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# Comparison of reading speed, phonological decoding, and comprehension in the group of children with anisometropic amblyopia and control group

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The purpose of this study was to compare the reading speed, phonological decoding, and comprehension between a group of children with anisometropic amblyopia (amblyopic group) ($N = 21$) and a group without visual problems (control group) ($N = 37$). Mean (± SD) age in amblyopic group was 10.3 ± 1.7 and 10.7 ± 1.3 years in control group ($p = 0.130$). The reading speed measurement was conducted with the use of Konopnicki test, phonological decoding and comprehension using the Prolexia tests – string words test and string sentences test. All reading tests were made binocularly with spectacle correction (subjective refraction result). The median (range) of the Konopnicki test in the amblyopic group was 62 words per minute (from 32 to 108), while 92 words per minute (from 51 to 125) in the control group ($p < 0.0001$). The mean (± SD) of the string words test for amblyopic group was 3 min and 55 s (± 1.68), while in control group it was 2 min and 55 s (± 0.95) ($p < 0.0001$). Median (range) of the string sentences test for amblyopic group was 4.18 min (from 1.52 to 10.32) and for control group was 2.50 min (from 1.30 to 5.12) ($p < 0.0001$). This study indicates that children with anisometropic amblyopia achieve significantly worse results in reading speed, phonological decoding, and comprehension.

Keywords: anisometropic amblyopia, reading speed, phonological decoding, comprehension, reading in amblyopia.

## 1. Introduction

Amblyopia is a unilateral (or more rarely bilateral) reduction in visual acuity (in spite of optimal refractive correction), which cannot be considered a direct consequence of any changes in the structure or pathological changes within the eye or optic nerve. Amblyopia, depending on the examined population, affects 1% to 5% of people [1–3]. Although the most common parameter defining amblyopia is visual acuity (VA), amblyopia is in fact a complex dysfunction involving reduced and inefficient functioning of the visual system in many aspects. Areas of dysfunction include reduced contrast sensitivity [4], abnormal eye movements [5, 6], accommodation [7, 8], impaired hand –eye coordination [9, 10] and spatial vision [11]. Moreover, it has been shown that patients with anisometropic amblyopia have different visual deficits compared to those who have amblyopia caused by strabismus [12].

Today, more and more researchers are also interested in the influence of amblyopia on the performance of various daily activities. It has been shown that for activities such as grasping objects, moving and driving, in which binocular vision is important, people with amblyopia perform more poorly than subjects without any visual problems [13–16].

The focus of this study is on reading, which is a complex mental process that often determines educational progress. Abnormal development of this skill is for many people an obstacle in obtaining an education adequate to their intellectual capacities. From previous reports we can conclude that children and adults with amblyopia have a slower reading speed (the "maximum reading speed") in the amblyopic eye compared with the normal eye [17–19]. Reading speed of the better eye in subjects with amblyopia is comparable to that of eyes of control subjects without visual problems, especially in anisometropic amblyopia and amblyopia caused by microtropia [18]. In the past it was assumed that subjects with amblyopia do not have problems with binocular reading [20]. Today however, reports indicate that the subjects with amblyopia due to anisometropia and/or microtropia have a slower reading speed even when binocular, compared to control subjects [18, 21]. In assessing the ability to read apart from reading rate, we should also assess phonological decoding ability, and more importantly, reading comprehension. It is the effective understanding of what we read that is the practical purpose of reading and learning. To date, we are unaware of any reports that compared a wider range of reading abilities in subjects with amblyopia to those of subjects without visual problems.

It appears valuable to test reading binocularly, the most natural way. We believe that it is valuable to employ standardized methods used for reading testing by teachers in the course of a child's education, and thus an interdisciplinary approach to verify the impact of visual impairment on human functioning. It is also relevant to evaluate a homogeneous group of subjects in terms of visual impairment type, due to possible differences in the functioning of the visual systems in different types of amblyopia [12].

## 2. Methods

Both the study protocol and consent forms were approved by the Bioethics Committee of the Poznan University of Medical Sciences, Poland, which approved conducting the study (resolution No. 388/12 of April 5, 2012). In accordance with the guidelines of the Declaration of Helsinki, appropriate written informed consent was obtained from the parents of subjects.

The subjects were recruited for this study from ophthalmic and optometric offices in Poznan and the surrounding area. The study involved 58 children, including 21 subjects with anisometropic amblyopia (refractive error difference between the eyes of greater than or equal to 1.00 D in one or both meridians) and 37 subjects with no visual problems (control group). Examined children were between 8 and 13 years of age, with the average in the amblyopic group being 10.3 years (± 1.7) and 10.7 in the control group (± 1.3). In the sample group of children there were 24 boys (representing 41% of the group), including 7 with amblyopia and 17 with no visual problems. There were 34 girls (58% of the group), 14 with amblyopia and 20 controls. Children were evaluated by ophthalmologists after a preliminary assessment of the fundus and anterior segment of the eye, and objective refraction (autorefraction) under cycloplegia. In order to classify the subjects into groups, the following additional tests were performed: subjective refraction, the visual acuity at distance and near (using the ETDRS charts), prism cover test (PCT) for distance and near vision, binocularity at distance and near vision (Worth dot test), stereopsis at near (Titmus stereo fly test), fixation test (visuoscopy), and near point of convergence (NPC) with accommodative target. The following inclusion criteria for the amblyopic group were used: refractive difference between the eyes equal to or greater than 1.00 D in one or both meridians; best-corrected VA of the amblyopic eye for distance in the range of 1.0 to 0.1 logMAR (with refractive correction); interocular difference in VA at distance ≥ 2 lines; binocular VA ≤ 0.1 logMAR at distance and near; eye alignment at distance and near – heterophoria; central steady or central unsteady fixation of the amblyopic eye; ophthalmological examination of the fundus and the anterior segment of both eyes normal; no indication of dyslexia based on report obtained from educators; no other general development disorders. Eligibility criteria for control subjects were as follows: refractive error less than or equal to +2.00 D hyperopia, –4.00 D myopia, 2.00 D astigmatism, with less than 0.75 D difference between eyes; monocular and binocular VA for distance and near ≤ 0.1 logMAR, with refractive correction if it was recommended; eyes posture for distance exophoria of 0-2 Δ base-in; for near exophoria of 0-6 Δ base-in (standards according to Morgan) [23]; normal binocular vision for distance and near (Worth dot test); stereopsis ≤ 60″ (Titmus test results); NPC: break ≤ 12 cm, recovery ≤ 15 cm; monocular fixation of each eye central and stable; no indication of dyslexia based on educators' report; no other general development disorders.

For the purpose of the study the authors passed the appropriate training and have earned qualifications to conduct and interpret the Prolexia tests. For reading assessment they applied standardized tests used by Psychological-Pedagogical Clinics in Poland: speed of reading aloud – Konopnicki test and Prolexia tests to assess phonological decoding and reading comprehension. The above tests were always administered by the same examiner. Reading tests were made binocularly with spectacle correction (the subjective refraction result). All of the anisometropic amblyopic children and thirteen subjects of the control group use spectacles for correction of refractive error.

The Konopnicki test is one minute long, individual, and consists of 121 monosyllabic Polish words. There is no relationship between the words. Reading speed is measured in words read per minute. Examining the rate of reading with the Konopnicki test was carried out binocularly with an appropriate correction of the refractive error, if needed. The test was presented at a distance of 40 cm. The lighting conditions of the room were moderate, and the test sheet was additionally illuminated for all subjects. The task for the patient was to read aloud as many words per minute as possible, starting from the top row. Each misread word was deducted from the overall result of the test without interrupting the reading.

Reading skills assessment with the Prolexia tests includes two stages of reading function development: reading individual words – the efficiency of reading single words (phonological decoding), and reading individual sentences – the ability to integrate the various meanings with the information contained in the sentence (comprehension). The authors of the Prolexia tests created two tests: string word test (SWT), and string sentence test (SST), which were used in this study (in Polish) [24]. String word test is used for *measuring the phonological decoding efficiency, i.e. reading letters, producing sounds, and stacking them into syllables, and eventually creating the actual words*. On the A4 test sheet, two columns of 11-letter "objects" – string words were presented. In each column there were 22 string words, which were composed of two nouns in dictionary form (without spaces), *e.g.* filmone. Each string word was a combination of words with letter lengths of: 8 + 3, 4 + 7, 5 + 6, 6 + 5, 7 + 4, and 3 + 8. The goal for the patient was to separate correctly (with a pencil) the words included in the string object, in the shortest time possible. All presented words were of the same size (font 16). In this test, the patient was forced to correctly read the individual letters and to break them into two meaningful words, which was to evaluate the phonological decoding of words. Lexical material in these tests is chosen according to the criteria of monosemantic and grade-appropriate for a second-grade child, with the exception of words specific to urban and rural language. String sentence test was performed to assess comprehension of the read content. On an A4 paper sheet, there were 20 random sentences presented, completely unrelated to each other. The text had no capital letters at the beginning, or periods at the end. Common names were written in accordance with Polish spelling rules. The subject's task was to correctly separate the individual sentences, putting a line between them, in the shortest time possible. Lack of capital letters and periods required careful reading of the correct grammatical form of words by the child, and understanding the text while reading. It is assumed that it is not possible to separate the expressions correctly if the grammatical form of the word was read improperly, or if there is no comprehension of either the place or the role of words in the correct syntax, and thus the whole sense of the expression will not be recognized. Tests were presented at a distance of 40 cm. The lighting conditions of the room were moderate, and the test sheet was additionally illuminated using a desk lamp with a 40 W light bulb. The results recorded for both tests were the time in minutes and seconds, measured with a stopwatch, and the number of errors. The number of errors indicated accuracy of reading, and the duration indicated reading skills in terms of decoding and comprehension.

For the statistical analysis of test results, the Statistica 10.0 software was applied, using the Mann–Whitney U test and the Student t-test for independent samples. Using these tests, the reading results from the amblyopic group and the control group were

T a b l e 1. General characteristics of the amblyopic group and the control group.

| Amblyopic group ($n$ = 21) | Control group ($n$ = 37) |
|---|---|
| Unilateral amblyopia: | VA monocular (logMAR) (median, range)<br>0.0 (from –0.20 to 0.20) |
| Low level (VA 0.4 to 0.1 logMAR)<br>16 children | |
| Medium level (VA 0.5 to 0.7 logMAR)<br>4 children | |
| High level (VA ≥ 1.0 logMAR)<br>1 child | |
| VA binocular (logMAR) (median, range) | |
| Distance: 0.00 (from –0.10 to 0.10) | Distance: –0.10 (from –0.20 to 0.10) |
| Near: 0.00 (from –0.1 to 0.2) | Near: 0.00 (from –0.1 to 0.1) |
| Anisometropia up to 2.00 D<br>7 children | Emmetropia<br>24 children |
| Anisometropia from 2.25 to 4.00 D<br>10 children | Hyperopia of both eyes with astigmatism up to 2.00 D<br>8 children |
| Anisometropia above 4.25 D<br>4 children | Myopia up to –4.00 D<br>5 children |
| Eye posture | |
| For distance and near vision: | For distance: |
| Esophoria (up to 9.0 Δ)<br>2 children | Orthophoria<br>33 children |
| Phoria within the Morgan norms<br>19 children | Phoria within the Morgan norms<br>4 children |
| | For near vision: |
| | Orthophoria<br>29 children |
| | Phoria within the Morgan norms<br>8 children |
| Stereopsis | |
| None<br>1 children | Range from 60″ to 40″<br>37 children |
| Weakened (from 80″ to 3000″)<br>13 children | |
| Normal (from 60″ - 40″)<br>7 children | |
| Fixation | |
| Central/steady<br>16 children | Central/steady<br>37 children |
| Central/unsteady<br>5 children | |
| | NPC [cm] (mean ± SD) |
| | Break 9 ± 3 |
| | Recovery 12 ± 2 |

compared. Additionally, we used Spearman rank correlation to test the association between the degree of anisometropia, reduced VA, stereopsis and the results of the all three tests of reading.

## 3. Results

Table 1 shows the general characteristics of the amblyopic children group and the control group in terms of selected results of the visual system.

The reading skills results can be affected by many factors. For the comparative analysis to be credible, it was assumed that both in terms of age and binocular visual acuity for distance and near vision, there are no statistically significant differences in the results between the compared groups. In the case of older children, the probability of more efficient reading is higher. Additionally, with regard to visual acuity, children having more difficulty seeing the text font will have more problems with reading. Both of these assumptions were met for both age groups (see Section 2) ($p = 0.130$), relative to VA at distance ($p = 0.173$) and near ($p = 0.637$).

### 3.1. Comparison of the results of aloud reading speed test – Konopnicki test

The results of our study indicate that subjects with anisometropic amblyopia (amblyopic group) read binocularly fewer words per minute compared to the group of subjects without visual problems (control group), on average 30 words fewer. This indicates therefore significantly weaker speed of reading aloud in the children with amblyopia, as shown in Table 2.

### 3.2. Comparison of the Prolexia tests results

The performance on phonological decoding, meaning the ability to decrypt the written word in its phonological representation (string word test) is shown in Table 3. For phonological decoding tasks, both in terms of efficiency and accuracy, the amblyopic group performed more poorly with a longer time of task completion and a greater number of errors.

Table 2. Aloud reading speed results – Konopnicki test for amblyopic and control group.

| | Aloud reading speed [words/min] | |
|---|---|---|
| | Median (range) | *p*-value |
| Amblyopic group ($n = 21$) | 62 (32–108) | < 0.0001 |
| Control group ($n = 37$) | 92 (51–125) | < 0.0001 |

Table 3. Results of the string word test in amblyopic and control group.

| | Time [min] | | Number of errors | |
|---|---|---|---|---|
| | Mean (± SD) | *p*-value | Mean (± SD) | *p*-value |
| Amblyopic group ($n = 21$) | 3.55 (± 1.68) | < 0.0001 | 0.9 (± 1.30) | 0.05 |
| Control group ($n = 37$) | 2.55 (± 0.95) | < 0.0001 | 0.35 (± 0.55) | 0.05 |

T a b l e 4. Results of the string sentence test in the amblyopic and the control group.

| | Time [min] | | Number of errors | |
|---|---|---|---|---|
| | Median (range) | *p*-value | Median (range) | *p*-value |
| Amblyopic group ($n = 21$) | 4.18 (1.52–10.32) | < 0.0001 | 3 (0–6) | 0.03 |
| Control group ($n = 37$) | 2.50 (1.30–5.12) | < 0.0001 | 1 (0–6) | 0.03 |

The string sentence test results provided interesting information about the differences in understanding the reading content between children with amblyopia and children in the control group (Table 4). It turns out that even in this reading task the amblyopic subjects achieved poorer results both in terms of task completion timing, and the number of errors. Both the differences in test times and the number of errors are statistically significant ($p < 0.0001$; $p = 0.03$).

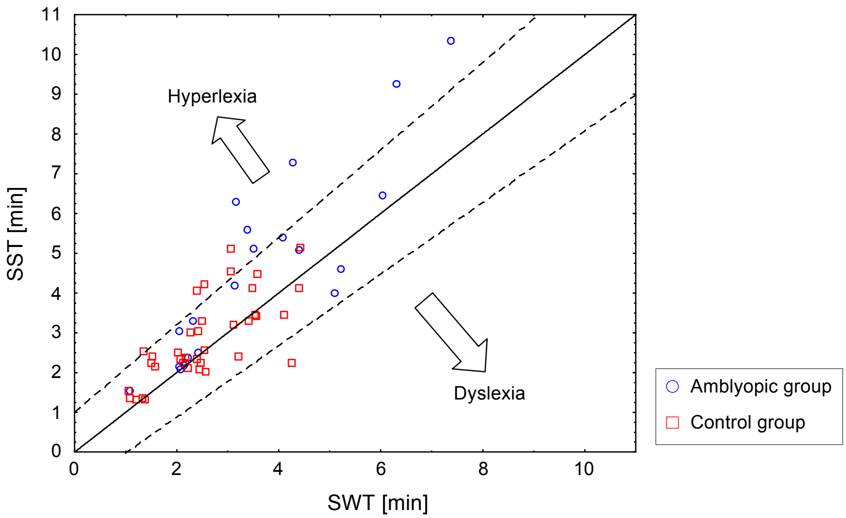


Figure. Two-parameter comparison of Prolexia tests – SWT and SST for individual subjects from the amblyopic and the control group (explanation in the text).

Prolexia tests allow for a two-parameter assessment of reading skills by placing in a two-dimensional space the results obtained from the SWT ($x$-axis) and the SST ($y$-axis). The results of the Prolexia tests in both groups were also compared in terms of mutual relation of these two parameters to each other, which is illustrated in the Figure. The chart also indicates ranges of norms set by the test authors (black dashed lines), the exceeding of which may indicate problems leading to dyslexia or hyperlexia.

Table 5 shows results of correlation between the degree of anisometropia, reduced VA on amblyopic eye (at distance and near), stereopsis and the results of all three tests of reading in the amblyopic group of children.

Results of the reading tests depend on the parameter if the $p$-value is less than or equal to the level of significance of $\alpha = 0.05$. $R$ Spearman positive value means that the increase factor of one another is accompanied by an increase. The negative values

T a b l e 5. Results of Spearman rank correlation between the degree of anisometopia (AN), reduced VA at distance (VAd) and near (VAn), stereopsis (ST), and results of Konopnicki test, SWT and SST for individual subjects from the ambliopic group ($n$ = 21).

| Reading tests | | Visual parameters | *R* Spearman | *p*-value |
|---|---|---|---|---|
| Konopnicki test [words/min] | | AN | 0.123 | 0.59 |
| | | VAd | –0.135 | 0.55 |
| | | VAn | –0.104 | 0.65 |
| | | ST | 0.074 | 0.74 |
| SWT | Time [min] | AN | –0.201 | 0.38 |
| | | VAd | 0.108 | 0.64 |
| | | VAn | –0.049 | 0.83 |
| | | ST | –0.035 | 0.87 |
| | Number of errors | AN | –0.006 | 0.97 |
| | | VAd | –0.125 | 0.58 |
| | | VAn | –0.153 | 0.50 |
| | | ST | –0.298 | 0.18 |
| SST | Time [min] | AN | –0.102 | 0.65 |
| | | VAd | 0.183 | 0.42 |
| | | VAn | 0.065 | 0.77 |
| | | ST | –0.004 | 0.98 |
| | Number of errors | AN | –0.313 | 0.16 |
| | | VAd | –0.427 | 0.06 |
| | | VAn | –0.382 | 0.08 |
| | | ST | –0.429 | 0.06 |

indicate that the growth of one factor causes a decrease in the other. In the case of our study there are no correlations between the results of the reading tests and the above visual parameters.

## 4. Discussion

The results of our study indicate that subjects with unilateral anisometropic amblyopia read binocularly fewer words per minute compared to the group of subjects without visual problems. Reading speed largely depends on the functioning of the visual system [25, 26]. Because binocular visual acuity for distance and near vision was comparable in both study groups, we can conclude that it is not the visual acuity that influences the differences in reading speed. Furthermore, the results of statistical analysis also indicate the lack of correlation between the reduced visual acuity of the amblyopic eye and results of aloud reading speed test (Table 5). An important visual parameter in the process of reading is the saccadic movement of the eyes [27]. Research shows that people with anisometropic amblyopia have a longer saccadic latency in the amblyopic eye compared to the normal eye [6, 28]. In contrast, the latency, amplitude and maximum speed of saccades under binocular conditions are comparable to those of controls [6].

Thus it is unlikely that a reduced reading rate would be caused by differences in saccadic movements. Anisometropic amblyopia however, often results in impaired fusion or stereopsis [11, 29]. Binocular vision disorders can cause problems with reading [30]. On the other hand, the results of correlation test between reduced stereopsis and the results of the Konopnicki test in the amblyopic group of children indicate no relationship between these values. We conclude that perhaps other aspects of binocular vision than stereopsis may be the reason for the weakened speed of reading aloud in the children with amblyopia.

This study also compared the performance of phonological decoding, meaning the ability to decrypt the written word in its phonological representation (string word test). For phonological decoding tasks, both in terms of efficiency and accuracy, the amblyopic group performed more poorly (longer time of task completion and a greater number of errors). Moreover the string sentence test results provided interesting information about the differences in understanding the read content between children with amblyopia and children in the control group. It turns out that even in this reading task the amblyopic subjects achieved poorer results both in terms of task completion timing, and the number of errors.

Analysis of common reading disorders in a group of 20 children aged 6–15 years with all types of amblyopia was undertaken by Koklanis *et al*. [22]. Their paper was different from others in the way that the wide range of skills associated with reading was examined with the use of WRAT III Reading Subtest, including the ability to read words, to understand sentences, and to spell. In addition, the evaluation accounted for the subjects' level of intelligence, phonological abilities and the ability to automatically name the presented objects/pictures, so-called RAN (rapid automatized naming). The results were not compared to a normal control group, but what was sought was the relationship between the specific problems with reading and the type of amblyopia. Data indicated that the subjects with strabismic amblyopia and additionally with suppression, achieved poorer results in tasks related to the decoding of words than subjects with anisometropic amblyopia. In addition, subjects with amblyopia had deficits in tasks related to RAN. The lack of a normal control group does not allow comparison of amblyopic children to peers without any visual problems.

It is assumed that decoding of words and text comprehension are two independent processes [31]. Respondents who have a significantly low level of phonological decoding, while comprehending the text, may have dyslexic problems. In contrast, subjects who efficiently decode words, with significantly poor comprehension of the text, may have disorders related to hyperlexia. Therefore, weak development of one skill is not necessarily the cause of difficulties in relation to the other. It is thus important to verify these two stages of reading, in order to have a full picture of what type of reading difficulties occur in the examined individual. The results of the Prolexia tests for both groups were also compared in regards to dependence of these two parameters with respect to each other, which is illustrated in the Figure. As can be seen from the graph, the control group was characterized by a much smaller variability in the results. The authors of the tests assumed that the maximum completion time for each task should be no longer than 8 minutes. In the case of patients with amblyopia, 2 children exceeded that time in the string sentence test. Moreover, up to 6 subjects with amblyopia (28.5% of the group) did not meet the set standards for Prolexia tests in terms of the interdependence of the results from the string word test and the string sentence test (dashed lines in the Figure), showing reading problems of a hyperlexia nature. The test results obtained in this study can contribute important information to existing knowledge about the functioning of subjects with anisometropic amblyopia in one of the most important skills of our lives – reading with comprehension.

Currently, most researchers believe that the primary area responsible for the visual condition of amblyopia is the primary visual cortex (V1 center) [32]. Studies of visual evoked potentials (VEP) conducted in subjects with amblyopia demonstrated a limited and distorted response recorded from the occipital lobe [33]. A study of the activity of the visual cortex monitored by functional magnetic resonance imaging (fMRI) after administration of deoxyhemoglobin (the so-called BOLD – blood oxygenation level dependent) also demonstrated weakness in the processing of stimuli by primary visual cortex areas responsible for the analysis of the visual signal from the visually impaired eye [34]. Once again, it can be evident that the irregularity in functioning of primary cortical centers in the case of amblyopia affects the further visual information processing steps by higher cortical centers, resulting in our finding a weakened phonological decoding ability and reading comprehension.

Based on the results of this work, we cannot clearly identify the cause of the weakening of reading speed, phonological decoding, and comprehension in the group of children with anisometropic amblyopia. Results of correlation between the degree of anisometropia, reduced VA on amblyopic eye (at distance and near), stereopsis and the results of the all three tests of reading indicate no relationship between these values. Certainly there will be further research to find the cause of weak reading results in a group of patients with amblyopia. The method of correcting the anisometropia may also be significant. Knapp's law suggests prescribing eyeglasses for aniseikonia secondary to axial length differences and contact lenses for refractive anisometropia [35]. Since most of anisometropia is due to axial length differences, then eyeglasses would be the good method of correction. But on the other hand, it can cause prismatic differences for the patient as she or he looks from one position of gaze to another. This can create a motor fusion problem. Whereas not-equal retinal imaging size only occurs in a small percentage of patients, this motor problem can affect all anisometropes after correction with eyeglasses [32]. All of the anisometropic amblyopic children in our research use spectacles for correction of refractive error, we do not rule out that it could affect in small extent results of reading.

## 5. Conclusion

In summary, it can be concluded that school-age children with anisometropic amblyopia have a wider range of reading disorders than merely reading rate, compared to their peers without any visual problems (also phonological decoding, and understanding the read content). The results obtained in this study suggest that, in addition to performing clinical eye examinations, practitioners might also consider the merits of examining reading skills in selected groups with visual disorders. In addition, these results may stimulate further research to find the cause of weak reading results in a group of patients with amblyopia and new methods of vision therapy for these subjects, aimed at stimulating selected aspects of reading.

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