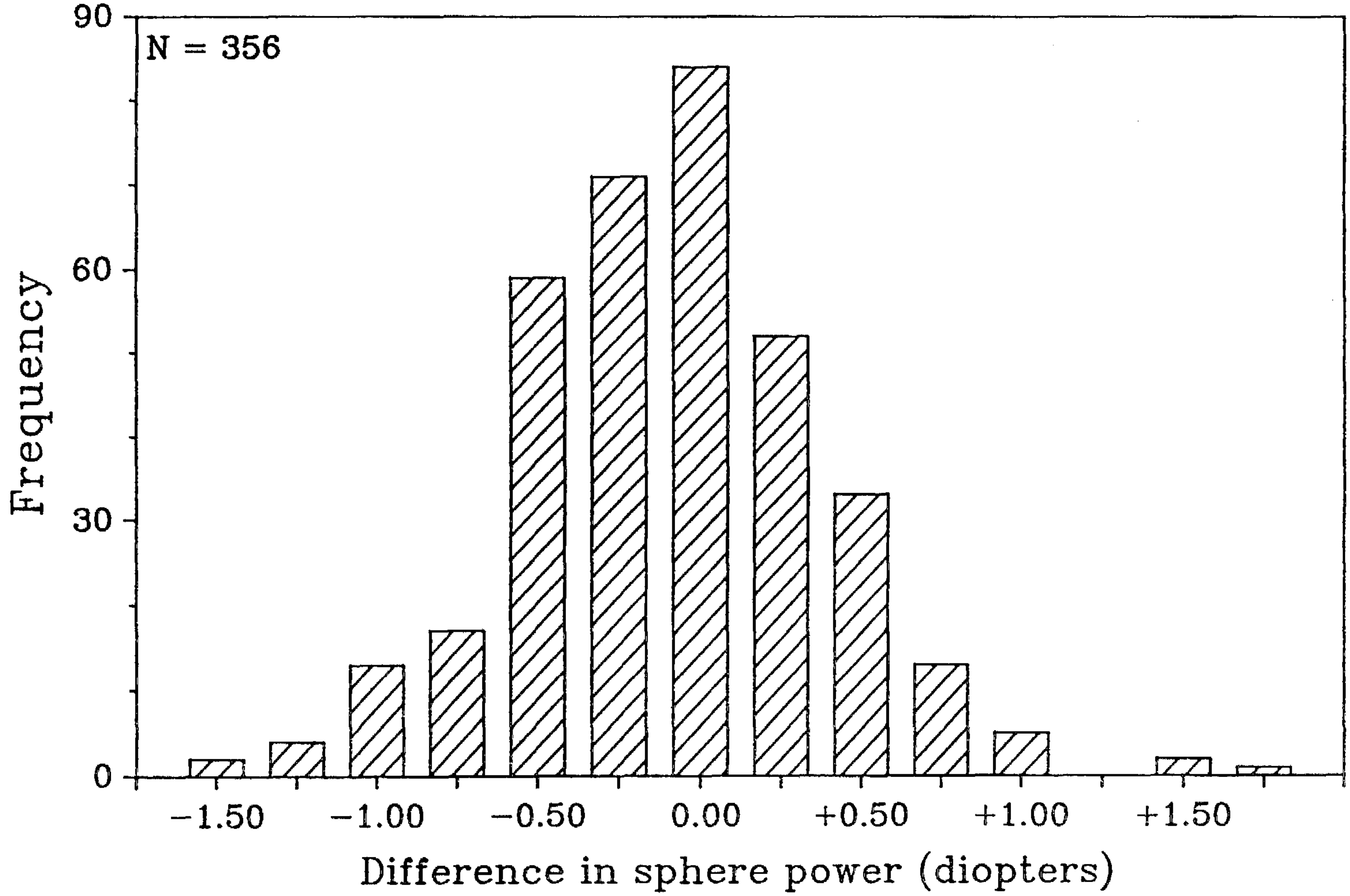

Figure 22. Sphere power differences between autorefractor readings and spectacle prescriptions.

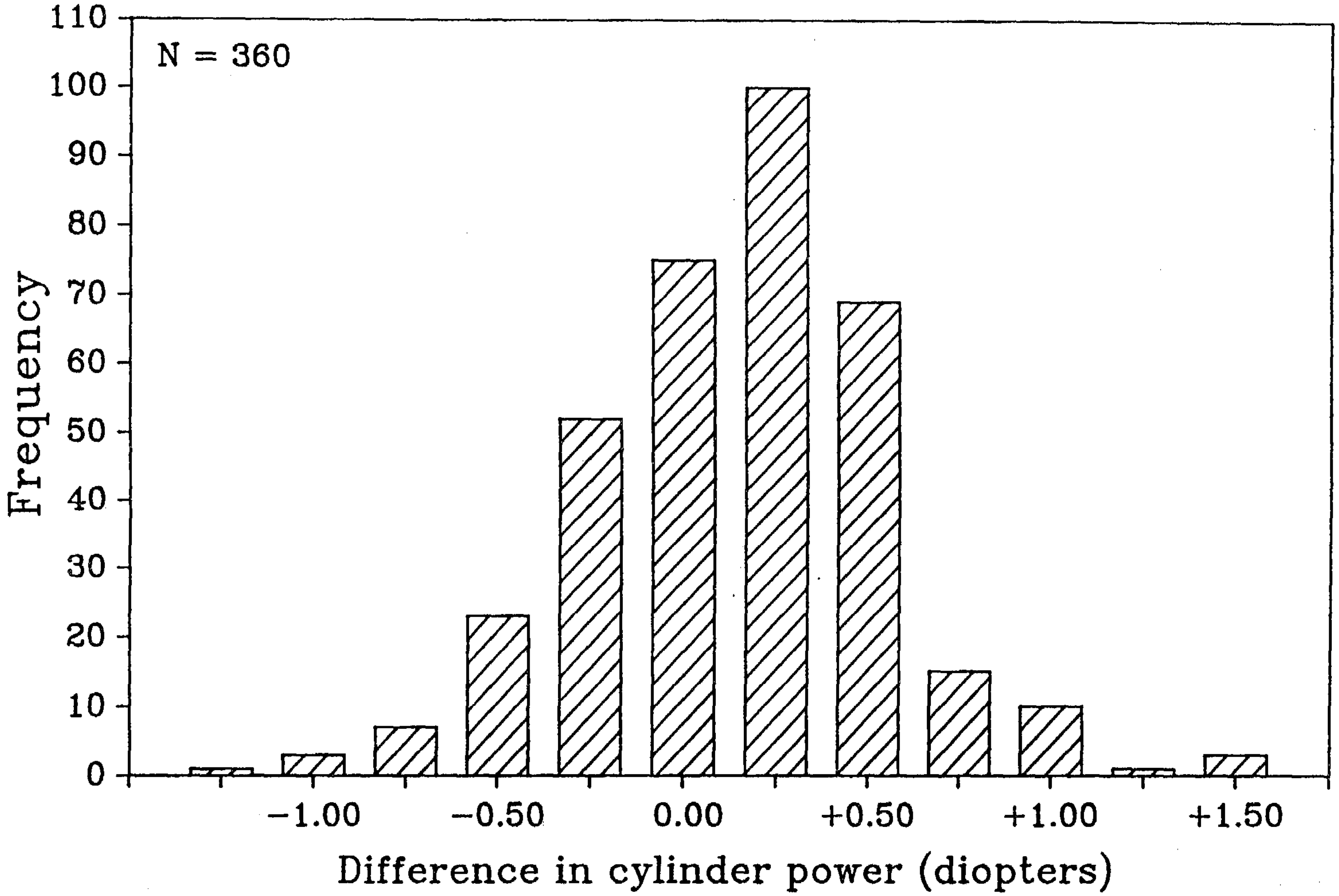

Figure 23. Cylinder differences between autorefractor readings and spectacle prescriptions.

When determining the orientation of astigmatism, the autorefractor was less accurate. Figure 24 displays the frequency distribution of the types of astigmatism for the refractive and spectacle axes. The autorefractor classifies a greater number of cases as with-the-rule (W/R) astigmatism and a much smaller number as against-the-rule (A/R) astigmatism.

Figure 25 displays the distribution of the differences, in degrees, between the refractive and spectacle axes of astigmatism. There is marginal consistency.

The sphere power and cylinder power components of the autorefractor data will provide an adequate representation of the population distributions for these measures. The autorefractor data will not provide an accurate estimate of cylinder axis orientation.

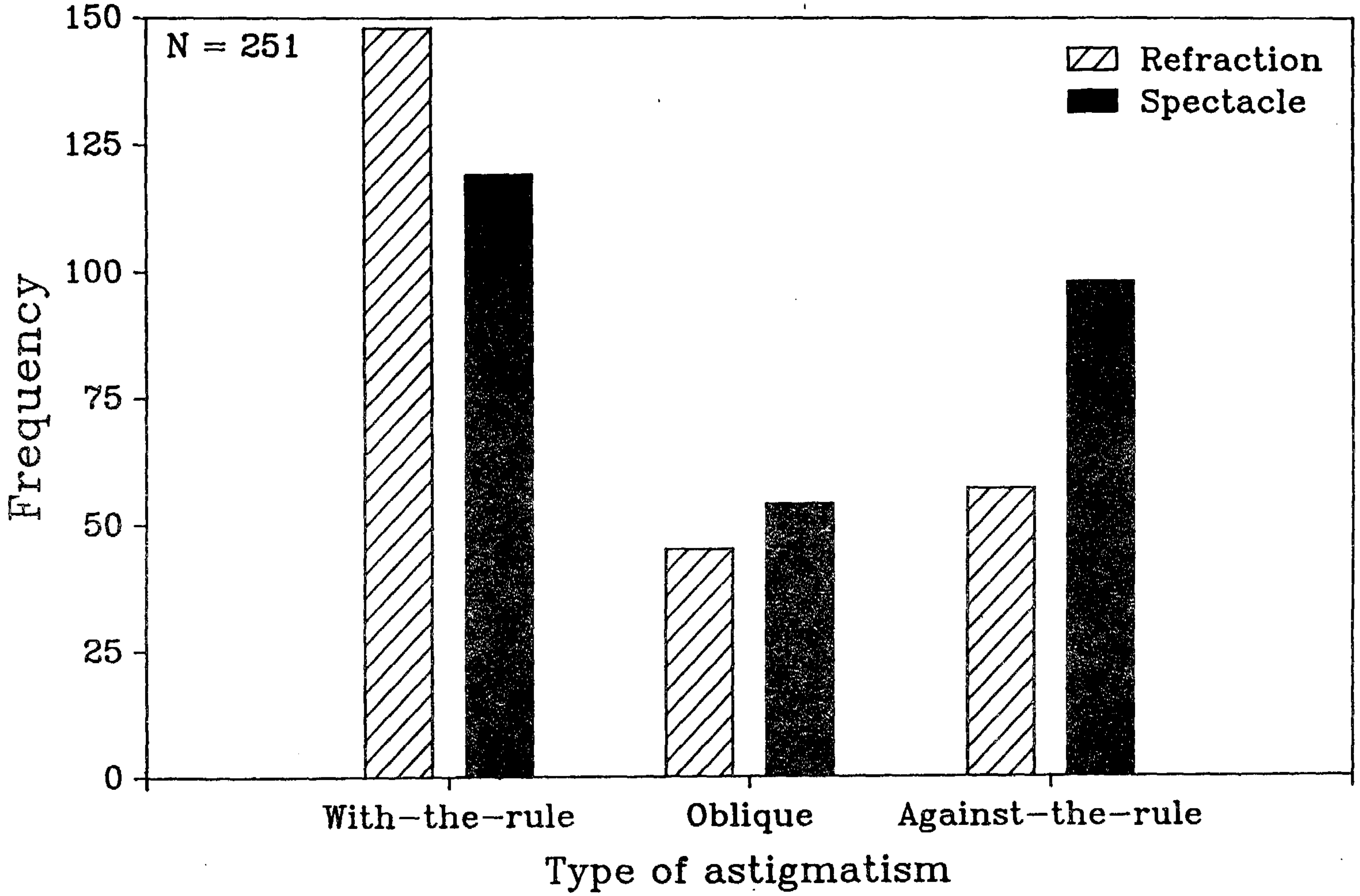

Figure 24. Astigmatism type classification differences between autorefractor readings and spectacle prescriptions.

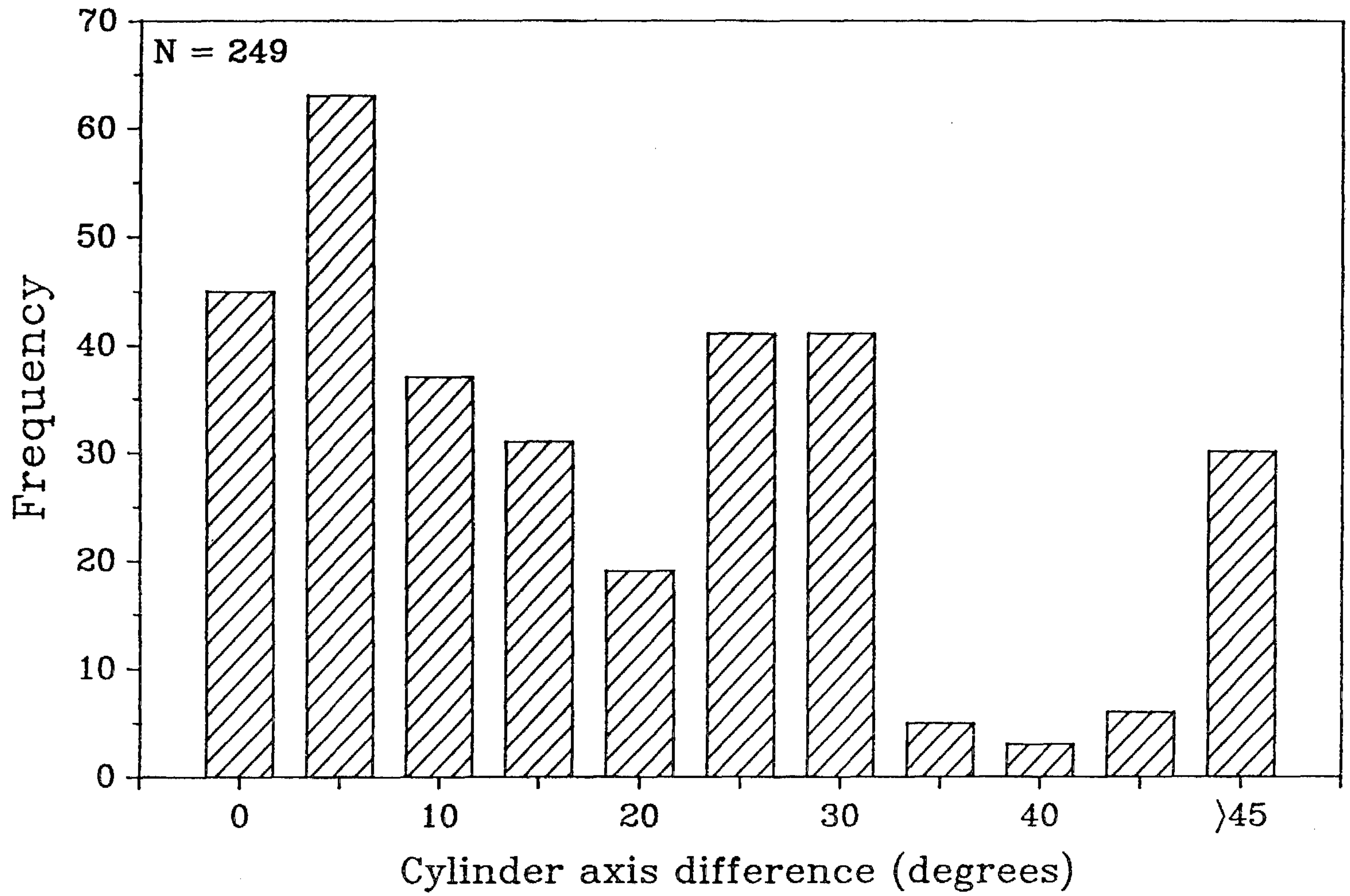

Figure 25. Differences in cylinder axis orientation for data from autorefractor and spectacle prescription.

Appendix C

List of equipment manufacturers

Bausch and Lomb
1400 N. Goodman Street
Rochester, NY 14692

Good-Lite Company
1540 Hannah Avenue
Forest Park, IL 60130

Humphrey Instruments, Incorporated
3081 Teagarden Street
San Leandro, CA 94577

Macbeth
Little Britain Road
Drawer 950
Newburgh, NY 12550

Silor Optical, Incorporated
262 Gel Head Road
Glen Head, NY 11545

West Coast Optical
925 26th Avenue, East
Bradenton, FL 33508