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Statistical normal values of visual parameters that characterize binocular function in children

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Abstract

A wide range of visual parameters used to evaluate binocular function were evaluated in a paediatric population (1056 subjects aged 6–12 years). Mean values are provided for these ages in optometric tests that directly assess the vergence system, horizontal phorias for near and far vision (measured by a modified version of the Thorington method), negative and positive vergence amplitude for near and far vision (step vergence testing), vergence facility (flippers 8 Δ BI/8 Δ BO), and near-point of convergence (penlight push-up technique and red-lens push-up technique), as well as stimulus accommodative convergence/accommodation ratio and stereoacuity (Randot test) which provide an overall evaluation of the vergence, accommodative and oculomotor systems. A statistical comparison (ANOVA and Bonferroni *post hoc* test) of these values between ages was performed. The differences, although statistically significant, were not clinically meaningful, and therefore we identified two trends in the behaviour of these parameters. For all parameters, except for vergence facility, we established a single mean reference value for the age range studied. The difference between the means for vergence facility indicated the need to divide the population into two age ranges (6–8 and 8–12 years). This study establishes statistical normal values for these parameters in a paediatric population and their means are a valuable instrument for separating children with binocular anomalies from those with normal binocular vision.

Keywords: age, binocular function, children, population means, vergence system

Introduction

Because of the high incidence of binocular anomalies, especially in schoolchildren, a routine examination or visual-screening programme should include tests to detect a wider range of these problems (Bailey, 1998). The American Optometric Association (1994) clearly suggests that the diagnosis and treatment of alterations of accommodation and binocular vision should be a priority aim for the entire paediatric population, but for this it is necessary to know the normal mean results of various visual tests at different ages in order to classify an individual child as normal or abnormal, as indicated by Scheiman and Wick (2002).

Several norms concerning parameters that characterize binocular function for the population have been reported (Morgan, 1944; Scobee and Green, 1948; Saladin and Sheedy, 1978; Wesson, 1982; Freier and Pickwell, 1983; Scheiman *et al*., 1989; Hayes *et al*., 1998; Walline *et al*., 1998; Scheiman *et al*., 2003), although there are several problems in using these data (Sheedy and Saladin, 1983). As indicated by Rutstein and Daum (1998), some clinical data suffer from poor reliability, and an abnormal finding cannot be discriminated from the norm if it differs by less than the normal variation. In addition, several studies available do not agree in the diagnostic criteria used to classify accommodative and binocular disorders (Duane, 1897; Tait, 1951; Grisham, 1980; Daum, 1983; Hokoda, 1985; Macfarlane *et al*., 1987; Wick, 1987; Scheiman and Wick, 2002), these having been presented only for binocular anomalies

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(Rouse *et al.*, 1998; Borsting *et al.*, 1999; Cacho *et al.*, 2002). In addition, few studies deal with the study of means for these parameters in populations which are exclusively paediatric: examples include near point of convergence (NPC) (Duane, 1926; Allen *et al.*, 1975; Hayes *et al.*, 1998; Chen *et al.*, 2000), phorias (Jackson and Goss, 1991; Letourneau and Giroux, 1991; Walline *et al.*, 1998; Chen *et al.*, 2000), step vergence testing (Wesson, 1982; Scheiman *et al.*, 1989), vergence facility (Scheiman *et al.*, 1996), accommodative convergence/accommodation (AC/A) ratio (Mutti *et al.*, 2000) and stereoacuity (Romano *et al.*, 1975; Tomac and Altay, 2000). Despite these problems, studies on means constitute a sound, first-order way to judge a patient's potential for binocular dysfunction.

As with accommodative dysfunctions, anomalies of the vergence system cause a great variety of symptoms that interfere with visual comfort and academic performance. The visual parameters normally used for characterizing the vergence system are: near and far horizontal and vertical phorias, near and far negative and positive fusional vergence, vergence facility and NPC. Other parameters, such as negative relative accommodation, positive relative accommodation, binocular accommodative facility, stimulus AC/A ratio and stereoacuity, evaluate the interaction between the vergence and accommodative systems.

Measurement of the near and far horizontal phorias often constitutes the starting point of the binocular evaluation, as most of the binocular anomalies are partially defined by this near/far relationship (Scheiman and Wick, 2002). Values for horizontal and vertical phoria (near and far) have been reported and studies agree in finding a lack of relationship with age in the infant years, despite the different methodologies used in the measurements (Jackson and Goss, 1991; Letourneau and Giroux, 1991; Schroeder *et al.*, 1996; Walline *et al.*, 1998; Chen *et al.*, 2000; Scheiman and Wick, 2002).

Horizontal vergences are disconjugate horizontal fusional movements of the eyes (Wesson, 1982), and the tests that evaluate these movements determine the amplitude (break and recovery point) of near and far fusional vergence. Standards for vergence have been established by many researchers (Morgan, 1944; Wesson, 1982; Scheiman *et al.*, 1989), although, as noted by Grisham (1980), it is possible to have normal fusion amplitude and still have problems such as dysfunction of fusional vergence. Thus, additional tests are required, such as vergence facility, because it is possible to have normal fusional vergence amplitudes and experience vergence facility problems (Scheiman *et al.*, 2003). Numerous works incorporate this test in their study, but there is no consensus on the appropriate prism values, which vary from 8 Δ BI and 8 Δ BO (Stueckle and Rouse, 1979; Atkinson *et al.*, 1980; Mitchell *et al.*, 1980) to 16 Δ BO and 4 Δ BI (Buzzelli, 1986; Scheiman and Wick, 2002). In a recent work, although in an adult population, Gall *et al.* (1998b) performed the first systematic study of vergence facility and found that the magnitude of choice is 3 Δ BI and 12 Δ BO, because of its sensitivity in separating symptomatic from non-symptomatic subjects, and repeatable results when used for near-vergence facility testing.

The NPC is another important visual parameter used to evaluate the vergence system, and a value deviating far from the normal NPC is used as one of the main signs to diagnose convergence insufficiency (Borsting *et al.*, 1999; Scheiman and Wick, 2002). A few studies have investigated the age effect of the NPC and found no significant change with increasing age (Scobee and Green, 1948; Mellick, 1949), whereas Hayes *et al.* (1998) and Chen *et al.* (2000) found that the NPC tends to decrease with age in children.

Stereopsis is one of the parameters used to evaluate the interaction of the vergence and accommodative systems. Stereopsis is the binocular recognition of disparity, and some patients with large phorias, intermittent strabismus, poor vergence ability, severe symptoms, and poor performance can summon the resources to reach a good level of stereopsis while the test is being performed (Rutstein and Daum, 1998). As in other visual parameters, there is no consensus on the age at which stereopsis reaches the adult values, results perhaps being influenced by the measurement method used (Romano *et al.*, 1975; Cooper *et al.*, 1979; Simons, 1981; Tomac and Altay, 2000).

The stimulus AC/A ratio determines the change in accommodative convergence that occurs when the patient accommodates or relaxes accommodation by a given amount, and is an important parameter for differential diagnosis in anomalies of binocular vision (Scheiman and Wick, 2002). In contrast to the universal agreement on the age-related reduction in accommodative amplitude (Hofstetter, 1944; Chen *et al.*, 2000; Jiménez *et al.*, 2003), considerable disagreement surrounds age-related changes in the AC/A ratio throughout life: increasing (Davis and Jobe, 1957), decreasing (Alpern and Larson, 1960) or remaining constant (Morgan and Peters, 1951; Ogle *et al.*, 1967; Ciuffreda *et al.*, 1997; Mutti *et al.*, 2000).

In a previous work, we determined the behaviour of the parameters used to evaluate the accommodative function of the oculomotor movements in infants (Jiménez *et al.*, 2003). In the present work, we analyse the behaviour of those visual parameters used for direct evaluation of the vergence system (near and far horizontal and vertical phoria, near and far negative and positive fusional vergence, vergence facility, NPC), as well as other parameters used to evaluate vergence and accommodative function (stimulus AC/A ratio and stereoacuity). In this way the expected values of visual examinations at different ages can be established. Obtaining means for these parameters from a large normal infant population, allows their use in optometric practice as cut-off values in the diagnostic criteria of non-strabismic binocular anomalies during infancy.

Materials and methods

Using the criterion of authority as the non-probabilistic selection method (Silva Ayçaguer, 1993), we chose three elementary schools in the city of Granada (Spain) having similar sociocultural levels and the same age range. Once the present work was approved by the administration and parent–teacher organizations of the three schools, we processed a report for each student detailing the objectives, such as the detection and measurement of possible defects in refraction in addition to the testing of certain visual parameters possibly related to academic performance.

For a total sample of 1167 Spanish-speaking subjects aged from 6 to 12 years (498 females and 558 males) who at the time of the test were studying in the first to the sixth grades in the public elementary schools, authorization in writing was requested from the parents. Of the total, 92 (7.9%) of the subjects failed to provide authorization without giving a reason, resulting in a sample of 1075 subjects. Of these, 19 (1.6%) did not complete the examination: 12 due to lack of co-operation and inability to take subjective tests, as they were in special-education programmes; one presented corneal opacity; and six revealed suppression in the Worth test for far vision or at a distance of 40 cm. The remaining 1056 subjects (90.5%), participated in the study voluntarily, although for various reasons (mainly, lack of attention, cooperation, motivation or understanding of the children) not all the subjects completed all the visual tests, as reflected in the different tables listing the statistical results for these parameters.

The data were collected from March to June 2000 and October to June 2001 in the respective schools during school hours and in the rooms designated for this purpose. The students were subjected to a visual examination consisting of a battery of tests, once the subject had been compensated for possible ametropia, evaluated by static retinoscopy, and confirmed by subjective refraction. Where possible, objective methods were used to avoid dependence on responses from the child, and the tests were also chosen to maintain the habitual conditions of the individual's visual environment.

The tests administered and the methodology are described below:

Negative and positive fusional vergence (near and far)

Near and far negative vergence amplitude by steps as well as near and far positive fusional vergence by steps were measured (Calvin *et al.*, 1996; Scheiman and Wick, 2002). The age of the subject determined the choice of the measurement method (Scheiman and Wick, 2002). In this case, the positive fusional vergence or convergence and negative fusional vergence or divergence, near and far, were measured by steps (not smooth), with bar prisms to control the response of the subject by the position of the eyes, making the test more objective (Scheiman and Wick, 2002). For both near and far, the negative fusional vergence was measured with base-in prisms (BI) to avoid affecting the value for vergence recovery (Rosenfield *et al.*, 1995) because of excessive stimulation of convergence. For the far measurement, a vertical column was selected in which a line of the Snellen optotype E appeared, corresponding to the highest visual acuity (Calvin *et al.*, 1996). In near measurements, the subject was supported in a chin rest placed at 40 cm from the tripod where the test was set up: this was a fixation stick of 20/30 letters (Scheiman and Wick, 2002). The prism bar with its corresponding base was placed in front of the subject, increasing the demand until reaching diplopia. This is the value in prism diopters at which fusion breaks. Then the prism was decreased until a single image was seen, and that value recorded to represent fusion recovery.

Interpupillary distance (mm)

With an interpupillometric ruler (Eskridge *et al.*, 1991).

Near and far horizontal and vertical phoria: modified method of Thorington

The method used was the Maddox bar. The subject, situated at 5 m from the point test, held the Maddox bar horizontally in front of his/her own right eye and was asked to indicate at what point of the horizontal axis of the Maddox cross the red vertical line was situated. Afterwards, the vertical phoria was measured in the same way, by rotating the Maddox bar vertically, and the subject indicating at what point of the vertical axis of the Maddox cross the horizontal line was situated. These were the values in prismatic diopters of the far horizontal and vertical phoria, respectively. When the value of the phoria lay outside the axes of the Maddox cross, an additional rotating prism was used, the phoria value being the sum of the prism and the test. The near phoria was measured by a modification of the Thorington method, as recommended by several authors (Schroeder *et al.*, 1996; Rainey *et al.*, 1998; Scheiman and Wick, 2002) for its simplicity, control over accommodation and high reliability and repeatability (Hirsch *et al.*, 1948). Also, as indicated by Scheiman and Wick (2002), an important advantage of this technique is that it can be used for subjects that are difficult to test with a phoropter, and is therefore valuable in children. The subject, situated at 40 cm from the Bernell Muscle Imbalance Measure (MIM) test, was requested to gaze at a point of light and to indicate at what point of the horizontal axis of the test the vertical red line was situated (in case of horizontal phoria) or at what point of the vertical axis of the test the horizontal red line was situated (in case of vertical phoria). These were the values in prism diopters for the near horizontal and vertical phoria. When the red line was outside the axes, an additional prism was used as described above.

Near point of convergence

Although this test is commonly used to diagnose convergence insufficiency, until recently there was no normative data for children (Hayes *et al.*, 1998) or adults (Scheiman *et al.*, 2003). Different targets have been suggested for NPC testing. These vary from an accommodative target, a penlight, a penlight with a red glass before one eye and a penlight with red–green glasses (Capobianco, 1952; Hoffman and Rouse, 1980; Cohen *et al.*, 1983; Shippman *et al.*, 1983; Carlson *et al.*, 1990; London, 1991; Griffin and Grisham, 1995; Grosvenor, 1996; Hayes *et al.*, 1998). None of the authors provided supporting data or references for their suggestions of either the recommended target or the expected findings. Our choice was a standard push-up technique with penlight and a red glass in front of one eye. More recently (subsequent to the gathering of our data), Scheiman *et al.* (2003) has compared the different methods of measuring the NPC on adults with normal binocularity and adults with convergence insufficiency and suggests that the NPC should be routinely evaluated with an accommodative target. However, this work has certain limitations. That is, the age range of the adult subjects used was limited to 22–37 years, and therefore it is not possible to determine whether these expected clinical values can be applied to child populations, and furthermore such results may have limited applicability to the general population because these subjects were optometry students.

The standard push-up technique with a penlight measures the subject's greatest convergence capacity. Seated in front of the examiner, the subject was requested to visually follow the approaching light. For the test, a ruler was supported at the centre of the forehead of the subject at the level of the brow (used as the zero measure point from which the NPC was taken), and a flashlight was moved frontally from some 40 cm away towards the subject at a speed of some 2–3 cm s^{-1}, until the examiner detected a break in the fusion or the subject announced seeing double. This is the first measurement for the break in fusion. Next, the flashlight was moved away at the same speed until the eyes appear to be realigned, indicating a recovery of fusion, this being the first recovery measurement. At all times, the examiner observed the position of the eyes as well as the break and recovery of fusion in order to achieve an objective measurement (Hayes *et al.*, 1998).

Next, a red filter was placed in front of the dominant eye, and the test was repeated, following the method of Capobianco (Rosner, 1982). Several authors recommend that this procedure be incorporated as part of the standard assessment of convergence amplitude (Burian and Von Noorden, 1974; Carlson *et al.*, 1990), although no research data have been produced to support its use. Faced with this doubt, we included this test in our study. Because of the great variability in the results (Hayes *et al.*, 1998), these diagnostic measurements are repeated twice more (with a rest period of no more than 10 s between each trial), alternating the two methods, to provide three measurements of fusion break and another three for recovery, using the flashlight only and each three times again with the red filter added. The break value was defined as the average of three measurements in which either the examiner observed one eye deviate or the subject reported diplopia, whichever occurred first. The recovery value was defined as the average of three measurements in which either the patient reported the resumption of single vision or the examiner observed the patient make a fusional response, whichever occurred first.

Stimulus AC/A ratio: gradient method and calculated method (Rutstein and Daum, 1998)

For the gradient method, following the measurement of the near horizontal phoria, the flipper with +1.00 lenses was placed in front of the Maddox bar, noting the new phoria value, and then was repeated with −1.00 D. lenses. These values were used for calculating the relationship between the accommodative convergence (AC) and accommodation (A). By the alternative calculated method, the AC/A ratio was calculated, using the expression:

$$AC/A = IPD + FD \times (NP - FP)$$

IPD, interpupillary distance in centimetres; FD, fixation distance of near vision in metres (in our case 0.4 m); NP, horizontal-phoria value for near vision, taking the exo values as negative and the eso- as positive; FP, far horizontal-phoria value, taking the exo values as negative and the eso- as positive.

The gradient AC/A is determined using the stimulus to accommodation, not the measured accommodative response, in the denominator. This results in higher calculated (response) AC/A ratio than gradient (stimulus) AC/A ratios (Scheiman and Wick, 2002). This is because of the influence of proximal convergence and the accommodation lag, which in the gradient remains constant.

Vergence facility (Griffin and Grisham, 1995)

Recently, Gall *et al.* (1998b) performed the first systematic study of vergence facility and found that the prism of choice for this test is 3 Δ base-in/12 Δ base-out, because of its sensitivity and repeatability for separating symptomatic from non-symptomatic adult subjects. In another study, these same authors (Gall *et al.*, 1998a) found that the vergence facility is nearly independent of the target. The literature on vergence-facility measurements in paediatric populations indicated however that most researchers use 8 Δ base-in/8 Δ base-out (Stueckle and Rouse, 1979; Atkinson *et al.*, 1980; Mitchell *et al.*, 1980) as opposed to 4 Δ base-in/16 Δ base-out (Buzzelli, 1986; Scheiman, 1986), and thus we used the former option.

A suppression control was carried out with the target generally used in a binocular accommodative facility testing: the Bernell No. 9 vectogram. This is a polaroid target that has one line seen by the right eye (row No. 4), one by the left (row No. 6), and one by both (row No. 5). These rows were of 20/30 Snellen letters. With the two eyes open, the subject is instructed to pay attention to the presence of the two rows (4 and 6 that control suppression), which do not disappear or the test will be seen double throughout the session. The number of changes of the position of the flipper of 8 Δ BI/8 Δ BO completed in 1 min was recorded.

Stereoacuity (Randot test)

The stereoacuity was tested with the Randot test (a vectograph test to identify forms from random-dot backgrounds). These patterns require the binocular individual to extract a form figure from a ground, using basic stereo test glasses at 40 cm, according to the test instructions. This test provides three variations to facilitate testing of individuals at different levels of comprehension, although, because of the age of the subjects examined, all were capable of responding at the maximum level: Graded Circle Test (400–20 s of arc).

Each test was administered consistently by the same optometrist to avoid variability between examiners. The illumination of the far-vision tests was controlled in such a way that the mean luminance levels were within photopic ranges (102.9 cd m^{-2}), close to the mean of the range recommended by the CIE (85 cd m^{-2}), providing retinal-illumination conditions in which visual acuity stabilized. In the near-vision tests, the mean luminance was 129.4 cd m^{-2}, measured by a Topcon model SR-1 radiospectrometer.

The data were analysed by the statistical package SPSS 9.0 (SPSS, Chicago, IL, USA).

Results

In the overall sample, all variables displayed a normal Gaussian distribution after the Smirnov–Kolmogorov goodness-of-fit test was applied in each case, indicating that the sample is homogeneous and useful for the purposes of the study. In addition, the homogeneity of the variances was confirmed with the Bartlet test for possible use of an analysis of variance (ANOVA).

In order to evaluate parameters according to the ages of the observers, the 1056 subjects were grouped accordingly, providing seven definitive subgroups of 6–12 years. Next, the means of all the variables measured were calculated for each of the age groups, these values together with the corresponding standard deviation appearing in *Table 1*. Afterwards, the values for the parameters in the seven age groups were compared. For this, an ANOVA was applied at a confidence level of 95%. Results showed that there were no statistically significant differences between the age groups for near and far horizontal and vertical phorias, stereo acuity, and the recovery value of near positive fusional vergence (*p*-value > 0.05, *Table 1*). *Table 2* lists the means of these parameters. The rest of the visual parameters presented statistically significant differences after the ANOVA ($p \leq 0.05$, *Table 1*). In these cases, it would be useful to identify the samples corresponding to this significance. For this, we performed a multiple comparison of the mean of the variables for the different ages (*Table 3*), using the *post hoc* Bonferroni test, which is based on one-by-one comparisons of the characteristics of the different subgroups, that is, the comparison of two means tested the null hypothesis to an error of α/K, K being the hypothesis tests (one for each characteristic), when we wished to attain an overall error $\leq\alpha$ (*Table 3*).

In some instances, because of the measuring method or the population studied, the discrepancies in the repetition of the measurements were greater than found between age groups. In other tests, the instrumental error was greater than the differences between ages, and therefore it would be useless to give values so close together that they could not be measured by the methods recommended. Thus, we conducted the analyses parameter by parameter in order to establish the different age categories statistically and optometrically. As a result of the overall analysis of the results, mean values were established for the parameters studied (*Table 3*).

Table 1. Parameters evaluated (mean ± S.D. for each age) and ANOVA ($p < 0.05$)

Age (years) *n* (%)	6 115 (10.9)	7 183 (17.3)	8 197 (18.7)	9 171 (16.2)	10 178 (16.9)	11 161 (15.2)	12 51 (4.8)	ANOVA ($p \leq 0.05$) *F*	*p*-Value
Far horizontal phoria (Δ)	0.5 ± 1.5	0.4 ± 2.0	0.6 ± 1.7	0.7 ± 1.8	0.6 ± 1.6	0.7 ± 1.7	0.7 ± 4.4	0.508	0.802
Near horizontal phoria (Δ)	−0.4 ± 2.1	−0.7 ± 3.0	−0.6 ± 2.9	−0.2 ± 2.8	−0.5 ± 3.2	−0.2 ± 3.2	−0.1 ± 3.8	0.674	0.670
Far vertical phoria (Δ)	0.0 ± 0.1	0.0 ± 0.1	0.0 ± 0.2	0.0 ± 0.2	0.0 ± 0.3	0.0 ± 0.2	-0.1 ± 0.3	0.530	0.786
Near vertical phoria (Δ)	0.0 ± 0.2	0.0 ± 0.2	0.0 ± 0.3	0.0 ± 0.3	0.0 ± 0.4	0.0 ± 02	0.0 ± 0.3	0.297	0.938
Far negative fusional vergence (break point) (Δ)	6 ± 2	6 ± 2	6 ± 2	7 ± 2	7 ± 2	7 ± 2	7 ± 2	7.051	<0.001
Far negative fusional vergence (recovery point) (Δ)	4 ± 2	4 ± 2	4 ± 2	4 ± 2	4 ± 2	4 ± 2	5 ± 2	7.811	<0.001
Far positive fusional vergence (break point) (Δ)	16 ± 8	17 ± 7	16 ± 7	17 ± 8	18 ± 6	17 ± 6	18 ± 7	2.654	0.015
Far positive fusional vergence (recovery point) (Δ)	10 ± 6	10 ± 6	10 ± 6	11 ± 7	11 ± 5	12 ± 5	11 ± 5	2.790	0.011
Near negative fusional vergence (break point) (Δ)	12 ± 3	12 ± 3	10 ± 3	10 ± 3	10 ± 3	10 ± 3	10 ± 3	14.319	<0.001
Near negative fusional vergence (recovery point) (Δ)	9 ± 3	8 ± 3	7 ± 3	7 ± 2	7 ± 3	7 ± 3	7 ± 3	8.504	<0.001
Near positive fusional vergence (break point) (Δ)	21 ± 8	19 ± 7	18 ± 7	17 ± 8	18 ± 7	17 ± 8	16 ± 9	3.727	0.001
Near positive fusional vergence (recovery point) (Δ)	14 ± 6	13 ± 5	13 ± 5	13 ± 7	13 ± 6	12 ± 7	12 ± 7	1.154	0.329
Vergence facility (cpm)	2.8 ± 1.4	3.1 ± 1.6	3.6 ± 1.9	4.7 ± 2.4	4.4 ± 2.2	4.2 ± 2.3	4.8 ± 2.6	18.519	<0.001
Near point convergence – break point (penlight push-up technique) (cm)	3.4 ± 2.0	4.3 ± 2.8	5.2 ± 5.3	6.2 ± 5.9	5.6 ± 5.0	5.7 ± 4.2	4.5 ± 2.9	6.479	<0.001
Near point convergence – recovery point (penlight push-up technique) (cm)	9.1 ± 5.2	10.8 ± 5.9	11.4 ± 7.5	12.6 ± 9.4	11.4 ± 7.7	11.5 ± 7.2	10.6 ± 4.7	2.946	0.007
Near point convergence – break point (red lens push-up technique) (cm)	4.3 ± 3.2	5.3 ± 4.3	6.7 ± 7.5	8.8 ± 9.5	8.7 ± 9.7	7.7 ± 6.1	5.8 ± 4.0	7.935	<0.001
Near point convergence – recovery (red lens push-up technique) (cm)	10.8 ± 6.2	12.7 ± 8.0	14.7 ± 12	15.8 ± 13.3	15.9 ± 14	15.3 ± 9.8	13.2 ± 6.5	4.137	<0.001
AC/A ratio (gradient method) (Δ/D)	2.1 ± 0.8	2.1 ± 0.7	2.2 ± 0.7	2.4 ± 0.7	2.4 ± 0.9	2.2 ± 0.9	1.9 ± 0.7	4.115	<0.001
AC/A ratio (calculated method) (Δ/D)	4.8 ± 0.7	4.8 ± 0.9	4.9 ± 0.8	5.1 ± 0.9	5.1 ± 1.0	5.8 ± 1.0	5.4 ± 1.3	7.214	<0.001
Stereoacuity (seconds of arc)	24 ± 8	24 ± 9	26 ± 16	28 ± 23	25 ± 11	24 ± 10	22 ± 6	1.985	0.065
IPD (mm)	52 ± 3	52 ± 2	53 ± 3	54 ± 2	55 ± 3	56 ± 3	57 ± 2	5.623	<0.001

n (%), Number of subjects (frequency in percentage); Δ, prism diopters; cpm, cycles per minute; IPD, interpupillary distance.

Table 2. Mean and standard deviation of those parameters that do not vary with age according to the ANOVA ($p \geq 0.05$)

Parameters	*n* (Subjects)	Mean ± S.D. (reference values)
Far horizontal phoria (Δ)	1016	0.6 ± 1.7
Near horizontal phoria (Δ)	1016	−0.4 ± 3.1
Far vertical phoria (Δ)	1016	0.0 ± 0.2
Near vertical phoria (Δ)	1016	0.0 ± 0.3
Near positive fusional vergence (recovery point) (Δ)	1016	13 ± 6
Stereoacuity (seconds of arc)	1016	25 ± 10

With respect to far negative and positive fusional vergence (break and recovery point), although differing significantly between at least two age groups, it was not appropriate to establish values for the different age groups because the measuring method (step vergence measured with a prism bar) had a greater instrumental error (±2 Δ) than the differences between the means in each age group.

The near-negative and -positive fusional vergence (break point) and the near-negative fusional vergence (recovery point), presented significant differences after a

Table 3. Mean and standard deviation for each established age category (statistical categories and clinic determination categories) of those parameters that vary with age according to the ANOVA ($p \leq 0.05$) and *post hoc* Bonferroni ($p < 0.05$)

Post hoc Bonferroni ($p < 0.05$)		Age subgroups (years)		
Parameters	*n* (Subjects)	Statistical categories	Clinic determination categories	Mean ± S.D. (reference values)
Far negative fusional vergence (break point) (Δ)	1016	6–8; 9–12		6 ± 2
Far negative fusional vergence (recovery point) (Δ)	1016	6–11; 12		4 ± 2
Far positive fusional vergence (break point) (Δ)	1016	6,8; 7,9,11; 10,12	6–12	17 ± 7
Far positive fusional vergence (recovery point) (Δ)	1016	6–8; 9–12		11 ± 6
Near negative fusional vergence (break point) (Δ)	1016	6–7; 8–12		11 ± 3
Near negative fusional vergence (recovery point) (Δ)	1016	6–7; 8–12		7 ± 3
Near positive fusional vergence (break point) (Δ)	1016	6–7; 8–12		18 ± 8
Vergence facility (cpm)	1015	6–8; 9–12	6–8; 9–12	3.2 ± 1.7; 4.5 ± 2.3
Near point convergence – break point (penlight push-up technique) (cm)	1016	6,7,12; 8–11		5.2 ± 4.4
Near point convergence – recovery point (penlight push-up technique) (cm)	1016	6; 7,12; 8–11		11.4 ± 7.2
Near point convergence – break point (red lens push-up technique) (cm)	1012	6; 7,12; 8; 9–11	6–12	6.5 ± 5.7
Near point convergence – recovery (red lens push-up technique) (cm)	1012	6,12; 7; 8–11		14.3 ± 11.2
AC/A ratio (gradient method) (Δ/D)	1016	6–10; 11–12		2.2 ± 0.8
AC/A ratio (calculated method) (Δ/D)	1016	6–10; 11–12		5.0 ± 0.9

Δ, Prism diopters; cpm, cycles per minute.

post hoc Bonferroni between ages 6 and 7 and the rest, but as these were minor differences or equal to the instrumental error, we did not consider it appropriate from an optometric standpoint to calculate means for the different groups.

The NPC break and recovery values (measured by both methods), after *post hoc* testing, presented a significance difference. However, the actual differences between age groups were not clinically significant because they fell well within the test–retest reliability of the method, and therefore it was not necessary to give measurements for each group.

The stimulus AC/A ratio (gradient and calculated method), although being parameters that vary significantly between age groups after the ANOVA analysis, also show no significant differences that would justify a division by age from a clinical standpoint.

The vergence facility would however be divided into two groups, 6–8 and 9–12 years after *post hoc* testing.

The IPD, given its evident evolution due to biological growth is a parameter that does present significant differences between all the ages.

Discussion

According to the results, we can consider two trends in the behaviour of the variables analysed:

The first group includes some variables that did not vary in the age interval sampled (ANOVA $p > 0.05$): near and far horizontal and vertical phorias and stereoacuity, and other parameters that although having varied between groups of ages (ANOVA $p < 0.05$ and *post hoc* test $p < 0.001$) did not justify the need to give different ranges of values for the different ages studied, as these differences were not clearly significant, either for the dimensions of them or because they did not exceed the instrumental error of the measurement method used. These were: NPC, break and recovery points of far positive and negative fusional vergence, break and recovery points of near positive and negative fusional vergence and the gradient and calculated AC/A ratio.

On the contrary, the second group includes the values which evolved clearly over the years, either up to an age where stabilization occurs, from which means are

Table 4. Mean for horizontal phoria in comparison with results of other studies

Author	***n* (Subjects)**	**Age**	**Method**	**Mean (Δ)**	
Horizontal phoria (Δ)					
Freier and Pickwell (1983)	663	5–74	Maddox	Far +0.84 to +1.50	
				Near −0.34 to −3.83	
Dowley (1990)	925	18–42	Modified Maddox	Far: orthophoria	
Letourneau and Giroux (1991)	2035	6–13	Maddox	Far +0.57 ± 2.54	
	2029			Near −0.78 ± 4.51	
Jackson and Goss (1991)	244	7,9–15,9	Von Graeffe	Far −1 ± 2	
				Near −3 ± 4	
				No change with age	
Walline *et al.* (1998)	1495		Cover test	*Far*	*Near*
		Kindergarten		−0.01 ± 0.39	−0.62 ± 1.46
		Second grade		−0.04 ± 0.67	−0.49 ± 0.60
		Fifth grade		−0.02 ± 0.51	−0.26 ± 1.59
Chen *et al.* (2000)	268	2–15	Modified Maddox	−1.29	
				No change with age	
Chen and Abidin (2002)	60	7–12	Far: Maddox Rod Method	Far: −0.28 ± 0.82	
			Near: Howell Card Method	Near: −1.84 ± 3.94	
Present study	1015	6–12	Modified Thorington	Far +0.6 ± 1.9	
				Near −0.4 ± 3.0	

Δ, Prism diopter; exo, negative; eso, positive.

derived for certain age groups (6–8 and 9–12 years), such as vergence facility, or else in a continuous and progressive way, as the IPD.

First group

Horizontal and vertical phoria. Table 4 presents a comparative analysis for horizontal phoria between our results and those of other authors. Although not all the mean values proved comparable, since the measuring methods used in each study differed, all these authors concluded (ourselves included) that the phoria value did not vary according to age in children. Letourneau and Giroux (1991) proposed that the absence of a change in the phoria value could be due to the fact that the infant stage studied is not a critical developmental period for this variable, or that no change occurs throughout life. There is apparently a greater incidence of heterophoria, either esophoria or exophoria, from 6 years of age (when the child first begins school), a fact that could be related to the near work and stress that can be induced on the visual system, as indicated by Chen *et al*. (2000). Walline *et al.* (1998) found that, between kindergarten children and those of the fifth grade, the mean near phoria was more convergent in the older group. This supports the results of Chen *et al*. (2000). From 20 years old on, individuals do seem to become progressively more exophoric for near vision (Hirsch *et al*., 1948; Freier and Pickwell, 1983), maintaining stable lifelong values for far phoria (Freier and Pickwell, 1983; Dowley, 1990), or even evolving towards esophoria (Hirsch *et al*., 1948; Kephart and Oliver, 1952).

With respect to vertical phoria (far and near), our results agree with previous studies (Scobee and Bennet, 1950; Amos, 1987; Scheiman and Wick, 2002) and therefore its value did not vary according to age, with a mean for the population of 0 Δ.

Stereoacuity. Stereoacuity also maintained constant values with age with a mean value for the total sample of 25 s of arc. No consensus exists in the literature concerning the evolutionary development of this parameter. Thus, authors such as Ciner *et al*. (1991, 1996), indicate that in the first 5 years of life, the mean values of the stereoacuity threshold gradually decline from 216.5 s of arc that those younger than 24 months can discriminate up to 60 s of arc at 65 months. From this age on, the threshold of stereoacuity continues progressively to diminish until reaching the adult value, although this seems to be due to greater attention from the child than to the physiological changes themselves. Other authors, such as Cooper *et al*. (1979) and Simons (1981) compared the results found with different stereotests for children 3–5 years of age, concluding that the development of binocular vision is still incomplete at 5 years. In addition, Romano *et al*. (1975) held that between 3 and 5 years, children already present adult levels of stereoacuity, 9 years being the age when stability occurs, as indicated by Pickwell (1996). However, the test used by this author was the Titmus stereoacuity test rather than the Randot test used in this study. The results from the former might have been better than TNO test, which has greater reliability in discrimination as it does not present monocular cues. Tomac and Altay (2000), using the TNO stereotest, indicated that stereoscopic acuity improves significantly between 4 and 5-1/2 years of age, approaching adult values after this age. Our results agree with those of these authors, given that in our series, we found no statistically significant differences between ages. The slight discrepancies between different works could be due to the different types of tests used, which can be stereotests of shape (two similar figures displaced laterally, as in the Titmus), overall stereotests (with Random dots, and without monocular cues, as in TNO), or a combination of both, as in the Randot test.

Near point of convergence. The NPC is an important measurement in practice, as it involves accommodative convergence, positive vergence amplitude and proximal and tonic vergence (Scheiman and Wick, 2002). In our study, although the ANOVA and *post hoc* Bonferroni confirmed significant differences between ages, the minimal differences between the means of this parameter in the different subgroups (not clinically meaningful), and the absence of a continuous evolutionary pattern with age implies no need to assign different reference values to our population. Rouse *et al.* (1996) found the 95% limits of agreement for the NPC measurement method with accommodative target to be approximately ± 3 cm, and therefore it can be generalized that there was no developmental trend in mean NPC break point measurement in children. Allen *et al.* (1975) also found similar behaviour of NPC break value (measured by a non-accommodative target) in children, with a mean of approximately 5 cm, a value similar to that found in our study. *Table 5* reflects a comparative analysis with other works. In a recent work (Hayes *et al.*, 1998), significant differences were found between means for break values, revealing a trend with age, as the smallest children presented lower values. However, the differences were of such magnitude that they could mask the error of the measurement method, giving a greater variability than the difference between the means found, as indicated by Rouse *et al.* (1996). In addition, Hayes *et al.* (1998) indicated that the differences between groups disappear when the measurement of the NPC (in cm) is transformed into prismatic diopters, using the values of the interpupillary distance in the child. For the recovery values, the trend in the results did not clearly emerge, and finally gave a single cut-off break value (6–10 cm) that was valid for all ages studied. However, Allen *et al.* (1975) found recovery values of between 8 and 9 cm, these values being lower than in our study (≅11 cm).

Chen *et al.* (2000), however, found differences in the break of the NPC related to the subject's age, the values (>5 cm) increasing from 8 years old. These authors offered the following conjecture: in agreement with the Skeffington's model of near-vision stress to which the child is subjected from the beginning of school there may be a considerable increase in the requirements on the visual system that are inconsistent with the child's psychology (Birnbaum, 1993). Alternatively, these authors indicate that it could also be argued that small children live in a closer visual world than schoolchildren, and this environment might help to train good convergence. However, precaution is advisable in comparing the results of this work with others, given that the fixation card used is a picture, and it measures only the NPC break point.

In our study, the mean of the youngest children (6–7 years) was statistically different from that of the other ages, and calculating the mean for the first measurement taken with the penlight, a classification could be proposed (on the basis of *Table 1*) with various age groups. However, this possibility was finally rejected because the differences did not confirm this significance for 12 years of age, and furthermore 85% of subjects

Table 5. Mean for near point of convergence in comparison with results from other studies

Author	*n* (Subjects)	Age	Method	Mean ± S.D. (break point/ recovery point) (cm)
Near point of convergence (cm)				
Hayes *et al.* (1998)	297	Kindergarten third grade sixth grade	Push-up with accommodative task three measurements	3.3 ± 2.6/7.3 ± 4.8 4.1 ± 2.4/8.7 ± 4.2 4.3 ± 3.4/7.2 ± 3.9 cut-off value 6/10
Rouse *et al.* (1998)	206	8–13	Push-up with accommodative task (three measurements)	2.7 ± 3.7/6.9 ± 7
Borsting *et al.* (1999)	14	8–13	Push-up with accommodative task (three measurements)	3 ± 2 (break point)
Chen *et al.* (2000)	485	1–17	Push-up with accommodative task (two measurements)	1.96 (S.D. not reported) increase after 8 years old
Present study	1015	6–12	Penlight push-up technique Red lens push-up technique	5.2 ± 4.4/11.4 ± 7.2 6.5 ± 5.7/14.3 ± 11.2

had a break value of ≤6.5 cm and a recovery value of ≤12.5 cm. Moreover, clinicians generally do measure the NPC break and recovery to the half-centimetre, and thus we suggest rounding off the clinical cut-off value for the NPC break and recovery to 6 and 12 cm, respectively, lower values but very similar to those reported by Scheiman *et al.* (2003), using a penlight (7 and 10 cm respectively). Nevertheless, it should be borne in mind that in the latter study the age range was limited to 22–37 years of age, and this population was comprised of optometry students, limiting the applicability of these data to the general population or to the paediatric population.

The near point would need greater uniformity in terms of the protocol followed in the evaluation, given that this has varied greatly in previous studies (Hayes *et al.*, 1998; Scheiman *et al.*, 2003). Scheiman *et al.* (2003), in a population of 175 subjects with normal binocular vision (age range 22–37 years), found no significant difference (< 1 cm) for any of the methods analysed (accommodative target compared with a penlight or a penlight compared with penlight and red–green glasses). Their results suggest that clinical diagnosis can be made with any of the three targets, although the accommodative target appears to provide the best precision. There has also been speculation about modification of the standard procedure to make the test more sensitive and of greater diagnostic and prognostic value (Capobianco, 1952). Although several authors recommend that this procedure (NPC measured with penlight and a red filter before one eye) be incorporated as part of the standard assessment of convergence amplitude (Burian and Von Noorden, 1974; Mohindra and Molinari, 1980; Carlson *et al.*, 1990) no research data had been produced to support its use or any of Capobianco's assertions about the value of the test. Scheiman *et al.* (2003) found that patients with convergence insufficiency had a break and recovery more receded with the Capobianco method compared with the accommodative target, and these differences should alert a clinician to the possibility of a subtle convergence insufficiency, although in subjects with normal binocularity, there should be virtually no difference between the break and recovery findings when the NPC is performed with an accommodative target or by Capobianco's method.

Far negative and positive fusional vergence. With respect to the far negative and positive fusional vergence by steps, as the instrumental error of the prism bar (± 2.00 Δ) was similar to or greater than the differences found between the mean values of the different groups, we consider that these differences although statistically significant are not reliable from the clinical standpoint. In both its break and recovery value, the literature consulted did not provide normal values for these age ranges. Scheiman and Wick (2002), for the general population, established reference values of 7 ± 3 for the break point of far negative fusional vergence, 4 ± 2 for the recovery point of the far negative fusional vergence, 11 ± 7 for the break point of far positive fusional vergence, and 7 ± 2 for the recovery point of the latter. Our results for the negative vergence are quite similar to those of the above authors; on the contrary, for the positive vergence, our results are far higher (*Table 3*). This could be due to the fact that the great range of accommodation observed at these ages in this population (Jiménez *et al.*, 2003) involves an increase in the amount of accommodative vergence at the distance indicated by the base prism out, with more interactive influence on pure disparity (or fusional vergence) (Semmlow and Hung, 1979). In the study of Chen and Abidin (2002), age differences were found in the far fusional vergences (positive and negative) of primary school children, however, the trend of changes with age (decreasing) was not absolutely clear because their sample size was small.

Near negative and positive fusional vergence. Numerous works concerning these parameters provide mean values for different populations and varying measurement techniques. *Table 6* summarizes the mean values found in our work and those reported by other authors. Thus, Pickwell (1965) gives mean values for prismatic vergences, noting that these are for a population of normal persons, without specifying values for children. A classic study often cited in the scientific literature, that of Morgan (1944), establishes mean reference values for fusional vergence. The measurements were made with a phoropter in an adult population and therefore these values are not comparable with those in our study. A work by Wesson (1982) used prism bars to measure the fusional vergence in 79 subjects (7–12 age) and concluded there is no significant influence of age in the result of the measurements. Scheiman *et al.* (1989) also used the stepped vergence test, and distinguished two groups, one including children of 6 years of age and one of the other ages (*Table 6*). We found statistically significant differences between the age groups 6–7 and 8–12 years (*Table 3*, *post hoc* test), although this difference between means was not significant from the clinical standpoint and furthermore did not exceed the instrumental error (± 2.00 Δ), and therefore we only give a single measurement for the age range studied (*Table 6*). Even so, it is surprising that the highest values for near positive and negative fusional vergence (break and recovery) are found for the youngest age (6 years *Table 1*). These results contrast with those given by Scheiman *et al.* (1989), as our break value for the near fusional vergence both positive and negative decline over the years, while the above authors hold that the convergence reserves

Table 6. Mean for near fusional vergences in comparison with results from other studies

Author	*n* (Subjects)	Age	Method	Mean ± S.D. (break point/ recovery point) (Δ)
Near negative fusional vergence				
Morgan (1944)	800	Pre-presbyopic	Risley prisms	21 ± 4/13 ± 5
Wesson (1982)	79	7–12	Prism bar	13 ± 5/10 ± 4
Scheiman *et al.* (1989)	386	6	Prism bar	12 ± 5/6 ± 4
		7–12		12 ± 5/7 ± 4
Jackson and Goss (1991)	244	7,9–15,9	Risley prisms	21 ± 4/9 ± 4
Chen and Abidin (2002)	60	7–12	Prism Bar	Decrease with age (not reported values)
Present study	1015	6–12	Prism bar	11 ± 3/7 ± 3
Near positive fusional vergence				
Morgan (1944)	800	Pre-presbyopic	Risley prisms	21 ± 6/11 ± 7
Wesson (1982)	79	7–12	Prism bar	19 ± 11/14 ± 9
Scheiman *et al.* (1989)	386	6	Prism bar	19 ± 7/10 ± 5
		7–12		23 ± 8/16 ± 6
Jackson and Goss (1991)	244	7,9–15,9	Risley prisms	27 ± 8/10 ± 6
Chen and Abidin (2002)	60	7–12	Prism bar	19.4 ± 9.4/14.6 ± 8.9
Present study	1015	6–12	Prism bar	18 ± 8/13 ± 6

Δ, Prism diopter.

improve with age. These authors suggested that the difference of the 6-year-old group work could be due to the lack of attention of the children. Finally, a work by Jackson and Goss (1991) performed smooth vergences, which gave greater prismatic-vergence values than those of Scheiman *et al.* (1989) using a prism bar. Jackson and Goss report values similar to those of other authors for adults measured by the phoropter. Consequently, our study is comparable only with that of Scheiman *et al.* (1989) and that of Chen and Abidin (2002), as they used a similar measurement technique and population. In this last work, although the number of schoolchildren was small, the values found were very similar to the present study (*Table 6*). In a recent study of Rouse *et al.* (2002), in 20 fifth and sixth graders in a school, the intraexaminer reliability between sessions was much less reliable for phorometric positive fusional vergence than other parameters such as NPC and von Graeffe near heterophoria. Typical between-sessions positive fusional vergence differences (median absolute difference) were between 3 and 4 Δ, whereas the coefficient of repeatability was as large as 12 Δ. As indicated by these authors, the large potential test–retest differences found could complicate clinical decision making with regard to diagnosis, and is a further reason to give only a single measurement for the age range studied.

AC/A ratio. As mentioned above, there has been considerable disagreement concerning age-related changes in the AC/A ratio, this being found to increase slightly (Davis and Jobe, 1957; Bruce *et al.*, 1995), decrease slightly (Alpern and Larson, 1960) or remain relatively constant (Morgan and Peters, 1951; Ogle *et al.*, 1967; Ciuffreda *et al.*, 1997), although all these findings correspond to the adult population. Gwiazda *et al.* (1999), in a population aged 5–21 years, found the response AC/A ratios to be negatively correlated with age, but only for the myopes. In the literature available, only one study (Mutti *et al.*, 2000) examines the way in which the AC/A ratio (response) varied as a function of refractive error and age in children 6–14 years of age, and in whom the response AC/A ratio, adjusted for refractive error, did not change according to age. Our results, although stimulus AC/A and not adjusted for the refractive error, agree with those of Mutti *et al.* (2000), because, although we found statistically significant differences between ages in the *post hoc* test, these were ≤0.50 Δ/D for the gradient method and ≤1.00 Δ/D for the calculated method: very similar to or lower than the standard deviation obtained in each age group, and therefore not considered to be clinically meaningful. We therefore established a reference mean of 5 ± 0.9 and 2.2 ± 0.8 for the calculated and gradient methods, respectively.

Second group

Vergence facility is a parameter in which, based on both the statistical results as well as on optometric judgment, it becomes necessary to establish different value ranges for different ages. For this case, the values showed an evolution over the period analysed, but not in a continuous way, but rather a stepwise fashion. This measurement is used to evaluate the dynamism of

Table 7. Mean for vergence facility in comparison with results from other studies

Author	*n* (Subjects)	Age	Method	Mean ± S.D. (cpm)
Vergence facility				
Stueckle and Rouse (1979)	30	9–12	8 Δ BE–8 Δ BI	6.3 ± 1.8
	30	12–13		10.2 ± 3.4
Mitchell *et al.* (1980)	75	9–10	8 Δ BE–8 Δ BI	5.0 ± 2.6
	151	12–13		6.5 ± 4.0
Atkinson *et al.* (1980)	140	12–13	8 Δ BE–8 Δ BI	6.7 ± 4.0
	50	20–30		8.1 ± 4.3
Buzzelli (1986)	310	5–8	16 Δ BE–4 Δ BI	3.8 ± 0.6
		8–14		5.8 ± 0.5
Scheiman (1986)	386	5–7	16 Δ BE–4 Δ BI	2.5 ± 1.0
		8–10		5.5 ± 1.0
Chen and Abidin (2002)	60	7–12	3 Δ BE- 3 Δ BI	20.2 ± 5.0
Present study	480	6–8	8 Δ BE–8 Δ BI	3.2 ± 1.7
	535	9–12		4.5 ± 2.3

cpm, cycles per minute.

the system of fusional vergence as well as its resistance (Scheiman and Wick, 2002). *Table 1* shows that the ability of the children to adapt to the rapid changes in vergence increased gradually from 6 to 9 years of age (significant *post hoc* test, *Table 3*). *Table 7* presents a comparative study with the results for other authors. The literature reviewed provides mean values for this parameter, which clearly differ because the measurement methods used vary considerably in the use and combination of prisms of different powers. These conditions demand dissimilar vergence and consequently elicit contrasting responses (Gall *et al.*, 1998b). In fact, some studies coincide in the need to give reference values for different age groups. Stueckle and Rouse (1979) distinguish two groups, the first of 9–12 years and the second from 12–13. Also, Mitchell *et al.* (1980) divided a population into two age groups (9–10 and 12–13) for differences between the values of the two groups. The values of vergence facility, according to Atkinson *et al.* (1980), continue to progress after this age, as their subjects of 12 and 13 years registered a mean lower than that of another group of subjects 20–30 years of age. In other studies, both Buzzelli (1986) and Scheiman (1986) examined children aged 5–14 years, and also divided this population into age groups, recording different means for each (*Table 7*). Gall *et al.* (1998b) performed the first systematic study of vergence facility and found that the magnitude of choice should be 3 Δ base-in/12 Δ base-out, as this combination of prism yielded the highest significance for separating symptomatic from non-symptomatic subjects. In the work of Chen and Abidin (2002), the vergence facility (20.2 ± 5.0) was approximately three times higher than the vergence facility reported by Scheiman and Wick (2002), but the power of the prism used in their study (3 Δ base-in/3 Δ base-out) was approximately three times lower than the prism power used by Scheiman and Wick (2002). The studies mentioned above do not agree with our values, and this may be due to the different measurement methods used, the type of population or the age ranges tested. Nonetheless, the evidence indicates that the ability of the fusional-vergence system to respond rapidly and accurately to changing prismatic demands, clearly changes during these years. This could be because the changes in far to near as well as near to far vision that new tasks demand of the child, where blackboard work forms part of habitual classroom activity, provide practice which improves the child's ability to adapt to the changes in vergence. As indicated by Kavner (1985), the visual-space development of a child has been reported to expand in six stages from 20 cm to 6 m during the first 5 years of life. As the child grows older, the expansion of visual space might reduce the time spent in close-distance viewing, and with age most scholarly activities require fast repetitive changes in accommodation associated with rapid changes in vergence in order to observe objects that are far away (blackboard) and near (textbooks) (Kulp and Schmidt, 1996). For this reason, different values for vergence facility appeared in our population after 8 years of age. At this age (second grade of primary school in our educational system), the child generally quickly recognizes and interprets texts, while in the first years of school (6–7 years of age) more time is needed, and therefore a lower number of cycles per minute is required (less accommodative facility – Jiménez *et al.*, 2003 – and less vergence facility) than when older, as indicated by Ritty *et al.* (1993).

Conclusions

In the present work, we analysed the behaviour (in terms of statistical means) of different parameters used to evaluate binocular function (vergence system or both the vergence and accommodative system) of subjects 6–12 years of age, belonging to a non-clinical school population.

With respect to the vergence system:

Far and near horizontal and vertical phoria, far positive and negative fusional vergence (break and recovery point), near positive and negative fusional vergence (break and recovery point) and NPC showed no change over the age range tested. Vergence facility presented different values for two different age groups (6–8 and 9–12 years). All of these results can be used as reference values to differentiate subjects with and without vergence dysfunctions in a paediatric population.

With respect to the combined vergence and accommodative system:

Both parameters studied – AC/A ratio (gradient and calculated method) and stereoacuity – revealed no significant differences between ages.

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References

Allen, D. D., Berman, P. E., Brownson, R. S. and Olson, D. L. (1975) *Analysis of Results of the Washington County District 15 Elementary School Vision Screening Program: The ABBO Study*, vol. 1, PhD dissertation. Pacific University College, Oregon.

Alpern, M. and Larson, B. F. (1960) Vergence and accommodation: IV. Effect of luminance quantity on the AC/A. *Am. J. Ophthalmol.* **49,** 1140–1149.

American Optometric Association (1994) *Optometric Clinical Practice Guideline. Pediatric Eye and Vision Examination.* American Optometric-Association, St Louis.

Amos, J. (1987) Vertical deviations. In: *Diagnosis and Management in Vision Care* (ed. J. Amos), Butterworth-Heinemann, Boston, pp. 431–460.

Atkinson, W. F., Moser, J. E. and Rouse, M. (1980) Vergence facility in a young adult population. Southern California College of optometry student research paper. Fullerton, C.A: Southern California College of Optometry. In: Gall, R.; Wick, B.; Bedell, H. (1998). Vergence facility: establishing clinical utility. *Optom. Vis. Sci.* **75,** 731–742.

Bailey, R. N. (1998) Assessing the predictive ability of the test positive findings of an elementary school vision screening. *Optom. Vis. Sci.* **75,** 682–691.

Borsting, E., Rouse, M. W., DeLand, P. N. and CIRS group (1999) Prospective comparison of convergence insufficiency and normal binocular children on CIRS symptom surveys. *Optom. Vis. Sci.* **76,** 221–228.

Bruce, A., Atchison, D. and Bhoola, H. (1995) Accommodation-convergence relationship and age. *Invest. Ophthal. Vis. Sci.* **36,** 406–413.

Burian, H. M. and Von Noorden, G. K. (1974) *Binocular Vision and Ocular Motility: Theory and Management of Strabismus*. Mosby, St Louis.

Buzzelli, A. R. (1986) Vergence facility: developmental trends in a school-age population. *Am. J. Optom. Physiol. Opt.* **63,** 351–355.

Cacho, P., García, A., Lara, F. and Seguí, M. M. (2002) Diagnostic signs of accommodative insufficiency. *Optom. Vis. Sci.* **79,** 614–620.

Calvin, H., Rupnow, P. and Grosvenor, T. (1996) How good is the estimated cover test at predicting the von Graefe phoria measurement. *Optom. Vis. Sci.* **73,** 701–706.

Capobianco, N. M. (1952) The subjective measurement of the near point of convergence an its significance in the diagnosis of convergence insufficiency. *Am. Orthop. J.* **2,** 40–42.

Carlson, N. B., Kurtz, D., Heath, D. A. and Hines, C. (1990) *Clinical Procedures for Ocular Examination*. Appleton & Lange, Norwalk, CT, USA.

Chen, A. H. and Abidin, A. H. Z. (2002) Vergence and accommodation system in Malay primary school children. *Malaysian J. Med. Sci.* **9,** 9–15.

Chen, A. H., O'Leary, D. J. and Howell, E. R. (2000) Near visual function in young children. Part I: near point of convergence. Part II: amplitude of accommodation. Part III: near heterophoria. *Ophthal. Physiol. Opt.* **20,** 185–198.

Ciner, E. B., Schanel-Klitsch, E. and Scheiman, M. M. (1991) Stereoacuity development in young children. *Optom. Vis. Sci.* **68,** 533–536.

Ciner, E. B., Schanel-Klitsch, E. and Herzberg, C. (1996) Stereoacuity development: 6 month to 5 years. A new tool for testing and screening. *Optom. Vis. Sci.* **73,** 43–48.

Ciuffreda, K. J., Rosenfield, M. and Chen, H. W. (1997) The AC/A ratio, age and presbyopia. *Ophthal. Physiol. Opt.* **17,** 307–315.

Cohen, A. H., Lieberman, S., Stolzberg, M. and Ritty, J. M. (1983) The NYSOA vision screening battery: a total approach. *J. Am. Optom. Assoc.* **54,** 979–984.

Cooper, J., Feldman, J. and Medlin, D. (1979) Comparing stereoscopic performance of children using the Titmus, TNO and Randot stereo test. *J. Am. Optom. Assoc.* **50,** 821–825.

Daum, K. M. (1983) Accommodative dysfunction. *Doc. Ophthalmologica* **55,** 177–198.

Davis, C. J. and Jobe, F. W. (1957) Further studies on the AC/A ratio as measured by the Orthorater. *Am. J. Optom. Arch. Am. Acad. Optom.* **34,** 16–25.

Dowley, D. (1990) Heterophoria. *Optom. Vis. Sci.* **67,** 456–460.

Duane, A. (1897) A new classification of motor anomalies of the eye. In: *Anomalies of Binocular Vision: Diagnosis and management*, Chap. 6 (eds R. P. Rutstein and K. M. Daum), J.H.Vail, New York; Mosby, St Louis, pp. 147–188.

Duane, A. (1926) The norms of convergence. In: *Contributions to Ophthalmic Science* (eds E. Jackson, W. H. Crisp and W. C. Finnoff), George Banta Publishing Company, Menasha, WI, pp. 34–46.

Eskridge, J. B., Amos, J. F. and Bartlett, F. (1991) *Clinical Procedures in Optometry*. Lippincoltt Willians & Wilkings, Pennsylvania, Chap. 5: pp. 39–52, Chap. 9: pp. 67–68.

Freier, B. E. and Pickwell, L. D. (1983) Physiological exophoria. *Ophthal. Physiol. Opt*. **3,** 267–272.

Gall, R., Wick, B. and Bedell, H. (1998a) Vergence facility and target type. *Optom. Vis. Sci*. **75,** 727–730.

Gall, R., Wick, B. and Bedell, H. (1998b) Vergence facility: establishing clinical utility. *Optom. Vis. Sci*. **75,** 731–742.

Griffin, J. R. and Grisham, J. D. (1995) *Binocular Anomalies: Diagnosis and Vision Therapy*, 3rd edn. Butterworth-Heinemann, Boston.

Grisham, D. (1980) The dynamics of fusional vergence eye movement in binocular dysfunction. *Am. J. Optom. Physiol. Opt*. **57,** 645–655.

Grosvenor, T. P. (1996) *Primary Care Optometry: Anomalies of Refraction and Binocular Vision*, 3rd edn. Butterworth-Heinemann, Boston.

Gwiazda, J., Grice, K. and Thorn, F. (1999) Response AC/A ratios are elevated in myopic children. *Ophthal. Physiol. Opt*. **19,** 173–179.

Hayes, G. J., Cohen, B. E., Rouse, M. W. and DeLand, P. N. (1998) Normative values for the nearpoint of convergence of elementary schoolchildren. *Optom. Vis. Sci*. **75,** 506–512.

Hirsch, M. J., Alpern, M. and Schultz, H. L. (1948) The variation of phoria with age. *Am. J. Optom. Arch. Am. Acad. Optom*. **25,** 535–541.

Hoffman, L. G. and Rouse, M. (1980) Referral recommendations for binocular function and/or developmental perceptual deficiencies. *J. Am. Optom. Assoc*. **51,** 119–126.

Hofstetter, H. W. (1944) A comparison of Duane's and Donder's tables of the amplitude of accommodation. *Am. J. Optom. Arch. Am. Acad. Optom*. **21,** 345–347.

Hokoda, S. C. (1985) General binocular dysfunctions in an urban optometry clinic. *J. Am. Optom. Assoc*. **56,** 560–562.

Jackson, T. W. and Goss, D. A. (1991) Variation and correlation of standard clinical phoropter tests of phorias, vergence ranges, and relative accommodation in a sample of school-age children. *J. Am. Optom. Assoc*. **62,** 540–547.

Jiménez, R., González, M. D., Pérez, M. A. and García, J. A. (2003) Evolution of accommodative function and development of ocular movements in children. *Ophthal. Physiol. Opt*. **23,** 97–107.

Kavner, R. S. (1985) *Your Child's Vision*. Simon & Schrister, New York, pp. 1–250.

Kephart, N. C., Oliver, J. E. (1952) A study of the relationship between lateral phoria and age. *Am. J. Optom. Arch. Am. Acad. Optom*. **29,** 423–429.

Kulp, M. T. and Schmidt, P. P. (1996) Visual predictors of reading performance in kindergarten and first grade children. *Optom. Vis. Sci*. **73,** 255–262.

Letourneau, J. E. and Giroux, R. (1991) Nongaussian distribution curve of heterophorias among children. *Optom. Vis. Sci*. **68,** 132–137.

London, R. (1991) Near point of convergence. In: *Clinical procedures in Optometry*, Chap. 9 (eds J. B. Eskridge, J. F. Amos and F. Bartlett), Lippincoltt Willians & Wilkings, Pennsylvania, pp. 67–68.

Macfarlane, D. J., Fitzgerald, W. J. and Stark, D. J. (1987) The prevalence of ocular disorders in 1000 Queensland primary schoolchildren. *Aus. New Zealand J. Ophthalmol*. **15,** 161–174.

Mellick, A. (1949) Convergence: an investigation into the normal standards of age groups. *Brit. J. Optom. Physiol. Opt*. **62,** 555–561.

Mitchell, R., Stanich, R. and Rouse, M. (1980) Norms of dynamic vergences. Southern California College of optometry student research paper. Fullerton, CA: Southern California College of Optometry. In: Gall, R.; Wick, B.; Bedell, H. (1998).Vergence facility: establishing clinical utility. *Optom. Vis. Sci*. **75,** 731–742.

Mohindra, I. and Molinari, J. (1980) Convergence insufficiency: its diagnosis and management – part 1. *Optom. Monthly* **71,** 155–160.

Morgan, M. W. (1944) The clinical aspects of accommodation and convergence. *Am. J. Optom. Arch. Am. Acad. Optom*. **21**, 301–313. In: *Clinical Management of Binocular Vision: Heterophoric, Accommodative and Eye Movement Disorders*, Chap. 1 (eds M. Scheiman and B. Wick), Lippincott Willians & Wilkins, Philadelphia, USA, pp. 3–52.

Morgan, M. W. and Peters, H. B. (1951) Accommodative convergence in presbyopia. *Am. J. Optom. Arch. Am. Acad. Optom*. **28,** 3–10.

Mutti, D. O., Jones, L. A., Moeschberger, M. L. and Zadnik, K. (2000) AC/A ratio, age, and refractive error in children. *Inv. Ophthalmol. Vis. Sci*. **41,** 2469–2478.

Ogle, K. N., Martens, T. G. and Dyer, J. A. (1967) *Oculomotor Imbalance in Binocular Vision and Fixation Disparity*. Lea and Febiger, Philadelphia, USA.

Pickwell, L. D. (1965) Average prism-vergences (non published). In: *Anomalías de la visión binocular. Investigación y tratamiento (Binocular vision anomalies)*, Chap. 3 (ed. D. Pickwell), Ed. JIMS, Barcelona, pp. 39–58.

Pickwell, D. (1996) *Anomalías de la visión binocular. Investigación y tratamiento (Binocular vision anomalies)*, Chap. 3. JIMS, Barcelona, pp. 39–58.

Rainey, B. B., Schroeder, T. L., Goss, D. A. and Grosvenor, T. P. (1998) Inter-examiner repeatability of heterophoria tests. *Optom. Vis. Sci*. **75,** 719–726.

Ritty, J. M., Solan, H. A. and Cool, S. J. (1993) Visual and sensory-motor functioning in the classroom: a preliminary report of ergonomics demands. *J. Am. Optom. Assoc*. **64,** 238–244.

Romano, P. E., Romano, J. A. and Puklin, J. E. (1975) Stereoacuity development in children with normal binocular single vision. *Am. J. Ophthalmol*. **79,** 966–971.

Rosenfield, M., Ciuffreda, K. J., Ong, E. and Super, S. (1995) Vergence adaptation and the order of clinical vergence range testing. *Optom. Vis. Sci*. **72,** 219–223.

Rosner, J. (1982) *Pediatric Optometry*. Butterwoth, Boston.

Rouse, M. W., Hyman, L., Hussein, M., Borsting, E., Cotter, S., Grisham, D., Scheiman, M., Press, L. and Solan, H. (1996). Reliability of binocular vision measurements. *Optom. Vis. Sci*. **73**(suppl), 140. In: Hayes, G.J.; Cohen, B.E.; Rouse, M.W.; De Land, P.N. (1998). Normative values for the nearpoint of convergence of elementary schoolchildren. *Optom. Vis. Sci*. **75,** 506–512.

Rouse, M. W., Hyman, L. and Hussein, M. (1998) Frequency of convergence insufficiency in optometry clinic settings. *Optom. Vis. Sci.* **75,** 88–96.

Rouse, M. W., Borsting, E., Del Land, P. N. and The Convergence Insufficiency and Reading Study (CIRS) Group (2002) Reliability of binocular vision measurements used in the classification of convergence insufficiency. *Optom. Vis. Sci.* **79,** 254–264.

Rutstein, R. P. and Daum, K. M. (1998) *Anomalies of Binocular Vision: Diagnosis and Management*. Mosby, St Louis, Chap. 3: pp. 61–94, Chap. 6: pp. 147–188.

Saladin, J. J. and Sheedy, J. E. (1978) Population study of fixation disparity, heterophoria and vergence. *Am. J. Optom. Physiol. Opt.* **55,** 744–750.

Scheiman, M. (1986) Fusional facility. *Am. J. Optom. Physiol. Opt.* **63,** 76–77.

Scheiman, M. and Wick, B. (2002) *Clinical Management of Binocular Vision: Heterophoric, Accommodative and Eye Movement Disorders*, Chap. 1. Lippincott Willians & Wilkins, Philadelphia, USA, pp. 3–52.

Scheiman, M., Herzberg, H., Frantz, K. and Margolies, M. (1989) A normative study of step vergence in elementary schoolchildren. *J. Am. Optom. Assoc.* **60,** 276–280.

Scheiman, M., Gallaway, M. and Ciner, E. (1996) Prevalence of visual anomalies and ocular pathologies in a clinic pediatric population. *J. Am. Optom. Assoc.* **67,** 193–201.

Scheiman, M., Gallaway, M., Frantz, K. A., Peters, R. J., Hatch, S., Cuff, M. and Mitchell, L. (2003) Nearpoint of convergence: test procedure, target selection, and normative data. *Optom. Vis. Sci.* **80,** 214–225.

Schroeder, T. L., Rainey, B. B., Goss, D. A. and Grosvenor, T. P. (1996) Reliability of and comparisons among methods of measuring dissociated phoria. *Optom. Vis. Sci.* **73,** 389–397.

Scobee, R. G. and Bennet, E. A. (1950) Hyperphoria, a statistical study. *Arch. Ophthalmol.* **43,** 458.

Scobee, R. G. and Green, E. L. (1948) Relationship between lateral heterophoria, prism vergence and the near point of convergence. *Am. J. Ophthalmol.* **31,** 427–441.

Semmlow, J. L. and Hung, G. (1979) Accommodative and fusional components of fixation disparity. *Invest. Ophthalmol. Vis. Sci.* **18,** 1082–1086.

Sheedy, J. E. and Saladin, J. J. (1983) Validity of diagnostic criteria and case analysis in binocular vision disorders. In: *Vergence Eye Movements: Basic and Clinical Aspects* (eds C. Schor and K. J. Ciuffreda), Butterworths, Boston, pp. 517–540.

Shippman, S., Infantino, J., Cimbol, D., Cohen, K. R. and Weseley, A. C. (1983) Convergence insufficiency with normal parameters. *J. Pediatr. Ophthalmol. Strabismus* **20,** 158–161.

Silva Ayçaguer, L. C. (1993) *Muestreo para la investigación en ciencias de la salud (Statistic for medical science)*. Díaz de Santos S.A., Barcelona, pp. 1–19.

Simons, K. (1981) Stereoacuity norms in young children. *Arch. Ophthalmol.* **99,** 439–445.

Stueckle, L. G. and Rouse, M. (1979) Norms for dynamic vergences. Southern California College of optometry student research paper. Fullerton, C.A.: Southern California College of Optometry. In: Gall, R.; Wick, B.; Bedell, H. (1998). Vergence facility: establishing clinical utility. *Optom. Vis. Sci.* **75,** 731–742.

Tait, E. F. (1951) Accommodative convergence. *Am. J. Optom. Physiol. Opt.* **34,** 1093–1107.

Tomac, S. and Altay, Y. (2000) Near stereoacuity: development in preschool children; normative values and screening for binocular vision abnormalities; a study of 115 children. *Binocul. Vis. Strabismus-Q.* **15,** 221–228.

Walline, J. J., Mutti, D. O., Zadnik, K. and Jones, L. A. (1998) Development of phoria in children. *Optom. Vis. Sci.* **75,** 605–610.

Wesson, M. D. (1982) Normalization of prism bar vergences. *Am. J. Optom. Physiol. Opt.* **59,** 628–633.

Wick, B. (1987) Horizontal deviations. In: *Diagnosis and Management in Vision Care* (ed. J. F. Amos), Butterworths, Boston, pp. 473.