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Visual skills of poor readers in high school

David Grisham, O.D., M.S.,[a,b] Maureen Powers, Ph.D.,[b,c] and Phillip Riles, M.A.[b]

[a]School of Optometry, University of California, Berkeley, California; [b]Gemstone Educational Management, LLC, and [c]Gemstone Foundation Research Institute, Rodeo, California.

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Binocular vision;
Accommodation;
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Reading

Abstract

BACKGROUND: Prior findings suggest that poor readers tend to have poor visual skills, but few reports give full frequency distributions of skill variables, and little data are available for adolescents.

METHODS: Visual skills and visual acuity were measured in 461 students (average age 15.4 years) in 4 California high schools within the same school district. Participating students had been identified by their schools as poor readers. Standard optometric tests and published criteria for "adequate" or "weak" visual skills were used.

RESULTS: In this sample, 80% of the students were found to be inadequate or weak in 1 or more of the following visual skills: binocular fusion ranges at near, accommodative facility, and convergence near point. More students were deficient in binocular fusion range than in either accommodative function or near point of convergence. In contrast, only 17% had deficient visual acuity—20/40 or worse in 1 eye—the standard model of deficiency for school vision screenings.

CONCLUSION: The results support and extend previous studies showing that large numbers of poor readers in high school may be at high risk for visual skills dysfunction.

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Recent studies have found that providing training of visual skills such as convergence, divergence, and accommodative facility can improve both the level of skill[1,2] and the symptoms associated with visual skill deficits.[2,3] The literature also suggests an association between visual skill level and reading outcomes, such as fluency and comprehension.[4,5] Although such an association may be apparent to optometrists,[6,7] it remains a source of controversy to experts in other fields, most notably education[8-10] and medicine,[11,12] because of a perceived lack of scientifically rigorous supporting evidence.

If an association between visual skills and reading exists, one would expect to find a higher prevalence of visual skill deficits in students who read poorly than in those who do not. In statistical terms, the hypothesis to be tested is whether the proportion of poor readers with poor visual skills is greater than would be expected by chance; some studies do report outcomes consistent with this hypothesis.[13,14] However, the answer to such a question depends critically on the precise definition of terms, which can vary from study to study. For example, convergence insufficiency (CI) may be determined through measures of near point of convergence (NPC) in combination with additional measures of exophoria at near, fusional ranges, or other variables[2,15,16] or by NPC alone.[17,18] Within given studies, CI may be defined as the inability to converge to 6 cm,[2] 7.5 cm,[15] or 10 cm.[18] Clinical criteria may necessarily vary with age and other practical concerns,[19] but the lack of standard definitions makes scientific descriptions difficult.

In this report, we present data from high school students who were designated as poor readers by their teachers. A primary goal of the report is to show full frequency distributions of the optometric data and then to apply the most

Corresponding author: Maureen Powers, Ph.D., Gemstone Foundation Research Institute, 575 San Pablo Avenue, Suite D, Rodeo, California 94572.

E-mail: maureenpowers@gemstonefoundation.org

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appropriate clinical criteria for "normal" that currently exist for each variable measured. This approach not only allows the reader to appreciate the range of measurements and the number of students who would be considered to have "normal" visual skills, but also to see how different criteria for "normal" would affect any inferences about the prevalence of visual skill deficits.

We have chosen to study specific visual skills that might affect reading performance, but are not directly related to visual acuity. Our rationale is that refractive corrections are already being addressed in school screening programs and most doctors' offices. But visual skills, such as the ability to move the eyes in a coordinated fashion, are ignored by many educational personnel and eye care practitioners, and even though refractive corrections are prescribed, many students (as we will show) do not wear glasses. Our hope is that by illustrating the frequency distribution of visual skills in a large sample of poor readers, we can begin to draw attention to these skills as important features of sensory input mechanisms for reading and learning.

Methods

Students

East Side Union High School District (San Jose, California) purchased the computerized Dynamic Vision Training program (Gemstone Educational Management, LLC, 575 San Pablo Ave., Rodeo, California 94572)[20] in 1999, to be incorporated into the curriculum in its poorest performing high schools during the school year 1999-2000.

San Jose is a large city environment. The total number of students in the 4 schools reported here was 7,735 (average per school 1,934); thus the initial sample size (*see* Table 1) was 8.1%. All but 1 school (HS-3) received Title I funds, and the percentage of students receiving free or reduced lunch ranged from 19.1% to 36.5%. The proportion of English Language Learners was 13.2% to 33.6%; other common languages were Spanish, Tagalog, and Mong, and when students did not understand the English necessary for vision assessments, testers used words in their language. Ethnicity varied from school to school, but the largest proportion of students at every school was Hispanic (39.6% to 65.6%), followed by Asian (9.1% to 32.8%), white (2.2% to 16.9%), Filipino (4.8% to 12.2%), and African-American (2.9% to 5.3%) percentages were lower. At these schools, less than 1% of students qualified for admission to the University of California system at graduation, and the average SAT scores for seniors ranged from 888 to 930. In the district as a whole, 36.4% qualified for admission, and the average SAT score was 1009.

Table 1 Number of students referred as poor readers in each of 4 high schools in 1 California school district

School	Number assessed	Complete data	Percent*
HS-1	132	124	93.9
HS-2	230	167	72.6
HS-3	175	133	76.0
HS-4	39	37	94.8
Total	576	461	81.7

* Percentage with data sufficiently complete to analyze.

Students who failed the assessment portion of the program (described below) were to use the computerized orthoptics program[20] in class during the school year. The basis for referral of students for assessment was poor reading performance, which was determined by the school and defined as reading 2 grade levels or more below grade level.

Students were assessed using an expanded Modified Clinical Technique (MCT) procedure[21] in the spring of 1999, which for most was their first year in high school. A total of 576 high school students from 4 high schools within the district were assessed for visual skills during that year. The number of students from each school is presented in Table 1.

Except for the consideration of sex ratio for referred students, only students with complete data are included in the remainder of this report. The most common reason for missing data was that a student skipped 1 of the screening stations and was not able to return to complete testing the next day. The average age of the 461 students with complete data was 15.4 years, but ages ranged from 14 to 19, with older students included because of the persistent problems with reading.

Measurements

Distance visual acuity, near point of convergence, convergence and divergence fusion ranges at near, accommodative amplitude, and accommodative facility were measured quantitatively on each student. Students were also asked whether they owned corrective lenses and if so, whether they wore them in class.

Distance visual acuity was measured monocularly with the Snellen eye chart at 20 feet. *Spectacle and contact lens wearing behavior* was assessed with a simple set of questions, including "Do you own glasses or contacts now?" "Do you wear them in class?" "Do you have them with you now?"

Convergence and divergence break and recovery were measured at 40 cm with a horizontal prism bar with prism diopter (PD) values of 1, 2, 4, 6, 8, 10, 12, 14, 16, 18, 20, 25, 30, 35, 40, and 45 diopters (D). The student was first asked if the clown face target on the smaller end of a standard optometric measure (Occlud-A-Measure; Bernell, Mishawaka, Indiana) could be detected. If so, then the student was requested to say whether the target appeared single or double. Examples of double images were shown if the student seemed uncertain by moving the bar to large prism dioptric values. Once single vision was obtained, the bar was moved relative to the student's eye until double images were reported. That point was considered "break."

Then the motion of the bar was reversed until the student reported the image single, and this point was considered "recovery." This procedure was first performed for base in (BI) position of the bar over the left eye, and then repeated with base out (BO) position over the right eye. We defined the difference between break and recovery as the "re-fusion interval," which is reported either in PD or in prism bar steps (the number of prism steps between break and recovery on the horizontal prism bar).

Near point of convergence was assessed by asking the student if the clown face target was seen as single when the experimenter held it approximately 20 cm in front of the student's eyes. If so, then the student was requested to say when the object appeared to double as it moved closer to the face. The experimenter placed 1 end of an accommodative rule on the student's forehead and judged where the 2 eyes diverged as the target moved toward the student's face. The measurement was repeated 3 times.

Accommodative amplitude was also assessed using the accommodative rule. The student held an occluder over the left eye. The experimenter asked if the student could see the 6 point (pt) (20/30) target at the larger end of the Occlud-A-Measure held at about 20 cm from the face. If yes, then the student was asked whether the target was in focus or "not blurry." If the student responded that the target was in focus, then the target was moved at approximately 2 cm per second toward the student's face, and the student was asked to report when the target first became blurry. This measurement was taken 3 times.

Accommodative facility was measured with ±2.00 D lenses, flipped each time the student said the target was "clear" in the student's native language. The target for this test was the 6 point (pt) word used for accommodative amplitude. The left eye was occluded. The student was asked whether the target was clear when held at about 40 cm. If so, then the student was told that the test would be timed and that it should be reported whenever the target was "clear." The experimenter then started a stopwatch and counted the number of times the lenses were flipped in 30 seconds. That number was taken to represent the cycles per minute (cpm) and therefore to represent the student's ability to change accommodation over time.

Developmental Eye Movement Test (DEM)[22] was administered to assess saccadic tracking behavior; the results will be presented in a separate publication in order to include data from an additional school where *only* the DEM was administered.

Procedure

Assessment sessions were carried out at the school in a large classroom (HS-1 and HS-4), multipurpose room (HS-2), or library (HS-3). At least 1 optometrist was present for each session. Assistants who had been trained by an optometrist performed the tests at different stations. Results were recorded on a standard form, which the student kept as he or she moved through the stations.

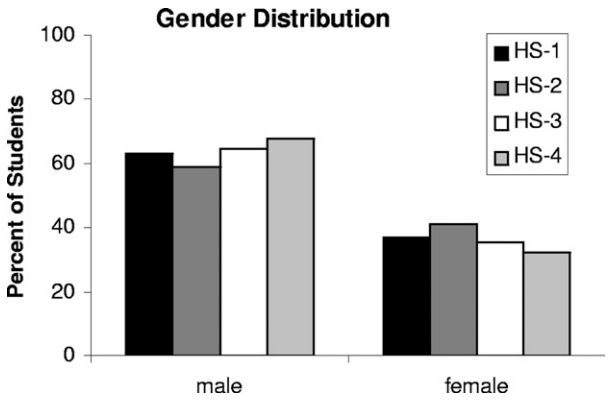

Figure 1 More boys than girls were referred as poor readers in every school. The distributions differed significantly by gender ($P < 0.0001$).

Results

Sex ratio

Of the 576 students selected by school personnel to be assessed for possible visual skill problems, 366 (63.5%) were boys. This proportion was the same as the average male-to-female ratio observed in each school when only the 461 cases in which data collection was complete were considered and represents a significantly higher referral ratio for boys than for girls ($P < 0.0001$, 2-tailed t test). In each of the high schools examined, the number of boys referred exceeded the number of girls (*see* Figure 1). Moreover, for both boys ($\chi^2 = 0.883$, degrees of freedom [df] = 3) and girls ($\chi^2 = 0.787$, df = 3), the distribution did not vary across the 4 schools. District-wide, 56.4% of students were boys and 52.5% were girls, according to statistics on their Web site.

Although the referral rate was higher for boys, we observed no significant male-to-female differences in any of the optometric variables measured. Therefore, in subsequent sections, data for girls and boys have been combined.

Visual acuity

Eye chart. Of the 461 students with complete data, 56.8% had 20/20 acuity in both eyes, 26.1% had between 20/20 and 20/40 in each eye, and 17.2% had 20/40 or worse in either eye (*see* Figure 2). The proportion of students in each category did not vary with school ($\chi^2 = 0.669, 0.301, 0.931$ for each of the 3 categories in Figure 3, with df = 3 in each), even though sample sizes were different (*see* Table 1).

Rx behavior. Students with acuity of 20/40 or worse—about 17% of the total population studied—tended not to wear corrective lenses (*see* Figure 3), either because they did not own glasses (72%, on average) or because they did not wear what they had (about 20%). Only 8% of the students in this study who needed corrective lenses actually wore them (*see* Figure 3).

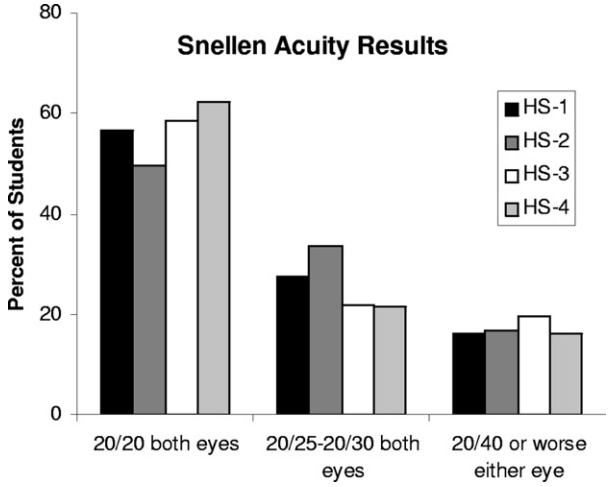

Figure 2 Snellen acuity for subjects in the study. No significant differences were found among schools ($P > 0.05$). More than 50% of students had 20/20 acuity in both eyes. An average of 17% had 20/40 or worse in either eye.

Significant differences did occur in glasses-wearing behavior across schools ($P < .01$ by χ^2 in each category), probably because of HS-2, where relatively more students had glasses but did not wear them when compared with the other schools. Because this was the only significant difference observed across schools, and because one of the goals of the current study was to measure visual skills while students wore their habitual correction, data from all 4 high schools were combined for most subsequent analyses.

Visual skills

Near point of convergence. Figure 4 shows the distribution of the *average* value for near point of convergence from the 3 measurements taken on each individual student. Whereas most (84.6%, N = 390) of the students had near points at 8 cm or closer, which would be considered "normal" for adults,[23] 15.4% had near point of convergence 9 cm or farther and would thus have convergence insufficiency diagnosed in a clinical setting.

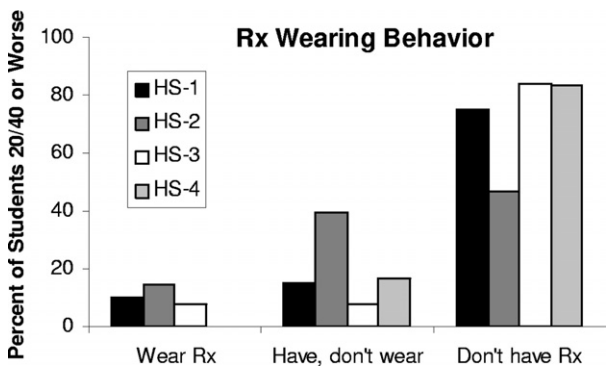

Figure 3 Students with acuity 20/40 or worse in either eye do not usually wear correction. Measurements in this study were taken while wearing habitual correction; on average, only 8% of subjects across schools have and wear glasses and contact lenses. About 20% have lenses but do not wear them, and more than 70% do not own corrective lenses.

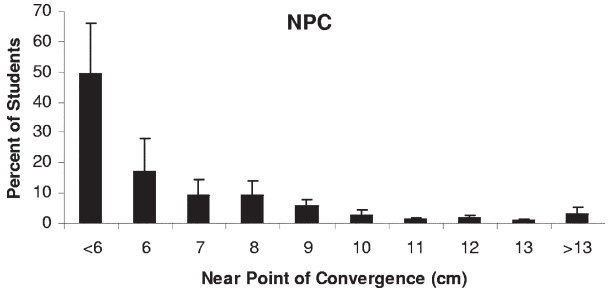

Figure 4 Average near point of convergence for the 461 subjects. Measurements were taken 3 times; the points plotted are the average and do not represent fatigue (below). "Normal" for adults has been considered to be 8 cm or closer.[23] By this criterion, 15.4% of subjects who are poor readers would fail. The error bars represent ±1 SEM across schools.

However, the *average* value of the 3 measurements provides a somewhat misleading picture, because 11.7% (N = 54) of the students also showed fatigue. That is, for these students, the near point of convergence receded away from the face as successive measurements were taken. It should therefore be noted that fatigue may be a problem for poor readers; even if they are able to converge at 8 cm, if they tire easily, then the ability to sustain convergence during longer periods of reading may suffer.

Convergence and divergence break and recovery. Figure 5 shows measurements of convergence break and recovery at near for the 461 students in this study. Although the modal values for convergence break and recovery were in the "very strong" category,[23] at 25 and 20 PD respectively, the distribution of values for both break and recovery are highly skewed. A large number of students had poor convergence skills: 38% break at less than 18 PD, and 9.5% recover at 7 PD or less. Both values are in the "weak" to "very weak" range.[23]

Figure 6 shows measurements of divergence break and recovery at near for the same students. In contrast to

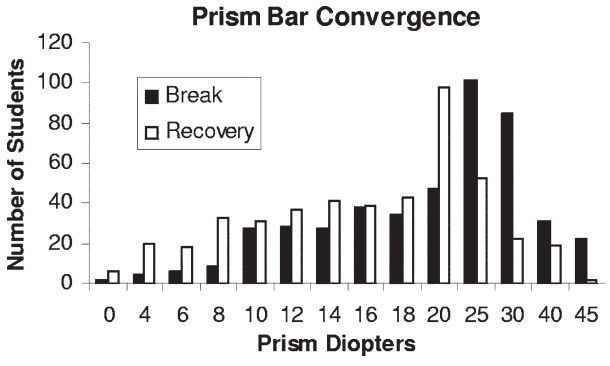

Figure 5 Horizontal prism bar measurements of base out (convergent) break and recovery of perceptual fusion from 461 high school students classified as poor readers by their teachers. Values are in PDs and are higher for break (*light bars*) than for recovery (*dark bars*). Note the skew toward lower values; adequate break and recovery for adult subjects[23] is greater than 18 PD and 7 PD, respectively.

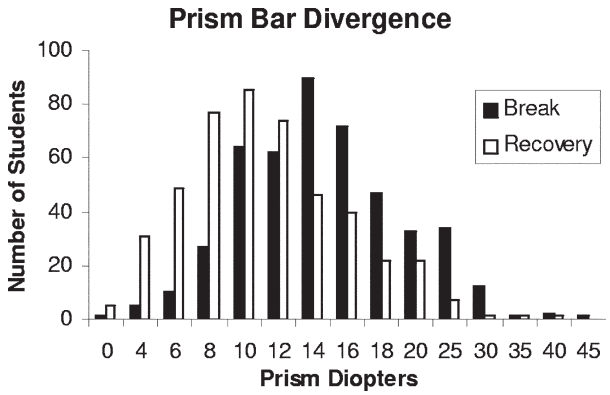

Figure 6 Horizontal prism bar measurements of base in (divergent) break and recovery of perceptual fusion from 461 high school students classified as poor readers by their teachers. Values are in PDs and are higher for break (*dark bars*) than for recovery (*light bars*). Note the absence of skew toward lower values; average expected minimum break and recovery for adult subjects[23]: 20 and 11, respectively. (The very high values are likely caused by exophoria and/or measurement error.)

convergence (*see* Figure 5), modal values for break (14 PD) and recovery (10 PD) were not in the "adequate" range but would be classified as "very weak" for break and "weak" for recovery.[24] As a result, very high percentages of students had poor divergence skills: 82% break at less than 20 PD, and 60% recover at less than 11 PD.

Figure 7 shows the re-fusion intervals for all students. Data from the 4 schools are shown separately for clarity; the pattern in each school was similar. The dashed line indicates the expected result if students' recovery of fusion was 1 prism bar step below their break; the solid line represents the expected values if fusion returns after 2 steps.

A relatively large proportion of students in each school fell below the solid line, meaning that for these students, binocular fusion was not recovered for 3 or more steps on the horizontal prism bar. For base out measurements, 19.6%

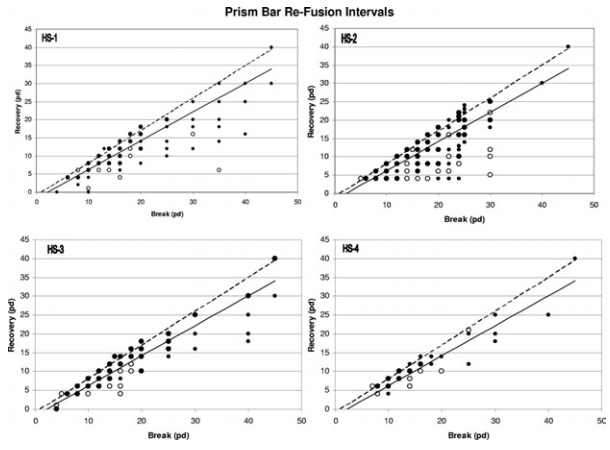

Figure 7 Scatterplots of break versus recovery of binocular fusion for base in (*open symbols*) and base out (*closed symbols*) horizontal prism bar measurements for all subjects. Lines represent a difference of 1 prism step (*dashed*) or 2 prism steps (*filled*) on the bar between break and recovery. A relatively large proportion of students in each school had re-fusion intervals of more than 2 prism bar steps.

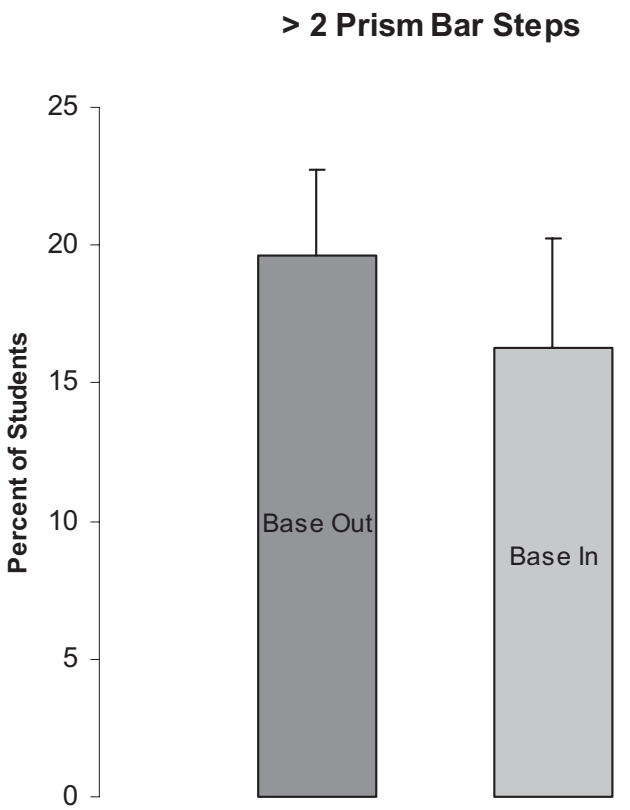

Figure 8 Percentage of students with more than 2 prism bar steps between break and recovery of binocularity. Error bars are ±1 SEM across schools.

(±3.1 SD across schools) had re-fusion intervals greater than 3 prism bar steps; for base out measurements, 16.3% (±3.99 SD) had re-fusion intervals greater than 3 prism bar steps. Depending on the position of the students' break on the bar, this difference could be as large as 25 PD as shown in Figure 8.

Near point of accommodation. Figure 9 shows the distribution of the *average* value for near point of accommodation from the 3 measurements taken on each student. Of the students tested, 63.8% (N = 294) had near points of 9 cm or

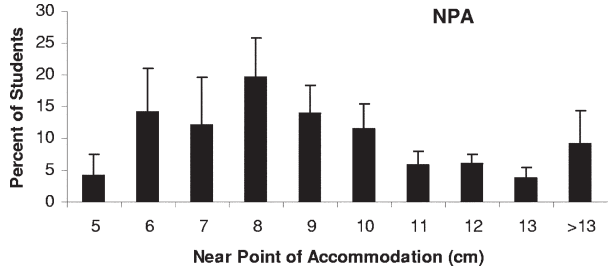

Figure 9 Average near point of accommodation for the 461 subjects. Measurements were taken 3 times; the points plotted are the average and do not represent fatigue (below). "Normal" for this age group has been considered to be 9 cm or closer.[23] By this criterion, 36.2% of subjects who are poor readers would fail. The error bars represent ±1 SEM across schools.

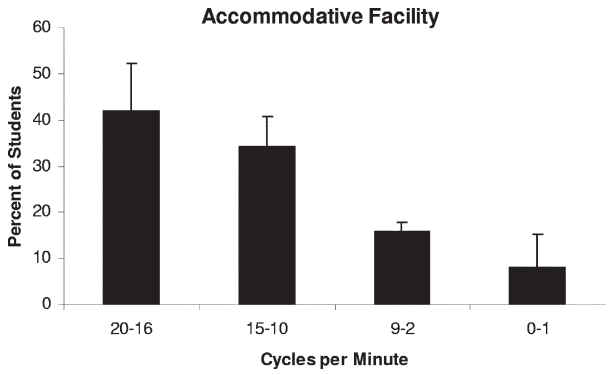

Figure 10 Average results for a 30-second ±2.00 D flipper test in cycles per minute. More than 20% of students were deficient in accommodative facility. Data are the average of 4 schools. Error bars, ±1 SEM.

closer (11 D), which is equivalent to the expected amplitude of accommodation for this age.[23] One hundred fourteen students (24.7%) had amplitudes of 11 cm or greater (9 D) and were thus "weak" or "very weak" according to values published by Griffin and Grisham.[23] The remaining 11.5% of students had accommodative amplitudes of 10 cm (10 D), which would place them in a "borderline" category.

As with the near point of convergence, we found that some students (14.5%, N = 58) experienced fatigue during the course of the 3 measurements of accommodative amplitude. For these students, the location of good focus moved away from them, so the average of the 3 measurements (plotted in Figure 9) actually yields a conservative estimate of the number of students who experience accommodative amplitude dysfunction.

Accommodative facility. Seventy-six percent of students tested had "adequate" monocular accommodate facility by the criteria in Griffin and Grisham.[24] The remaining 23.6% (N = 109) were "weak" or "very weak," with

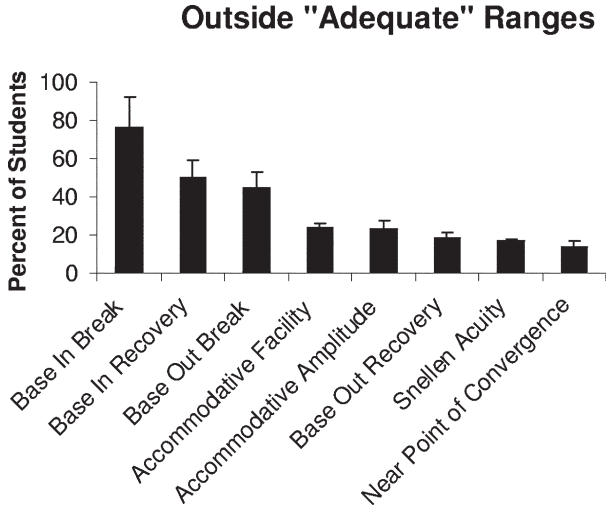

Figure 11 Percentage of students in this sample whose measurements were "weak" or "inadequate" by published clinical norms. Average of 4 schools; error bars, ±1 SEM.

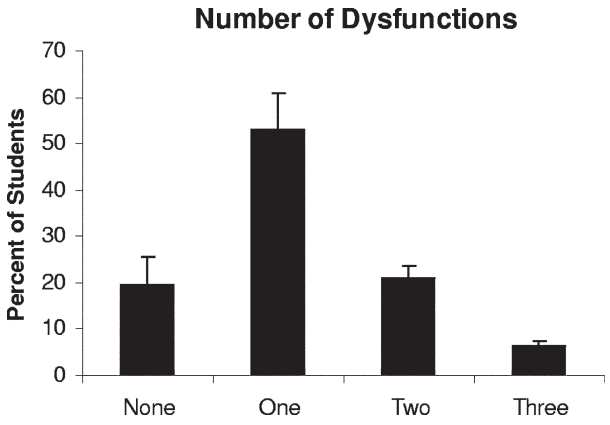

Figure 12 Distribution of subjects in the study according to how many areas of visual skill function they failed. The categories for this graph were binocular fusion and fusion intervals, accommodative function, and convergence insufficiency. Average of 4 schools; error bars, ±1 SEM.

values of 9 cpm or less. Thirty-seven (8.1%) of students achieved extremely low scores of 1 or zero cpm (*see* Figure 10).

Proportion of students with visual skill dysfunction

Figure 11 shows the percent of students who exhibited inadequate values, by published clinical standards[23] or school screening criteria,[24] on each of the visual functions measured in this study. It is clear that at least as many students in this sample suffer from visual skill difficulties as have unacceptable visual acuity for schoolwork according to the standards of the state of California.[24]

Interestingly, the proportion of students who have convergence insufficiency, as conventionally defined by an inadequate near point of convergence, approximately equals the proportion of students with visual acuity that would require referral by California school screening standards.[24]

It must be acknowledged that the proportion of students in any given category who are categorized as dysfunctional will depend critically on the criteria selected to define "dysfunction." That issue is important and will be revisited in the Conclusion section.

With the above caveat in mind, Figure 12 shows the percentage of students with 0, 1, 2, or 3 dysfunctional visual skill areas. For this graph, we considered the 3 "areas" of visual skills examined to be (1) fusion: any deficiency in base out or base in break or recovery, (2) accommodative function: poor accommodative amplitude and/or poor accommodative facility, and (3) near point of convergence.

Only about 20% of the students in this sample had "adequate" visual skills in all areas. Of the 80% who had some dysfunction, nearly half were deficient in more than 1 area of visual skills.

Conclusions

Our findings regarding sex distribution are consistent with reports published by others.[25] For reasons that remain unclear, boys are more likely to be referred for reading problems than girls. Although we found no evidence that the higher referral rate for boys is caused by visual factors, we were not equipped to examine this issue in detail.

The proportion of students who fail school screenings in California high schools is unknown, because schools are required to continue screening only through eighth grade. However, elsewhere in the literature, 15% to 25% of children age 15.4 years (the average in this study) have been shown to have acuity problems that warrant referral.[26] Thus, the findings regarding acuity in this study are consistent with other reports. It is also disturbing that so few students wear corrective lenses in high school. Perhaps making contact lenses and attractive frames more available to low-income patients would facilitate better compliance.

Eighty percent of the students passed visual acuity testing with 20/40 or better, yet only 20% had adequate visual skills. Given that distance visual acuity is not generally associated with reading difficulties,[27] the apparent disconnect between acuity and visual skills in this study is not surprising. The literature in fact suggests that myopic refractive error is associated with good reading, whereas hyperopic error is associated with poor reading.[28] Because distance measures of visual acuity typically used in school screenings tend to reveal myopia and not hyperopia, students who are at risk for reading problems caused by hyperopia will be missed.

Nonetheless, the number of students in the current study who were found to have dysfunctions in visual skills related to vergence and/or accommodative function seems very high, even though we used standard measurement techniques and published clinical criteria. Here are some of the reasons why the proportion of students with visual skill problems might be so large.

1. **Measurement error.** If the individuals who performed the measurements were inadequately trained, the results could be unreliable or invalid or both. If they were unreliable, we should have seen much higher variability across schools than we observed (especially with the large number of testers involved). A lack of validity is also unlikely because optometrists not only trained each individual tester, but also were present and actively taking measurements themselves at each school. Thus, we do not believe that the consistently high percentages are caused by measurement error.
2. **Definition of clinical criteria.** Any decision about whether "dysfunction" exists depends completely on the definition of "dysfunction" that one selects. For this study, we used the standards previously published in a standard textbook,[23] which were in turn distilled from the optometric literature at large. Most of the standards apply to adult vision and, of course, if one selected less stringent criteria, then the proportion of students with any given dysfunction would decrease. However, to reduce the proportion of students with dysfunctions in 1 or more areas to around 15% (instead of about 80%—*see* Figure 12), drastically lower criteria than are typically used in clinical assessments would be needed.
3. **High school students with reading problems tend to have deficient visual skills.** This is the reason we favor, and a recent study demonstrated this relationship in middle school students[13]; however, the data we present does not prove the point because of the relatively loose definition of "reading problems." Like all other variables, "reading problems" must be defined carefully to draw firm conclusions. Thus, the strongest statement we can make based on the data presented is the following:

When standard optometric tests of binocular and accommodative function were applied to high school students whose reading was 2 or more levels below grade, many more of them were found to be deficient in visual skills than were deficient in distance visual acuity. Considered another way, the results of this study show that although 60% of students who read poorly in high school have 20/20 acuity, only 20% have "adequate" visual skills. We suggest that poor readers in high school are at high risk for visual skill dysfunction and that the relationship between visual skill dysfunction and reading performance should be rigorously examined in future studies.

Acknowledgments

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