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# Correlation between reading skills and different measurements of convergence amplitude

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## Abstract

*Purpose*. To find correlations between convergence amplitude and reading ability, as assessed in various methods.

*Methods*. Convergence of 66 children aged 8–10 years was evaluated using 1) Non-accommodative target at near and distance; 2) A near computerized stereogram; and 3) Measurement of near point of convergence (NPC). Reading ability was examined by: 1) a reading comprehension test and 2) the Developmental Eye Movement Test (DEM), which evaluates saccadic speed and accuracy.

*Results*. Convergence amplitudes on a distant target and on a near stereogram were correlated with the DEM score ($P$ = 0.005/0.02, $r$ = –0.38/–0.32 and $P$ < 0.001/0.002, $r$ = –0.53/–0.53 for break/recovery respectively), while NPC and convergence on a near non-accommodative target did not. Reading comprehension test score was not correlated with any of the convergence measurements.

*Conclusion*. Convergence amplitude measured while accommodation is controlled was correlated with the DEM score, which evaluates saccadic speed and accuracy. Further study to evaluate whether improvement in vergence control improves DEM scores is needed.

**Keywords:** convergence; saccade; reading; Developmental Eye Movement Test; accommodation

## Introduction

The near vision task of reading requires several actions to be taken by the reader. Primarily these are 1) localization, as manifested by convergence; and 2) identification, as manifested by accommodation. In addition saccadic eye movements are necessary to precisely guide the visual system from word to word thus enabling visual data to flow to the processing centers of the brain. Although some researchers have claimed to find no correlation between binocular anomalies and reading problems,[1,2] many others have found an abundance of binocular anomalies in the reading disabled. Special attention was directed towards the saccadic performance in children with reading disorders.[3–11]

Since reading also requires sustained convergence, a substantial body of research activity was directed to ascertain whether convergence ability could be correlated with reading skills.[12–17] Maddox has described four components that are involved in convergence: tonic, accommodative, fusional (disparity) and proximal (psychic). Accordingly, convergence amplitudes can be measured in a variety of methods. Near point of convergence is measured by asking the patient to fixate on a small target that moves closer until diplopia is perceived. This test measures "absolute convergence" as it allows convergence to be influenced by all four components described above. Measuring the influence of three of the above components: tonic, proximal and fusional, can be achieved by asking the patient to fixate on a near non accommodative target, such as a light source, while base out prisms in increasing amounts are placed in front of one eye. This allows the patient to increase converge with out limiting accommodation until diplopia is reported. Employing the same test using a light source placed 6 meters from the subject eliminates the influence of proximity to the viewed object. Measuring convergence on a near accommodative

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target will measure the motor (tonic) and proximal components of convergence since accommodation remains constant throughout the test.[18]

It was noted before by Simons *et al*., that the literature on the subject of reading and vergence amplitude suffers from methodological problems related to the different methods employed to assess reading and convergence.[19] The purpose of this study was to investigate how different measurements of convergence correlate with reading abilities of school children, as reflected by a reading comprehension test and saccadic eye movement test, in order to better understand the relation between these factors.

## Methods

The group studied included all the children from grades 3 and 4 of an urban elementary school, 66 children aged 8–10 years (mean age 9.3 ± 0.7 years) in total. All children underwent the following tests:

*Visual functions*

1. Visual acuity (VA) for distance and near (using Snellen chart at 6 meters and Rosenbaum Card at 33 centimeters distance)
2. Non-cycloplegic refraction
3. Eye vergence evaluation
4. Alternate cover test
5. Titmus Stereo-Fly test

Children with VA less than 20/40 in either eye, anisometropia of more than 1.0 diopter, hyperopia of more than +3.00 diopters or manifest strabismus were excluded from the study and referred for further evaluation.

The following *convergence tests* were conducted:

1. Measurement of the near point of convergence on an accommodative target in the size of Jaeger 2 letter.
2. Convergence amplitude on a small, non-accommodative light source placed 33 cm and later 6 meters from the child. While a horizontal prism bar with increasing amounts of prism diopter power was placed in front of one eye, the children were asked to report when diplopia was perceived and when fusion was recovered.
3. Convergence on a near stereogram (3-D test): The child sat at a distance of 33 cm from a 17′ computer screen, wearing red-blue goggles. On the screen red and blue computer generated stereogram images were presented (Computer Orthoptics Inc., Cicero, IN, USA). When fused, these images created a 3 dimensional (3-D) image of a square that protruded towards the viewer. The child had to report the location of the square on the screen (right, left, up or down). Each correct response caused the images to separate from each other, creating increasing convergence demand, while a wrong response caused the images to move in the opposite direction. The child was asked to report when the 3-D image was no longer perceived, and instead, two separate images were seen (breaking point) and using the space bar he/she were encouraged to move the targets closer together until fusion was regained (recovery point). Breaking and recovery points were presented in prism diopters.

*Reading ability* was evaluated by two methods:

1. A standard reading comprehension test that is used by the Israel Ministry of Education throughout the country, to evaluate reading achievements (SHEMA test for reading comprehension, Israel Ministry of Education). Each student had to read a paragraph and answer multiple-choice questions. Correct answers were scored as well as the time for completion of the test. We calculated a composite score S by the equation $S = N/T$ in which $N$ = number of correct answers and $T$ = time for completion of the test.
2. The Developmental Eye Movement test (DEM).[20] This is a clinical test used to evaluate ocular motility function in school-age children.[8,9,21] It is composed of two subsets: vertical and horizontal. Children are asked to read aloud a chart with vertical lines of numbers. This test is dependant of their visual-verbal automatic calling skills. Then they are asked to read aloud horizontal lines of unequally spaced numbers without the aid of a pointing finger. The time for reading the vertical as well as the horizontal charts is recorded. For every mistake in reading a number 5 seconds are added to the reading time. The final score is the ratio between horizontal and vertical reading scores. This allows to correct for visual-verbal factors such as vigilance (sustained visual attention), number recognition and retrieval, visual-verbal integration time, hesitation time (pausing) between spoken names and vocalizing time (speaking time) that would influence both the vertical and horizontal reading speed, and focus the test on the ability to perform accurate horizontal saccades. This feature of the test is particularly important as children with reading disabilities, who are known to have difficulties in rapid automatic naming of objects like colors, numbers etc.[22]

Each of the following tests: DEM, convergence on a computerized stereogram, NPC, and convergence on near and distant light sources, was conducted by a different examiner, unaware of the results obtained by his/her colleagues. The schoolteachers gave the reading comprehension test on a different date.

Possible correlations between measurements were examined using the 2-Tailed Pearson Correlation Test for parametric data and the Spearman Correlation Test for non-parametric data.

## Results

Of the 66 children examined, 3 were excluded because of manifest strabismus or significant refractive error that caused amblyopia. Mean LogMAR visual acuities were –0.056 and

−0.054 for right and left eye respectively and mean spherical equivalents were +0.52 ± 0.3 and +0.67 ± 0.4 ($P = 0.92$, 0.66 respectively). All children completed the convergence and reading ability tests. Mean DEM horizontal and vertical reading times were 59.4 ± 10.2 and 44.0 ± 9.2 seconds respectively, well within the normal ranges for this age group as published by Garzia *et al.*[20] Average reading comprehension score was 1.15 ± 0.45. This score was above the national average for that age group as published by the Israel Ministry of Education.

Average NPC was 5.9 ± 5.7 cm and 6.2 ± 6.6 cm (break and recovery respectively), again, within the normal limits found by Griffin,[23] and slightly above the limits published by Chen *et al.*[24] Seven children had NPC break values of more than 8 cm (average 12.6 ± 8.4 cm as opposed to 3.9 ± 1.9 cm in the rest of the group). However, these children did not differ in the average DEM score or the average reading comprehension score from the rest of the study group, (1.4 ± 0.3 and 1.03 ± 0.3 respectively as opposed to 1.40 ± 0.11 and 1.1 ± 0.7 respectively for the rest of the children, $P = 0.82$, 0.92 respectively).

One child had intermittent exotropia on alternate cover test for near. This child performed extremely poorly on the DEM test (99 seconds for DEM horizontal test), and the reading comprehension test (composite score = 0.5) as opposed to 58.4 ± 11.2, 1.15 ± 0.3 for the rest of the children respectively. This child was referred for orthoptic treatment.

Average convergence amplitude on a near penlight was 27.9/21.6 diopters (break/recovery), significantly higher than the amplitude measured using the near 3-D test (20.7/11.9 $P < 0.001$). This may reflect the ability to increase convergence when a non-accommodative target is used, giving false high results.

Table 1 describes correlation between different measurements of convergence and reading tests. Several points should be highlighted: 1) near point of convergence and convergence amplitude on a near non-accommodative target had no correlation with either the reading comprehension test composite score or DEM score; 2) convergence amplitudes on a small distant target and especially on the near stereogram were correlated with the DEM scores; 4) reading comprehension composite score was not correlated with any of the convergence tests.

## Discussion

The relationship between convergence ability and reading performance has long been a matter of debate. As noted by others,[19,25] this debate may be partly due to the lack of consistent research methods used by different authors. There are many ways to evaluate convergence, as well as to assess reading performance. In this study we have tried to examine whether there was a correlation between any of the various methods of assessment of convergence and reading skills.

This study failed to find correlation between any measurement of convergence and reading comprehension as evaluated by the reading comprehension test that was given by the schoolteachers. This supports observations made by Helveston *et al.*,[1] which performed a large study on 1910 first to third grade students. In this study there was no correlation between the assessment of reading ability as given by the teachers and a comprehensive assessment of visual function. Similar results were reported by Blika *et al.*,[2] in his study on pupils with reading difficulties. Academic performance may be influenced by numerous factors like intelligence, attention, environmental factors, language barriers and others. It is therefore conceivable that convergence ability may only be one factor out of many which influence academic achievements. However, one of us (DA) had shown that enhancing convergence ability could influence both technical reading ability and reading comprehension, in a similar manner to reading tuition.[26]

By using the Developmental Eye Movement Test (DEM) we have tried to overcome this difficulty and focus on the control of saccadic eye movements during reading. It is well established that rapid and accurate saccades are essential for an efficient reading process.[27,28] The DEM test is acceptable today as a clinical test, which evaluates the speed and accuracy of saccadic eye movements of school children.[29] We have found good correlation between convergence amplitude on a near computerized stereogram and the DEM score, but not with other clinically used measurements of convergence

*Table 1.* Correlations between different measurements of convergence and reading ability tests scores (statistically significant correlations are presented in bold and marked with*).

| | Near point of convergence (break/recovery) | Convergence on a near penlight (break/recovery) | Convergence on a distant light source (break/recovery) | Convergence on near stereogram (break/recovery) |
|---|---|---|---|---|
| Reading comprehension test score | $P = 0.58/0.57$<br>$r = -0.08/-0.09$ | $P = 0.73/0.65$<br>$r = 0.05/-0.07$ | $P = 0.11/0.61$<br>$r = 0.24/0.07$ | $P = 0.32/0.06$<br>$r = 0.14/0.27$ |
| Developmental Eye Movement Test score | $P = 0.69/0.5$<br>$r = 0.06/0.1$ | $P = 0.2/0.09$<br>$r = -0.18/-0.24$ | **$P = 0.005$*/0.02***<br>**$r = -0.38$*/−0.32*** | **$P < 0.001$*/0.002***<br>**$r = -0.53$*/−0.53*** |

like the NPC or convergence on a near penlight. Convergence on a near accommodative target is recommended as the gold standard test for convergence.[30] Converging on a non-accommodative target like the penlight achieved higher convergence ranges that may be a sign of over-convergence done when accommodation can be employed out of a closed-loop control. This may result in clinically non-significant results. NPC measurements can also be increased by over-accommodation and achieve high false results. The use of the near stereogram target, which requires constant accommodation control to be sharply seen, is therefore likely to be the most accurate representation of convergence during the actual reading process. Another measurement of convergence, which also correlated with the DEM score in our study, was fusional amplitude on a distant target. In this test accommodation was non-active and that may explain the similar results.

Although much research activity was directed to ascertain whether convergence ability could be correlated with reading skills,[12–17] and a similar effort was directed towards the research of saccadic activity during reading,[3–11] the relationship between the ability to perform accurate saccades and convergence ability is not well studied in the literature. Eden et al, compared convergence ability as well as saccade performance of dyslexic children to that of normal children with either good or poor reading.[10] Dyslexic children had significantly worse eye movement stability, fixation instability at the end of saccades and lower vergence amplitudes than normal children with good reading ability. The children with poor reading performed similarly to the dyslexics on all tests, suggesting that the deficiencies observed in this study are not specific to children with dyslexia. This observation was supported by Latvala and colleagues, who compared a variety of visual-motor skills in children with normal reading and dyslexic children. They found that dyslexic children had a high rate of convergence insufficiency type of exodeviation occurring in 36–38% of children.[31]

One explanation for the relationship between vergence control and reading was suggested by Riddel *et al.*, who found that children with poor vergence control had impaired accuracy of spatial localization that may impend their ability to accurately determine the position of letters within words.[32] This hypothesis was supported by Stein *et al.*,[33] who showed that monocular occlusion, which eliminates the need for accurate convergence, improved reading ability in dyslexic children. They also found that although these children lacked binocular fixation stability initially, improving their reading ability was accompanied by improvement of binocular fixation stability. It is conceivable that better localization of optotypes may improve performance in the DEM test, as seen in our study.

Kulp *et al.*[9] tried to correlate commonly used clinical saccadic eye movement tests, like the DEM and the Optometric Association King-Devick saccade tests with visual skills such as Randot stereoacuity. A trend toward significance was found between DEM ratio and stereoacuity worse than 50 sec arc. This agrees with our results: the seven children in our study which achieved Titmus results of more than 50 sec had also poor DEM scores: mean score $1.72 \pm 0.6$ as opposed to $1.39 \pm 0.3$ in the rest of the group studied ($P = 0.0299$).

In conclusion, we have found that, in school children, convergence amplitude that is measured while accommodation is controlled is correlated with the achievements on the DEM test, which evaluates the speed and accuracy of saccades. We have found that NPC has little clinical value in that regard. Further study to evaluate whether improvement in vergence control does improve DEM scores is needed.

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