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Reference intervals for visual acuity and contrast sensitivity of a school population in Pereira, Colombia*

Intervalos de referencia de agudeza visual y sensibilidad al contraste en una población escolar de Pereira, Colombia

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ABSTRACT

Introduction: The tests that assess visual acuity (VA) and the contrast sensitivity function (CSF) allow to quantify and evaluate vision quality. In Colombia, reference intervals for these two visual tests have been established based on parameters mainly found in foreign populations. *Objectives*: To determine reference intervals for VA and CSF in a healthy school population aged 5 to 19 years in Pereira, Colombia. Materials and methods: In this descriptive cross-sectional study, 626 subjects aged 5 to 19 years were evaluated in a random two-stage cluster sample. VA was evaluated using logMAR charts, and CSF was assessed using CSV 1000E. *Results*: The study found that in a normal subject aged 5 to 19 years VA oscillates between −0.20 and 0.10 logMAR, with a median of 0.0. VA is higher between 15 and 19 years of age; in addition, men have higher VA. The normal intervals for CSF, using CSV 1000E at spatial frequencies of 3, 6, 12, and 18 cpd, are: 1.49 logSC and 2.08 logSC; 1.70 logs and 2.29 logs; 1.40 logSC and 1.99 logSC; and 0.96 logSC and 1.55 logSC, respectively. *Conclusions*: VA in school children aged 5 to 19 years is similar to the values reported in the literature, while CSF is lower at low spatial frequencies.

Keywords: visual acuity, contrast sensitivity, reference intervals, vision tests.

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RESUMEN

Introducción: las pruebas que evalúan la agudeza visual (AV) y la función de sensibilidad al contraste (FSC) permiten cuantificar e identificar la calidad de la visión. En Colombia, los intervalos de referencia para estas dos pruebas visuales se han establecido a partir de parámetros hallados principalmente en poblaciones foráneas. *Objetivos*: determinar los intervalos de referencia de la AV y la FSC en una población escolar sana de 5 a 19 años de Pereira, Colombia. *Materiales y métodos*: estudio descriptivo-transversal en el que se evaluaron 626 sujetos entre los 5 y los 19 años de edad, identificados en un muestreo aleatorio por conglomerados bietápico. La AV se evaluó con cartas tipo logMAR y la FSC, con el CSV 1000E. *Resultados*: se encontró que la AV en un sujeto normal entre los 5 y los 19 años oscila entre −0,20 y 0,10 logMAR, con una mediana de 0,0. La AV es superior entre los 15 y los 19 años; así mismo, los hombres presentan mayor AV. El intervalo de normalidad de la FSC con CSV 1000E en las frecuencias espaciales de 3, 6, 12 y 18 cpd son 1,49 y 2,08 logSC; 1,70 y 2,29 logSC; 1,40 y 1,99 logSC y 0,96 y 1,55 logSC, respectivamente. *Conclusiones*: en relación con la literatura, la AV en escolares entre los 5 y los 19 años es similar y la FSC es menor en las frecuencias espaciales bajas.

Palabras clave: agudeza visual, sensibilidad al contraste, valores de referencia, pruebas de visión.

INTRODUCTION

According to the World Health Organization (WHO), valid, reproducible, and reliable assessment methods are required for the detection, diagnosis, prognosis, and management of diseases that affect the quality of life of individuals, such as alterations in the visual and ocular system. Professionals use logarithm of the minimum angle of resolution (logMAR), HOTV, and Snellen charts among others to measure visual acuity (VA) and the Pelli–Robson test, the MARS test, the functional acuity contrast test (FACT), the visual contrast sensitivity test (VCTS), or CSV 1000E to assess contrast sensitivity function (CSF). Evaluation results are compared with reference intervals that allow for the interpretation of the clinical trial. The assessment of VA and contrast sensitivity using vision tests allows us to quantify as well as identify the quality of vision.

In Colombia, VA is the most widely used parameter to determine a person's vision, with the Snellen chart being the most commonly used eye chart to measure VA. This chart has several disadvantages, one of which is the unequal number of optotypes between lines and variable spacing between optotypes, thus affecting recognition and visibility of each of the lines. These irregularities may lead to the over or underestimation of the ability to see (1). LogMAR charts, on the other hand, allow more accurate estimates of VA (2).

Several authors (3,4) have analyzed their own results, as well as those of other studies to determine if VA presented changes in subjects of different age groups. To establish these variations, data were adjusted to the following linear regression: $logMAR\ AV = 0.0021 \times age - 0.20$. They found that VA improved between age 18 and 24 (−0.13 to −0.16 logMAR); however, after age 25, VA decreased until 75 years of age (−0.02 logMAR). These researchers do not indicate what should be the vision cut-off points in different age groups, and based on only the graphs presented, it can be assumed to be approximately 0.05 logarithmic units, which corresponds to a standard deviation.

Data submitted by Elliot (3) and Pan et al. (5) demonstrated a VA that was superior to Pitts' (6). Pitts reported that VA after birth was poor (1.70 logMAR, 20/1.000 to 1.60 logMAR, 20/800), which improved to an almost normal VA (0.0 logMAR, 20/20) during the first year of life.

In Colombia, Molina and Figueroa (7) estimated reference intervals for VA in a group of children aged 3–6, using Lea symbols and HOTV; they found that the median for VA was similar at these ages (0.0 logMAR, 20/20), but the 95th percentile pointed out that the cut-off point for VA should be 0.1 logMAR (20/25) in children aged 5–6; however, this study did not include statistical tests that would allow the identification of significant differences between evaluated ages.

Similar to our study, Larsson, Rydberg, and Holmström (8) used VISTECH VCTS 6500 (different spatial frequencies and stimuli for grids) to measure CSF in 420 children, with an average age of 10 years; they found that CSF was higher in full-term children and slightly lower in preterm children. Average values for spatial frequencies of 1.5, 3, 6, 12, and 18 cycles per degree were 1.73, 2.11, 2.13, 1.92, and 1.49 logarithm for contrast sensitivity (logCS), respectively. VectorVision, the manufacturer of CSV 1000E, proposed normal values for two age groups: 6–10 years and 11–19 years. For the younger age group, CSF evaluated for spatial frequencies 3, 6, 12, and 18 cycles per degree were 1.82, 2.04, 1.74, and 1.29 logCS, respectively, and for the adolescent group, they were 1.92, 2.19, 1.89, and 1.42 logCS, respectively.

Medina et al. (9) measured CSF with the VCTS 6500 in different age groups in Mexico and showed that the CSF curve was less than quoted as normal for the implemented test; however, result presentation is poor, which does not allow a clear understanding of the conclusions.

In Colombia, López (10) determined the reference curve for CSF using the FACT on a group of children aged 6–12 years and reported that values obtained were similar to those obtained from adults; however, León et al. (11), using CSV 1000E in a sample of 50 children (aged 7–10 years), found that CSF was almost the same as that reported by López only for low spatial frequencies, but CSF was greater for higher spatial frequencies.

The reviewed studies showed an approximation to reference values for VA and CSF; however, as shown by other studies, the components of the visual system, such as accommodation-convergence relationship (12), the lag (13), and the amplitude of accommodation (14), yielded different results from those found in other populations. In addition, studies on VA and CSF performed in Colombia had limitations of small sample size and sampling for convenience; these can create few inference possibilities of results in different populations.

All these confirm the need to identify reference intervals for the optometric tests, such as those for VA and CSF, with the goal to design and propose standards that facilitate the identification and treatment of preventable visual impairment in minors.

MATERIALS AND METHODS

A descriptive cross-sectional study was used to determine reference intervals for VA in age groups 5–9 years (Group 1, schoolers), 10–14 years (Group 2, schoolers), and 15–19 years (Group 3, adolescents), according to the classification of the WHO.

The study population consisted of subjects enrolled in public educational institutions in the city of Pereira, Colombia, registered with the Secretary of Education, between the ages of 5–19, selected according to matters raised by randomized multistage cluster sampling; the unit of sampling for the first stage was public schools in the city of Pereira and for the second stage it was the classrooms as final cluster. The units of analysis were the students.

Sample sizes were estimated as suggested by Silva (15) and selected as the primary parameter to determine the demographic mean. Further details were taken regarding relative error, with a maximum of 10%, considering that the approximate average values for different age groups vary, with a reliability of 95% and a type I error of 0.05. Based on this, we calculated a minimum of 121 subjects per group.

Ametropias diagnosed in the subjects were corrected, as they previously underwent an assessment with objective and subjective refraction techniques. Subjects with ametropias of >+/−3.66 dpt in the spherical component and −2.25 dpt in cylindrical values, nystagmus or neurological alterations, amblyopia, strabismus, and alterations or pathologies of the anterior and/or posterior segment as well as those who did not complete all scheduled tests were excluded.

For the assessment of VA in this study, we used logMAR charts, whose design allows control of the size's progression, size range, number of optotypes per line, and spacing between optotypes, which helped in the standardization of the test. Sloan font, which is a non-serif font, such as that used in Snellen optotypes, ensures that the letters included are readable.

The chart was located 3 *m* away from the subject, which used the obtained correction with the subjective refraction. VA for each eye and binocular vision was evaluated. In the test, one eye was blocked, and the subject was asked to name aloud the optotypes as he saw them, starting at the lowest level (0.9 logMAR, 20/160) and continuing up to the maximum reachable level. The test was stopped when the subject committed two consecutive errors or when he stated incapability to identify more optotypes. VA was registered in logMAR units with the following formula:

$$VA = HVLR - (E \times 0.02)$$

Where HVLR is the highest visual level reached (in units of the logarithm of minimum angle of resolution), *E* is the number of errors found in each level, and 0.02 is the constant corresponding to the value of the optotype. It should be clarified that when the level of only three optotypes per line was reached, the constant changed to 0.03, and at four figures per line, the constant was 0.025.

CSV 1000E was used to assess CSF for four spatial frequencies in eight levels of contrast, with a back monitor of diffuse light and a sensor (self-standardization) for controlling the amount of light in each stimulus. Answers obtained with this test were not influenced by the minor's development of laterality.

The test was conducted on each eye individually and for binocular vision. The test always started by blocking one eye and with any of the four spatial frequencies (3, 6, 12, or 18 cycles per degree). The CSV 1000E chart was located 3 *m* away from the subject, and one row of the chart was lightened up at a time at random. The subject was asked to indicate in which of the two rows of round patches the grid pattern was located. The subject could answer "up," "down," or "not seen." The test was stopped whenever the patient committed two consecutive errors or stated it impossible for him to show where the lattice pattern was. The test was continued with the other spatial frequencies. Data were recorded in the logCS, which is found in the device's instructions manual.

This study was approved by the Bioethics Committee of the Autonomous University of Manizales under Record No. 037 of 2014. The study was conducted in compliance with Resolution 8430 of 1993 by the Ministry of Health, and informed consent for minors was obtained from legal guardians.

To facilitate statistical analysis, results of VA and CSF are expressed in logMAR and logCS units, respectively. Distribution was assessed according to a standard normal using the Kolmogorov–Smirnov test; according to the results, the mean and median were used as center measures and percentiles, whereas standard deviation was used as a measure of dispersion. Parametric and non-parametric tests were used in hypothesis contrast following the compliance of specific conditions in the distribution of data. Analyses were conducted using the Stata Software, Version 12.0.

RESULTS

The study sample consisted of 626 subjects (57% females, 43% males). Children were grouped according to age: 37% was children aged 5 to 9 old (230 subjects), 29% was children aged 10 to 14 years old (185 subjects), and 34% was children aged 15 to 19 years old (211 subjects). The population evaluated was distributed according to their academic degree: 60% (377 subjects) of them were primary school children aged 5 to 12 years old who, according to the WHO, are schoolers, and 40% (249 subjects) were high schoolers aged 12 to 19 years old.

No differences in VA were found between RE and LE (Wilcoxon signed-rank test: 0.001 logMAR; p = 0.519); therefore, it was decided to continue the analysis only with data on RE.

Analysis of Visual Function

VA and contrast sensitivity have a non-normal distribution (Kolmogorov–Smirnov test, $p < 0.0001$ for both tests), for which it is appropriate to use non-parametric statistical methods for the analysis of data.

Visual Acuity

In general, the median of VA in the examined population is 0.00 logMAR, with a range between the 5^{th} and 95^{th} percentile of four lines of VA (–0.02 to –0.10 logMAR).

Among the age groups, VA varies (Kruskal-Wallis, $p < 0.0001$), and it is evident that the median of VA is superior in one line for the age group of 15–19 years compared with the other groups (Table 1).

TABLE 1. **Visual acuity (logMAR units) according to age groups**

Age group (years)	Percentiles		
	p5	p50	p95
5–9	0.1	0	0.1
10–14	–0.2	0	0.1
15–19	–0.2	–0.1	0.0

In the distribution by sex (Figure 1), it is evident that VA in males (p50 = –0.08 logMAR) is greater than that in women (p50 = 0.00) (Wilcoxon signed-rank test, p = 0.003) in approximately one line of VA. However, the range is similar for both groups (p5 = 0.20 logMAR and p95 = 0.10 logMAR).

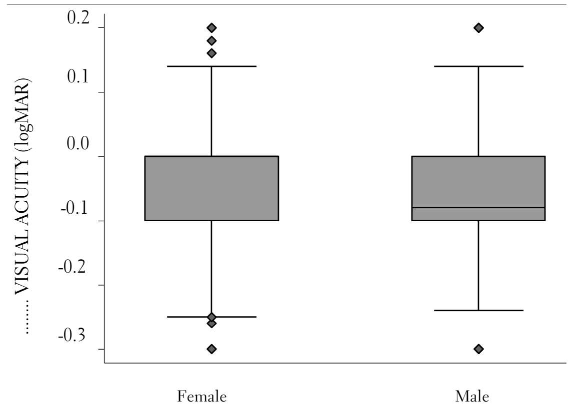

FIGURE 1. **Distribution of visual acuity according to sex**

Contrast Sensitivity Function

Table 2 shows the median of logCSF obtained with CSV 1000E.

TABLE 2. **Distribution of the logarithm of the contrast sensitivity with CSV 1000E in the school population. Percentiles are shown for 5%, 50% (median), and 95%**

Contrast Sensitivity (Cycles per Degree)	Percentiles		
	p5	p50	p95
Frequency 3	1.49	1.68	2.08
Frequency 6	1.70	2.14	2.29
Frequency 12	1.40	1.84	1.99
Frequency 18	0.96	1.40	1.55

Figure 2 represents percentiles 5 and 95 for reference intervals of CSF with CSV 1000E, and the graph is divided by a red dotted line, which represents the union of medians of each spatial frequency. A slight dispersion of data toward low spatial frequencies of the test can be observed, whereas a slight tightness in reference intervals toward high spatial frequencies is also seen.

No significant differences were observed in contrast sensitivity between age groups (Kruskal-Wallis test, p = 0.275, p = 0.944, p = 0.232, p = 0.565, respec-

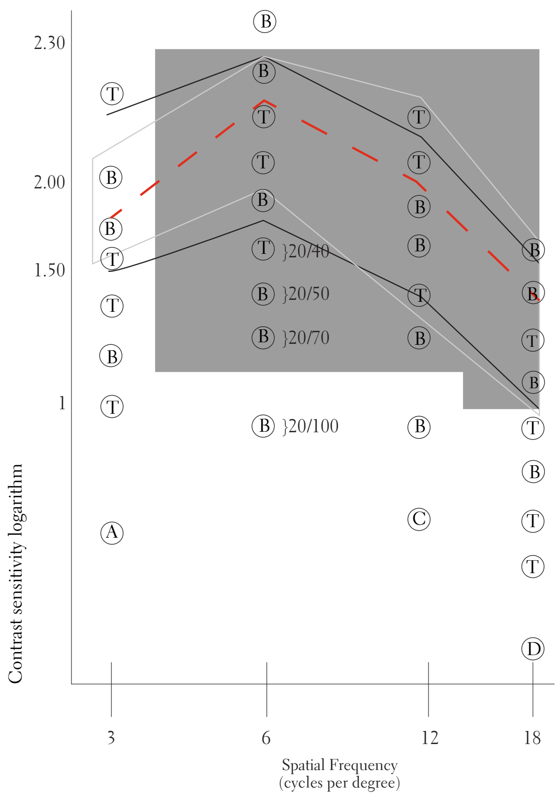

FIGURE 2. **Intervals of the contrast sensitivity function with CSV 1000E in age groups starting from the normality curve**

tively). Clinically, a difference of 0.15 logCSF is not significant, which was reported in the age group of 15–19 years in low spatial frequencies (3 cycles per degree), and the age group of 10–14 years for mean spatial frequencies (6 cycles per degree). The same behavior was observed in the mean spatial frequency, in relation to the analysis by sex, with greater contrast response in men but without clinical significance ($p > 0.05$).

DISCUSSION

VA values obtained in the present study are consistent with those reported by other authors such as León and Estrada (1) and Molina and Figueroa (7), who showed that VA in children aged 3–6 years has a range of –0.20 logMAR at the 5 percentile and 0.20 logMAR at the 95 percentile, with a median of 0.0 logMAR, compared with data from this study.

TABLE 3. **Distribution of the contrast sensitivity function (logCS) with CSV 1000E in age groups. A p-value of <0.05 was considered**

Age Groups (years)		Percentiles			p Value
		5	50	95	
logCS 3	5–9	1.49	1.68	2.08	0.275
	10–14	1.49	1.68	2.08	
	15–19	1.49	1.68	1.93	
logCS 6	5–9	1.7	2.14	2.29	0.944
	10–14	1.7	1.99	2.29	
	15–19	1.7	2.14	2.29	
logCS 12	5–9	1.33	1.84	1.99	0.232
	10–14	1.4	1.84	1.99	
	15–19	1.4	1.84	1.99	
logCS 18	5–9	0.96	1.4	1.55	0.565
	10–14	0.96	1.4	1.55	
	15–19	0.96	1.4	1.55	

Sonsken et al. (16) suggested that the VA median in children aged 5–8 years is –0.08 to –0.15 logMAR, similar to results of other authors such as Drover et al., Rincón and Rodríguez (17), Merritt et al. (18), and Sanker et al. (19), who defined normal values of VA for ages >5 years in the range of –0.13 to –0.10 logMAR (20/15–20/25 Snellen), thus supporting our findings.

In this study, there was a slight tendency for VA to increase with age (3,5,20); however, the dispersion does not allow it to be clinically representative.

Results obtained in this study showed that there are differences in VA based on sex because the value is higher in men for one line of vision than in women. Although there are no specific differences in visual function according to sex, major efforts have been devoted to compare such performance between men and women in various tasks in the cognitive domain, for which differences in visual perception have been contemplated, having to do with the visuospatial function, the ability to visualize or mentally manipulate geometric objects (21,22).

It is important to recognize that our results are comparable when VA is evaluated with similar protocols and clinical evaluation charts. To reduce bias of this type, we used the logMAR chart for VA, which is based on "the logarithm of the minimum angle of resolution." This standard chart is recommended by organizations such as the International Council of Ophthalmology, WHO, or the Royal College of Ophthalmologists, as the number of figures in each level and spacing between optotypes, both horizontal and vertical, can be controlled (1).

As the purpose of assessing VA tests should be early detection of alterations such as amblyopia, the criterion for referral of patients aged 5–19 years with a VA of <0.10 logMAR (20/25 Snellen) should be considered as subjects who present a visual problem and therefore require a complete assessment of their visual function.

The American Academy of Pediatrics, the American Association of Pediatric Ophthalmology and Strabismus, and the American Academy of Ophthalmology recommend that a pediatric patient should be referred for evaluation by optometry when there are two lines of VA difference between the right eye and left eye, and when the visual acuity is <20/40 Snellen (0.30 logMAR), a criterion that should be taken cautiously in the study population.

Regarding CSF, the curve was slightly lower than that reported by Krásny et al. (23) in a group aged 6–20 years (Figure 2). In addition, lines delimiting a standard deviation are broader. This study also found that the shaded zone that delimits the normality area proposed by the manufacturer is much more extensive, and the 5th and 95th percentiles are evidence that the area has a similar range, although broad for the lower spatial frequencies. The latter is consistent with that reported by León et al. (24), who, in a sample of elementary schoolers, found that limits were broaded in the same frequencies.

It is important to note that the greater amplitude of the area of normality described by the manufacturer is because it involves a much wider age range (6–75 years); in fact, in elderly persons, the contrast sensitivity curve tends to decrease mainly toward high spatial frequencies; this may be due to the presence of pathologies of the fundus of the eye (such as age-related macular degeneration) or cataract. Therefore, it should be borne in mind that for the age group evaluated, the range of the normal area is narrower, so alterations in the eye should be suspected when the curve of a subject is at least 0.15 units of logCSF (a contrast step) above the lower limit stated by the manufacturer.

With respect to López's work (10), comparison of values in different spatial frequencies is not possible, as the author's analysis was based on the level (steps) of contrast achieved by each patient and not the threshold or contrast sensitivity, that is, if the subject reached step number 6.

The strength of this investigation lies in the number of evaluated subjects, which made it possible to estimate the normal ranges for these age groups with a confidence level of 95%.

Finally, "average" values and ranges of VA from far and near are like that reported in other studies, but caution should be exercised with regard to the point when the presence of altered vision is suspected, because for VA, the minimum value would be 0.2 logMAR (20/32) and for CSF the threshold would be approximately 0.15 logarithmic units lower than that cited as normal by other authors and the test manufacturer.

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CONFLICTS OF INTEREST

The authors hereby declare that they have no conflict of interest in the research.

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