In recent years, the effectiveness of office-based vision therapy for convergence insufficiency and accommodative disorders has been demonstrated with several randomized clinical trials.\(^1\)\(^-\)\(^4\) These studies use traditional clinical measures of vergence and accommodation, along with a validated symptom questionnaire, as outcome measures. Both the clinical measures and the symptom questionnaire are subjective measurements that depend on the child’s ability to accurately report what he/she is experiencing and seeing and hence may be prone to bias. Thus, outcome measures that are objective and do not depend upon a child’s subjective report are preferred. A number of studies have used such objective measures of disparity vergence as outcome measures after vision therapy for both participants with normal binocular vision\(^5\)\(^-\)\(^6\) and those with convergence insufficiency.\(^6\)\(^-\)\(^10\)

In these previous studies, objective eye movement parameters (latency, peak velocity, time to peak velocity, response amplitude) were reported for both disparity vergence step responses and saccades in participants with convergence insufficiency before and after vision therapy.\(^6\)\(^-\)\(^8\)\(^,\)\(^9\)\(^,\)\(^11\) However, one limitation of these studies is the author’s inability to compare study results to normative vergence data from participants with normal binocular vision, because those data are not available in the literature. Instead, prior studies compare the oculomotor function of convergence insufficiency patients with small cohorts of participants with normal binocular vision (n ≤ 10).

We were able to find one recent study of normative data for saccadic eye movements (only 25 children),\(^12\) but we were unable to find any studies of normative data for disparity vergence in the pediatric population. This lack of availability of normative data creates an obstacle for researchers developing study protocols in which objective testing of vergence and saccadic eye movements is used as a primary outcome measure within a randomized clinical trial.

The purpose of this research was to develop normative values of objective measures of disparity vergence and saccadic eye movements for children between the ages 9 and 17 years using an infrared, video-based, binocular eye tracking system. The data from this study will enable researchers to better understand the significance of objective disparity vergence and saccadic measures by providing them with an appropriate comparison group and will be useful for researchers planning future treatment studies.
METHODS

The tenets of the Declaration of Helsinki were followed throughout the study. The institutional review boards of Salus University and the New Jersey Institute of Technology approved the protocol, and written informed consent and assent, as well as Health Insurance Portability and Accountability Act authorization, were obtained before participation for all participants.

Patient Selection and Definition of Normal Binocular Vision

Participants were recruited from the patient population of The Eye Institute of the Pennsylvania College of Optometry at Salus University and from the New Jersey Institute of Technology. To be eligible, patients had to be between 9 and 17 years old, scored less than 16 on the Convergence Insufficiency Symptom Survey,13,14 had 20/25 visual acuity or better with best correction, and had normal binocular vision and accommodation. Eligibility and exclusion criteria are reported in Table 1.

Study Design

Clinical testing was first performed to determine eligibility. For those patients who were found to be eligible, objective eye movement recordings were administered.

Eligibility Examination for Enrollment

After obtaining written consent/assent, a vision examination was performed to determine whether the patient was eligible for the study. Eligibility testing included administration of the Convergence Insufficiency Symptom Survey to identify whether the patient was symptomatic.13,14 Other eligibility tests included the following: (1) best-corrected visual acuity at distance and near; (2) a sensorimotor examination that included (a) cover test at distance and near, (b) near point of convergence (vertical line of 20/30 letters as a target and the Gulden Near Point Rod [Gulden Ophthalmics, Elkins Park, PA]), (c) positive and negative fusional vergence at near (prism bar and vertical line of 20/30 letters as a target), (d) vergence facility (12 base-out, three base-in prism) at near, (e) near stereocuity (Randot Stereotest, Stereo Optical, Chicago, IL), (f) monocular accommodative amplitude (vertical line of 20/30 letters as a target and the Gulden Near Point Rod), and (g) monocular accommodative facility (±2.00 flipper lenses and 20/30 vertical line of letters); (3) cycloplagic refraction; and (4) an ocular health evaluation. This test battery was identical to that used in several previous studies in which objective eye movement measures were investigated.7,10,11

Objective Outcome Measures of Disparity Vergence: Instrumentation

Using the pupil as a natural anatomical marker, the ISCAN RK-826PCI binocular tracking system (ISCAN, Woburn, MA) was used to objectively record horizontal vergence eye movements within a traditional haploscope (Fig. 1A). This video-based system uses an infrared emitter (950 nm) and two infrared video cameras to digitize each individual eye movement for horizontal and vertical angular position. Each camera sampled data at 240 frames per second. The eye position tracking system quantifies the reflection of infrared light to determine the pupil centroid. The manufacturer reports an average accuracy of 0.1°. The resolution of the ISCAN system is reported by the manufacturer to be about 0.1°. Our empirical measurement computing the standard deviation of last second of the eye movement responses during the steady state for 10 participants was on average 0.11° with a range of 0.06 to 0.18° resolution.

Stimuli Presentation, Data Collection, and Calibration

It is well established that the accommodation and disparity vergence systems interact.15-19 Hence, a study of disparity vergence should minimize the contribution of accommodation as much as possible. A vertically oriented visual stimulus target

| TABLE 1. Eligibility and exclusion criteria for normal binocular vision |
|-----------------------------|-----------------------------|-----------------------------|-----------------------------|
| Eligibility criteria        | Exclusion criteria          |
| 1. Age 9 to 17 y            | 1. Constant strabismus at distance |
| 2. CI Symptom Survey score <16 | 2. Vertical heterophoria ≥2 at distance or near |
| 3. Distance phoria: 2 esophoria to 4 exophoria | 3. ≥2 Line interocular difference in best-corrected visual acuity |
| 4. Near phoria 2 esophoria to 6 exophoria | 4. Manifest or latent nystagmus |
| 5. Normal near point of convergence of <6-cm break | 5. History of strabismus surgery or refractive surgery |
| 6. Normal PFV at near (i.e., passing Sheard’s criterion or PFV >15 base-out break) | 6. History of head trauma or known disease of the brain |
| 7. Normal amplitude of accommodation (minimum of 15°/4 years of age) | 7. Diseases known to affect accommodation, vergence, or ocular motility |
| 8. Best-corrected distance visual acuity of 20/25 or better in each eye | 8. Inability to comprehend and/or perform any study-related test |
| 9. Random dot stereopsis appreciation of 500 s of arc or better | CI = convergence insufficiency; PFV = positive fusional vergence; SE = spherical equivalent. |
(Fig. 1B) was used to minimize the stimulus to accommodative vergence. This visual stimulus is appropriate for this study because a prior investigation comparing the stimulus used here on a haploscope, a line stimulus on haploscope presented on a haploscope, and light-emitting diodes located at different focal lengths, which have very different accommodative demands, did not have significantly different vergence peak velocities. In addition, Hung et al. report that, when comparing the responses from a blur-only stimulus to responses from a disparity-only stimulus, the responses with blur had an increase in response variance about 100 to 200 milliseconds after the peak velocity of disparity vergence. All stimuli within this current study were presented on a traditional haploscope, which keeps the blur stimulus to the oculomotor system constant throughout the experiment (Fig. 1A). All experiments were conducted in a darkened room to reduce influence from proximal vergence. Hence, the major visual cue that changed within this study was disparity vergence.

**Experimental Design Parameters**

We selected 4 (~7°Δ) and 6° (~11°Δ) symmetrical disparity steps to maximize the ability to gather quality data for each observation. Previous studies demonstrate that disparities with magnitudes greater than 6° elicit more saccadic eye movements in binocularly normal controls compared with vergence step stimuli of 4° or less, which mask the peak disparity vergence velocity and thus need to be eliminated from the analysis. For disparity vergence testing, 12 presentations of each of the following six stimuli were presented: 4° symmetrical disparity convergence steps from a vergence angular demand of 2 to 6°, 4 to 8°, 6 to 10°, and 8 to 12°; as well as 6° symmetrical disparity convergence steps from 6 to 12° and 4 to 10°. This resulted in a total of 72 convergence movements. Divergence 4 and 6° step responses were recorded over the same range, specifically, from the following vergence angular demands: 6 to 2°, 8 to 4°, 10 to 6°, and 12 to 8° for 4° divergence steps and from 12 to 6° and 10 to 4° for 6° divergence steps. A total of 72 divergence movements were recorded. In addition, we used an experimental design that had randomized visual stimulus latency (presented stimulus after a delay of 1 to 2 seconds), magnitude (4 or 6°), and direction (convergence or divergence) so that participants would have difficulty anticipating or predicting when a visual stimulus would be presented next, its size, or direction. This protocol was used to reduce prediction, which is known to influence vergence eye movements. For the saccadic eye movement experiment, 80 observations of 5 and 10° horizontal saccades were randomly presented.

**Calibration**

The participant’s head was restrained using a chin/head rest to minimize head movement and influence from the vestibular system. A midline adjustment procedure was performed to ensure proper positioning within the chin/head rest. Using a physical target placed at 55 cm from the participant's eyes, the participant was asked to position his/her head so that the physical rod appeared to be symmetrically displaced left or right when viewed with each eye individually to ensure that the participant was positioned symmetrically within the system. Monocular calibration was used because studies have shown that fixation disparity can impact calibration results. Calibration consisted of a 6-point, monocular calibration (1, 3, and 5° monocular, corresponding to 2, 6, and 10° binocular vergence angle demand, or 4, 5, and 6° monocular, corresponding to 8, 10, and 12° binocular vergence angle demand). Calibration for saccade responses consisted of a 4-point, monocular calibration (5 and 10° monocular into the left and right visual fields from midline). These calibrations were performed before and after completion of each experimental group.

**Eye Movement Analyses**

Eye movement data were processed and analyzed with a custom MATLAB program (Waltham, MA). All of the 4° step vergence data were pooled for analysis, as were the 6° step vergence data. The
vergence eye movements were filtered with a fourth-order low-pass Butterworth filter, with a cutoff frequency of 40 Hz to eliminate instrumentation noise especially 60-Hz noise that is probably not physiological in nature. Saccadic eye movements were filtered with a fourth-order low-pass Butterworth filter, with a cutoff frequency of 120 Hz. Each individual left-eye and right-eye vergence movement response was manually inspected for the presence of any blinks or saccades during any portion of the transient portion of the vergence eye movement. Saccades were easily identified because saccadic dynamics are an order of magnitude greater than vergence. Saccades that occurred during the transient portion of the vergence response were omitted from the peak velocity analysis because several studies suggest that saccades facilitate the maximum velocity of vergence.6,24,29

Objective eye movement parameters assessed included peak velocity, time to peak velocity, latency, and response amplitude (Fig. 2). Peak velocity was defined as the maximum value within the transient portion of the vergence movement. Time to peak velocity was defined as the time when the movement reaches its peak velocity within the transient portion of the response measured from target onset. Latency was defined as the time at which the average positional data deviated 5% from the stimulus amplitude and were measured from target onset. Hence, for our study, this threshold was at 0.2° away from the initial response position for a 4° stimulus.

Data and Statistical Analysis

All analyses were performed using IBM SPSS Statistics for Windows, version 24 (IBM Corp., Armonk, NY). Data from a previous pilot study of objective eye movement recordings using the ISCAN on 10 participants with normal binocular vision were used to determine the appropriate sample size.10 The calculation of the sample size for estimating the mean peak velocity required the choice of the width of the 95% confidence interval and an estimate of the standard deviation. A width of 3.0°/s for the 95% confidence interval was chosen as precise enough to result in clinically useful data.

The standard deviation was estimated as 4.6°/s based on a pilot study of 10 participants with normal binocular vision.10 Using a confidence interval of 3.0 and the standard deviation of 4.6, the required sample size was determined to be 36.

Based on this finding, a recruitment goal of 50 participants was established to ensure that enough valid data would be available. The normal distribution of the objective measures was determined using a Shapiro-Wilk test30 (P >.05) and an assessment of histograms and Q-Q plots. The mean and the standard deviation, minimum, maximum values, range, and 95% confidence intervals for each parameter were calculated. Sex differences were evaluated by looking at the mean difference and 95% confidence intervals of each of the four parameters (latency, time to peak velocity, peak velocity, and response amplitude) for 4 and 6° convergence and divergence symmetrical disparity step stimuli and 5 and 10° saccadic stimuli. Pearson correlation coefficients were used to evaluate the relationship between age and the four outcome measures for both disparity vergence step and saccadic eye movements.

TABLE 2. Mean and SD data for clinical measurements for distance and near

| Clinical test                          | Mean | SD (±) |
|----------------------------------------|------|--------|
| Cover test (D)                         | 0.4  | 3.03   |
| Exophoria                              |      |        |
| Cover test (N)                         | 1.4  | 2.20   |
| Exophoria                              |      |        |
| Negative fusional vergence blur Δ (at 40 cm) | 12.0 | 6.20   |
| Negative fusional vergence break Δ (at 40 cm) | 17.6 | 5.82   |
| Negative fusional vergence recovery Δ (at 40 cm) | 12.1 | 4.84   |
| Positive fusional vergence blur Δ (at 40 cm) | 19.6 | 6.60   |
| Positive fusional vergence break Δ (at 40 cm) | 25.3 | 11.20  |
| Positive fusional vergence recovery Δ (at 40 cm) | 18.1 | 9.61   |
| NPC (cm) break                         | 3.2  | 2.86   |
| NPC (cm) recovery                      | 4.5  | 3.85   |
| Monocular accommodative facility (cpm) (at 40 cm) | 14.1 | 6.61   |
| Monocular accommodative amplitude      | 15.4 | 4.53   |
| Vergence facility (cpm) (at 40 cm)     | 17.3 | 8.79   |

cpm = cycles per minute; D = distance; N = near (40 cm test distance); NPC = near point of convergence; SD = standard deviation.

RESULTS

Participant Characteristics

One hundred eighteen participants (mean age, 13.5 years; 54.5% female) with normal binocular vision were recruited between July 2016 and October 2017 from the Salus University community and clinic and from the New Jersey Institute of Technology. The data were usable for 77.1% (91/118) of the participants. The data from the remaining participants could not be used because of poor quality, defined as two standard deviations or more away from the mean, which was primarily caused by head movement, excessive blinking, lack of concentration, or fatigue. The difference among the age groups in the proportion of unusable data is statistically significant, with ages 9 to 11 years having a higher proportion of unusable

FIGURE 2. Data analysis of objective eye movements where the position in degrees is plotted as a function of time in seconds (upper plot) and the velocity in degrees/second is plotted as a function of time in seconds (lower plot).
data than the older age groups (45.5% in the 9- to 11-year-old age group, 18.2% in the 12- to 14-year-old age group, and 13% in the 15- to 17-year-old age group) ($\chi^2 = 13.74, P = .001$).

Descriptive statistics for clinical measures of accommodation and binocular vision are summarized in Table 2, and these findings show that the cohort had normal binocular vision and accommodation.

### Objective Measures of Disparity Vergence

**Descriptive Data**

The means, standard deviations, minimum and maximum values, range, and 95% confidence intervals for convergence and divergence peak velocity, time-to-peak velocity, latency, and response amplitude for both 4° and 6° step vergence data are shown in Table 3. Peak velocities for convergence are greater than those for divergence, and the peak velocities for convergence and divergence eye movements increased as the magnitude of the stimulus demand increased. The only vergence data that were normally distributed were those for 4° step convergence peak velocity and 4° step convergence response amplitude (Table 3).

**Sex**

Sex differences were evaluated by looking at the mean difference and 95% confidence intervals of each of the four parameters for 4° and 6° convergence and divergence. There were no significant differences observed in any vergence disparity parameters based on sex (data not shown).

**Age**

Pearson correlation coefficients were used to evaluate the relationship between age and the four outcome measures for both disparity convergence and divergence. The results show that there were no strong relationships between age and any of the four

**TABLE 3. Descriptive data for objective measures**

| Eye movement       | Mean (SD) | Minimum | Maximum | Range  | 95% CI  |
|--------------------|-----------|---------|---------|--------|---------|
| Convergence 4°     |           |         |         |        |         |
| Peak velocity (°/s)| 25.4 (2.9)| 18.4    | 30.6    | 12.2   | 24.9 to 26.0 |
| Time-to-peak velocity (s) | 0.56 (0.18) | 0.30    | 1.06    | 0.76   | 0.52 to 0.59  |
| Response amplitude (°) | 3.8 (0.6)   | 1.8     | 5.2     | 3.3    | 3.7 to 3.8    |
| Latency (s)        | 0.28 (0.1) | 0.17    | 0.82    | 0.65   | 0.26 to 0.30  |
| Convergence 6°     |           |         |         |        |         |
| Peak velocity (°/s)| 27.1 (2.8)| 20.1    | 31.0    | 10.9   | 25.9 to 27.1 |
| Time-to-peak velocity (s) | 0.53 (0.14) | 0.29    | 0.83    | 0.54   | 0.49 to 0.56  |
| Response amplitude (°) | 5.0 (1.0)   | 3.3     | 7.7     | 4.4    | 4.81 to 5.25  |
| Latency (s)        | 0.31 (0.14) | 0.15    | 1.00    | 0.85   | 0.28 to 0.34  |
| Divergence 4°      |           |         |         |        |         |
| Peak velocity (°/s)| 22.9 (3.0)| 16.2    | 27.0    | 10.8   | 22.3 to 23.5 |
| Time-to-peak velocity (s) | 0.49 (0.13) | 0.30    | 0.77    | 0.47   | 0.47 to 0.52  |
| Response amplitude (°) | 3.7 (0.6)   | 2.2     | 5.5     | 3.3    | 3.6 to 3.8    |
| Latency (s)        | 0.28 (0.16) | 0.16    | 0.94    | 0.78   | 0.24 to 0.31  |
| Divergence 6°      |           |         |         |        |         |
| Peak velocity (°/s)| 26.2 (3.3)| 20.0    | 30.9    | 10.9   | 25.5 to 26.9 |
| Time-to-peak velocity (s) | 0.51 (0.13) | 0.30    | 0.78    | 0.48   | 0.48 to 0.54  |
| Response amplitude (°) | 5.0 (0.9)   | 3.9     | 8.3     | 4.4    | 4.8 to 5.2    |
| Latency (s)        | 0.30 (0.13) | 0.16    | 0.74    | 0.58   | 0.27 to 0.33  |
| Saccades 5°        |           |         |         |        |         |
| Peak velocity (°/s)| 225.0 (16.7)| 185.0   | 260.1   | 75.1   | 221.2 to 228.8|
| Time-to-peak velocity (s) | 0.26 (0.06) | 0.18    | 0.43    | 0.25   | 0.24 to 0.27  |
| Response amplitude (°) | 5.4 (0.6)   | 4.1     | 6.7     | 2.5    | 5.3 to 5.6    |
| Latency (s)        | 0.23 (0.05) | 0.16    | 0.41    | 0.25   | 0.22 to 0.25  |
| Saccades 10°       |           |         |         |        |         |
| Peak velocity (°/s)| 332.5 (20.5)| 301.7   | 377.7   | 76.0   | 327.8 to 337.1|
| Time-to-peak velocity (s) | 0.25 (0.05) | 0.16    | 0.40    | 0.24   | 0.24 to 0.27  |
| Response amplitude (°) | 10.1 (1.2)  | 5.6     | 12.2    | 6.4    | 9.8 to 10.4   |
| Latency (s)        | 0.23 (0.05) | 0.15    | 0.39    | 0.24   | 0.22 to 0.25  |

SD = standard deviation.
between age and the four outcome measures for both 5 and 10° saccadic eye movements. There were no significant differences in any saccadic eye movement parameters based on sex (data not shown).

**Objective Measures of Saccadic Eye Movements**

**Descriptive Data**

The means, standard deviations, minimum and maximum values, range, and 95% confidence intervals for peak velocity, time-to-peak velocity, latency, and response amplitude for both 5 and 10° saccadic eye movement data are shown in Table 3. Peak velocities for 10° saccadic eye movement were higher than those for 5° saccadic eye movement, and the peak velocities for saccadic eye movements increased as the magnitude of the stimulus demand increased. The only data that were normally distributed were those for 5° saccadic eye movement peak velocity and 5° saccadic eye movement response amplitude (Table 3).

**Sex**

Sex differences were evaluated by looking at the mean difference and 95% confidence intervals of each of the four parameters for 5 and 10° saccadic eye movements. There were no significant differences in any saccadic eye movement parameters based on sex (data not shown).

**Age**

Pearson correlation coefficients were used to evaluate the relationship between age and the four outcome measures for both females and males. We found one previous study that suggested a possible age effect on latency of both disparity vergence and saccades. The main goal of the study was to investigate the difference in latency between children and adults for both saccades and disparity vergence eye movements. However, the sample size was small (15 children aged 4.5 to 12 years and 15 adults aged 22 to 44 years). The authors reported results for only one outcome measure—latency. To examine developmental aspects, they grouped the 15 children into three groups, 4.5 to 6 (n = 6), 7 to 8 (n = 4), and 10 to 12 years of age (n = 5). Their main finding was that latency was longer in children than in adults, and there was a progressive decrease with age. Latencies approached or reached adult lengths at approximately 10 to 12 years. However, the small sample size is a limitation of this study. We did not find a relationship between latency and age or any other parameter for saccades or disparity vergence in our study; however, the youngest child in our study was 9 years of age, and we had only six children younger than 10 years in our study. Thus, we cannot determine if there is an age effect that occurs before 9 years of age.

**Normative Data**

Table 3 reports the 95% confidence intervals. Table 4 presents the suggested normative data for both convergence and vergence for each of the four parameters based on the mean ± 1 standard deviation.

**DISCUSSION**

The results of this study provide normative data for objective measures of disparity vergence and saccadic eye movements in children 9 to 17 years old, using an infrared, video-based eye movement recording system. The data presented here are similar to previous research that shows that the peak velocity of disparity vergence and saccadic eye movements is related to magnitude of the stimulus. This relationship is referred to as the main sequence. The main sequence for eye movements is a plot of maximum response velocity as a function of response amplitude for a number of responses to different stimuli with a range of amplitudes. In this study, the velocity of convergence, divergence, and saccadic eye movements increased with increased amplitude of the stimuli. In addition, our data agree with previous studies showing that convergence responses have a higher velocity than divergence responses. We did not find any significant age or sex effects, so the normative data presented in this study should be applicable for the age span of 9 to 17 years of age and for both females and males.

Comparing these data with previous research is difficult because we were unable to find a normative study of disparity vergence in children and found only one normative study of saccades in the pediatric population. In this study, 102 participants between the ages of 6 and 76 years (25 children aged 6 to 17 years) were evaluated using infrared video-oculography with a sampling rate of 240 Hz. The stimuli used were 5, 15, and 30° horizontal saccades. The 5° stimuli were identical to the stimuli used in our study. The mean peak velocity reported in this study (225 ± 16.7°/s) was statistically significantly greater (t = 3.81, P < .001) than the results reported by Hopf et al. (213 ± 29°/s). Because of the age differences in the two samples, it is difficult to explain the significance of the differences between the two studies.

We found one previous study that suggested a possible age effect on latency of both disparity vergence and saccades. The main goal of the study was to investigate the difference in latency between children and adults for both saccades and disparity vergence eye movements. However, the sample size was small (15 children aged 4.5 to 12 years and 15 adults aged 22 to 44 years). The authors reported results for only one outcome measure—latency. To examine developmental aspects, they grouped the 15 children into three groups, 4.5 to 6 (n = 6), 7 to 8 (n = 4), and 10 to 12 years of age (n = 5). Their main finding was that latency was longer in children than in adults, and there was a progressive decrease with age. Latencies approached or reached adult lengths at approximately 10 to 12 years. However, the small sample size is a limitation of this study. We did not find a relationship between latency and age or any other parameter for saccades or disparity vergence in our study; however, the youngest child in our study was 9 years of age, and we had only six children younger than 10 years in our study. Thus, we cannot determine if there is an age effect that occurs before 9 years of age.

**TABLE 4.** Normative data for objective parameters of vergence and saccades

| Objective Measure | 4° Expected Range (mean ± 1 SD) | 6° Expected Range (mean ± 1 SD) |
|-------------------|---------------------------------|---------------------------------|
| **Convergence**   |                                 |                                 |
| Peak velocity     | 28.2–22.5                       | 29.9–24.3                       |
| Time-to-peak vel  | 0.7–0.4                         | 0.7–0.4                         |
| Response amplitude| 4.4–3.2                         | 6.1–4.0                         |
| Latency           | 0.4–0.2                         | 0.5–0.2                         |
| **Divergence**    |                                 |                                 |
| Peak velocity     | 25.9–19.9                       | 29.4–22.9                       |
| Time-to-peak vel  | 0.6–0.4                         | 0.6–0.4                         |
| Response amplitude| 4.3–3.1                         | 5.9–4.1                         |
| Latency           | 0.4–0.1                         | 0.4–0.2                         |
| **Saccades**      |                                 |                                 |
| Peak velocity     | 241.7–208.3                     | 353.0–321.0                     |
| Time-to-peak vel  | 0.3–0.2                         | 0.3–0.2                         |
| Response amplitude| 6.0–4.9                         | 11.3–8.9                        |
| Latency           | 0.3–0.2                         | 0.3–0.2                         |

SD = standard deviation.
Two recent studies investigated the effectiveness of vision therapy for the treatment of symptomatic convergence insufficiency in children using objective eye movement recordings. In the first study, the authors were only able to compare data pre-therapy and post-therapy. They did not include a group of participants with normal binocular vision, and because normative data were not available at that time, the authors were unable to state that the various parameters reached normal levels. They were only able to determine that there were significant improvements in the measures after treatment. In the second study, the authors did include a small sample of participants with normal binocular vision as a comparison group for the experimental group. These are examples of clinical studies that would have benefited from having normative data for objective measures of disparity vergence and saccades.

A limitation of the study is that we recruited only children 9 years or older, and we cannot report on a possible age effect for children younger than 9 years. Given the significant relationship between age and the ability to gather usable data, we suggest that in future studies using a similar apparatus the age eligibility criterion should be 12 to 17 years. In addition, providing children who appear inattentive or restless with more breaks and frequent reminders to try and remain as still as possible is a potentially helpful strategy to reduce loss of data.

CONCLUSIONS

These normative data provide an important contribution to the literature. Researchers will now have normative data for the pediatric population (9 to 17 years of age) for four objective disparity vergence and saccadic eye movement parameters based on stimuli that can be used with children with normal and abnormal binocular vision. These new data will enable researchers to incorporate objective eye movement measures in clinical trials as outcome measures. Although the data were gathered with the ISCAN table-mounted haploscopic device, the same normative data should be generalizable to any similar video-based system that is testing at 240 frames per second or more with a resolution of about 0.1°.

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