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Eye-movement parameters and reading speed

A study of oral and silent reading performances of twelve-year-old children

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Abstract. This study addressed the relationship between four eye movement parameters and reading speed of 20 twelve-year-old children during silent and oral reading. The results indicated that each of the parameters correlated significantly with speed of silent reading. In fact, reading speed could be predicted by the following variables: recognition span, average fixation duration, and number of regressive saccades. Moreover, the relationship between silent and oral reading speed, on one hand, and between reading fluency and reading errors in oral reading speed, on the other, was examined. The results indicated that in terms of reading speed, significant interrelationships existed between silent and oral reading. Furthermore, fluency and errors were intercorrelated phenomena, but only fluency was substantially related to oral reading speed.

Keywords: Eye movements, Oral reading, Reading errors, Reading fluency, Reading speed, Silent reading

Introduction

Research on basic skills has emphasized two significant criteria when testing competence on subject matter achievement: precision or accuracy of the performance, and speed (Calfee & Drum 1986; Singer 1982; Søvik 1975, 1987; Søvik, Heggberget & Samuelstuen 1996). However, there is support (cf. Perfetti & Lesgold 1979; Høien & Lundberg 1991) for adding the criterion of comprehension to reading profiency. Therefore, the speed, accuracy, and comprehension of reading performance should be considered in relation to components of the reading process and their interactions.

The main purpose of this study was to investigate the relationship between a sample of eye movement parameters and reading speed. Previous studies have shown how various conditions may determine whether or not speed indicates competence. For example, such responses are sometimes only a sign of impulsivity (Kagan, Rosman, Day, Albert & Phillips 1964). Usually, speed is assumed to be a valid criterion of competence, and it follows that poor readers in general are considered slow readers. Reading speed is thus considered to be an important criterion of the reading competence of an older child or an adult. However, it is quite dependent on the ability to decode and recognize the printed words in a reading task. Research has shown that the competent reader decodes the text with accuracy, that is, with relatively few reading errors, and fluency (Calfee & Drum 1986; Winograd 1984). The accuracy aspect of silent reading performance cannot be tested precisely, but reliable measures can be achieved regarding reading speed. Fluent reading requires a certain speed in the reading performance which indicates that, although not synonymous, the terms fluency and speed are closely related. In oral reading, fluency can be observed and rated satisfactorily. When studying the relations between eye movement parameters and reading speed, it therefore seems reasonable to measure reading speed/fluency by means of silent as well as oral reading tests, and to study their interrelationships with eye movement parameters. In using both kinds of tests when examining the relation between speed in silent reading and fluency in oral reading, it is also possible to measure the accuracy of the oral reading skill by observing the frequency of reading errors.

Although silent reading gradually plays a more significant role compared to oral reading as pupils proceed through elementary school, it is important that they perform satisfactorily in both types of reading at all grade-levels. Few studies, though, have examined the relation between children's reading performances in oral and silent reading. One can question to what extent oral and silent reading are similar operations. Previous investigations have found that linguistic characteristics (different word categories) have substantial effects on oral reading performance, especially for poor readers (Gjessing 1977; Høien & Lundberg 1991). In silent reading, the impact of the linguistic characteristics was less noticeable (Seidenberg 1984; Søvik, Samuelstuen, Svarva & Lie 1996). Studies have shown that words are read aloud more quickly when placed in context than in isolation which suggests that syntactic and semantic clues aid reading speed (Calfee & Drum 1986). Thus, although reading speed is a significant end in its own right, it is simultaneously an indicator of other advantages, for example, the ease of understanding a text when the reading rate is adequate.

Previous research has indicated that skilled readers have at least two advantages in comparison with poor readers: They are more efficient at context-free verbal coding, and they are more able to use context in anticipating words (Perfetti & Lesgold 1979). Such information might lead to a renewed consideration and analysis of interactive models of reading based on empirical work in eye movement research. These models argue that, although the basic mechanisms of eye movement control are similar across tasks (such as reading, scene perception, and visual search), the trigger to move the eyes differs as a function of the specific task, and lexical variables can produce such triggering effects (Rayner 1995; Reichle, Pollatsek, Fisher & Rayner 1998).

Visual attention then seems to play an essential role when studying eye movements related to reading. The issues of if and how visual attention and saccadic eye movements are related have been systematically examined since the late seventies (Posner 1980; Schneider & Deubel 1995). Visual attention is usually operationalized as differences in reaction times or recognition performance (Van der Heijden 1992). Recent research has indicated that there is a close association between saccadic eye movements and visuospatial attention (Rizzolotti, Riggio, Dascola & Umilta 1987). Whenever a saccadic eye movement is about to be executed, the direction of visuospatial attention is constrained to be compatible with the direction of the eye movement (Hodgson & Müller 1995). Consequently, eye movement data have often been used to infer something about the process of reading (Rayner 1995). Research has found that several factors can affect the fixation time on a word; for example, word frequency, contextual constraints, semantic relations between words in a sentence, and lexical ambiguity (Høien & Lundberg 1991; Hyönä, Lain & Niemi 1995). Recent studies have made inquiries concerning the relations between textual variables and eye movement parameters (Hyönä 1994; Hyönä, Laine & Niemi 1995; Rayner 1998). The relation between eye movement patterns and reading time has also been investigated to some extent (Vauras, Hyönä & Niemi 1992). However, Vauras and her collaborators focused primarily on variables associated with the reading material (comprehension and retrieval of it), used as tasks in their study.

Having reviewed past research in the selected problem area, it can be stated that the earlier studies have not shed much light on the relationships between the eye movement parameters, which were investigated in the present study, and reading speed (Rayner 1978). In the current study, the main purpose was to investigate to what extent a sample of eye movement parameters were related to the speed of silent as well as oral reading performances of 12 year old children. In addition, it was reasonable to check whether speed in silent and oral reading were correlated variables. Furthermore, as reading fluency and reading errors have been considered important reading criteria in some recent studies, information on their relations with children's speed performances in oral reading were also collected in the present study.

Method

Sample, tests, and instrumentation

A stratified, random sampling procedure was followed in selecting the subjects (Ss) for the study. First, all the sixth-graders in a large city in Norway were stratified on the gender variable (N = 1256, that is, 643 boys and 613 girls). Then, ten boys and ten girls were chosen randomly from each of the respective strata. No data concerning scores on intelligence or achievement tests were available for the twenty Ss. However, because of the sampling procedure used in the study, it was reasonable to conclude that the selected Ss were pupils representing diverse levels of reading and spelling skills. Every child had to complete all of the three tests designed for the study.

Two main types of texts have been used in earlier studies of reading comprehension: narrative and expository texts (Chall & Stahl 1986; Pressley & McCormick 1995). As the problems of the present study were concerned with older children's reading speed and their eye movements, the choice of texts was an important issue to take into consideration. The choice of texts had further consequences, however, as this study also intended to test children's speed in oral as well as silent reading. Three reading tests were developed and used for collecting data. The first two tests were silent reading tests. The first test (T 1) was used for registration of the children's eye movements as well as general reading speed (number of words read per minute). It consisted of 102 words. The second test (T 2) was a text consisting of 55 words. The purpose of this test was simply to check the reliability of T 1 with regard to the children's average speed in silent reading. The texts in T 1 and T 2 were chosen from ordinary textbooks used for social sciences at the sixth grade-level in Norwegian schools so that the children would likely be familiar with the kind of text used for the current study. Efforts were made in finding texts which were considered almost equal with regard to level of difficulty.

Gjessing's oral reading test (Gjessing 1979) was chosen as the third reading test in the study (T 3). The test is a standardized instrument used for oral reading. It was used in order to score the children's (1) reading fluency and (2) number of errors in oral reading, both of which are considered important criteria of oral reading behavior. Reading fluency was defined as a reading performance dependent on the number of observable (extra) breaks, repetitions, or phonic problems (details) in the continual (natural) reading process, for instance, whenever the pupil encounters a word in the text which s/he finds difficult. Thus, reading fluency was considered to be a valid criterion of oral reading in which to register the children's continuity in their reading performances. In other words, the more breaks, repetitions, and phonic problems that occurred in an oral reading performance, the more such phenomena would influence the score of oral reading. (The researchers were fully aware of the fact that these criteria for reading fluency, such as repetitions, might be expressions of orthographic processing difficulties, especially when encountering irregular words, and might even be signals of comprehension problems.) Moreover, studies have shown that reading fluency will be more weakly related to reading comprehension than to reading error. On the other side, the relatively high correlations found between reading fluency and reading errors also indicate high construct validity for the term reading behavior in the present study (Samuelstuen 1996; Søvik et al. 1996). Consequently, the reading error score was also considered a useful criterion of oral reading. Both fluency and frequency of errors in reading were variables operationalized in correspondence with Gjessing's grouping and scoring of these criteria on reading behavior (1977: 65–68). The text of the test is a story, divided into four parts with increasing levels of difficulty and lengths, read continuously. The test, which consists of 277 words, is thus longer than T 1 and T 2, but the first two parts of it consist of relatively easy items, whereas the remaining words and sentences are comparable with the level of difficulty in the texts used for T 1 or T 2. During data collection, a tape-recorder was used to record the children's oral reading performances in T 3. The recordings would be used later in scoring the children's reading errors and reading fluency. A stopwatch was used in order to register the children's reading time when doing T 2 and T 3, whereas the computer registered Ss' reading time in T 1.

Texts used for the three reading tests were always available in front of the Ss during the data-collection, and the tests were administered to the Ss one at a time. The OBER-2 eyetracking system was used to record eye movements during the reading of T 1. The system is a limbus tracker, and consists of a pair of goggles, a controller unit, and software developed especially for the system. The glasses in the goggles are replaced with electronic circuitry mounted on small boards. In each board there is a rectangular aperture so that incoming light can reach the eye. It is possible to mount eye glasses on the goggles in case the Ss normally uses them. The controller unit is an expansion board for an IBM-compatible personal computer. The limbus tracking system utilizes the difference in light reflection abilities of the sclera and the iris. Infrared light is transmitted towards the eye surface, and a portion of this light is reflected. The ratio between transmitted and reflected light is dependent on the position of the iris, or, in other words, the gaze direction. The OBER-2 system can present stimuli on the computer screen simultaneously as the test is running, but in the reported study it was preferred to present the text on paper in order to create a 'normal' reading situation.

During the test, the Ss read the text from a sheet of paper (A-4 format) at a distance of 500 millimetres. The sheet was held in place by a concept holder. If the subject looked at the middle of the text, the gaze direction would be perpendicular on the sheet. The spatial resolution (horizontally) of the OBER-2 system was 0.5 minutes of the arc, which yields a horizontal resolution on the sheet of 0.07 millimetres. The text width was 160 millimetres; hence, the horizontal visual angle was 18 degrees. The sampling rate was set to 100 Hz. This is equal to a temporal resolution of 10 milliseconds and sufficient to find saccades and fixations in the eye movement data. During the analysis, the data curves were derived. This derivative is equal to the speed of the gaze shift. High speed indicates a saccadic movement, and low speed, or no movement, a fixation (low speed is due to a correction of the gaze direction when the head moves). By evaluating the speed of the gaze shift and the duration of the speed intervals, fixations and saccades could be found. Fixation findings shorter than 50 milliseconds were rejected.

Procedure and collection/scoring of data

Testing and data-collection were performed in a laboratory where the tests and related instrumentation were located. The testing in the laboratory was always carried out as individual testing, administered by the second and third authors. When the Ss were on the point of starting a reading test (T 1 through T 3) the test administrator gave short, standard instructions about how to do the test. Thus, the Ss were told to read the text with 'normal' speed. Each child was informed that a series of questions concerning the contents of the text would follow when the reading had come to an end. The Ss were supposed to answer the questions as well as they could.

A counter-balanced procedure was followed as to the sequence of T 1–T 3. For each of the three tests, a series of eight questions about the recollection/understanding of the contents was performed right after the Ss had finished each of the tests. All Ss were able to answer correctly 50%–100% of the questions. This was considered a satisfactory score, that is, the Ss in general had comprehended the texts presented by the tests.

Whereas the Ss had an opportunity for pretraining and adapting to the OBER-2 system in T 1 before the real testing took place, no such pretraining was found necessary for T 2 and T 3. Once the Ss had become acquainted with the goggles and the testing procedure in T 1, testing and collection of data could begin. The Ss sat with the goggles on his/her head, reading the text from a sheet of paper. Data registering the eye movement parameters were recorded while testing the Ss with T 1, and stored in the computer for later data analysis. Measurements of the following parameters were performed while administering the test (T 1) to Ss:

1. Recognition span which was equal to the average number of words in a fixation;
2. The average fixation time measured in milliseconds;
3. The total number of progressive saccades;
4. The total number of regressive saccades; and
5. Reading speed (rate) in the silent reading test (T 1).

Reading speed (number of words read per minute) was the only measure carried out in conjunction with T 2. The test was administered to the Ss by the third author of the paper who also administered and scored the Ss' performances on T 3.

Since an oral reading performance is somewhat different from silent reading, it was necessary to select and use different criteria and a different procedure for scoring T 3 compared to T 1. The question of defining the term reading fluency was raised and dealt with above. Here, the measures which were used for finding the sum-score of this variable are described. When scoring reading fluency in T 3, the following measures were used for finding the sum-score of this variable:

1. Number of pauses during the reading act;
2. Number of repetitions in reading; and
3. Reading behavior expressing phonic problems (indicators of such difficulties could be observed from the Ss' reading performances, e.g. by reading the word, or parts of it, extraordinarily slowly).

Concerning the construction of a composite score (the sum-score) for fluency in oral reading, the following explanation can be given: one point was given for each longer (unnatural) pause that occurred when reading T 3, and then the frequency of such pauses became equal to the points the S received for the first measure. Similarily, a sum of points equal to the frequency of repetitions and as indicators of phonic problems was based on the frequencies of these phenomena for the second and third measures mentioned above. The composite score was finally constructed by adding the scores (points) for each of the three observations (criteria). Finally, the sum-score was placed in one of the categories on a derived ordinal scale running from 1 (far above average) to 5 (far below average).

The criteria for reading errors were intended to cover all kinds of errors. The following categories were used:

1. Reversals
2. Omissions of sounds or a part of a word
3. Addition of sounds
4. Corrections
5. Reading errors without corrections
6. Other errors

The sum-score of reading errors was psychometrically organized and used in the same way as the sum score for reading fluency. It should be noted that the higher the score on reading fluency or errors in reading, the poorer was the reading performances on T 3.

Results

Descriptive statistics

Descriptive statistics of central variables are presented in Table 1; both the individual and the average scores for each of the nine variables are shown. Although data of skewness and kurtosis achieved from the statistical analyses of the variables are not given in Table 1, it should be mentioned that the distributions of data were close to normality for all of the nine variables except for variable 2, average fixation time (skewness = 0.919 and kurtosis = 2.661), and variable 8, fluency in oral reading (skewness = 1.267 and kurtosis = 1.065). Furthermore, it should be noted that no missing data occurred for any of the 20 Ss. When commenting on the contents of Table 1, it might be instructive to categorize data into three groups: Variables 1–4, variables 5–7, and variables 8–9.

The data of variables 1–4 represented measures of the Ss' eye movement parameters sampled for the current study. Thus, the range of the individual scores equaled 1.03 to 2.00, signaling relatively large variations in the recognition span for the 20 Ss. Their average score is 1.39. Similarily, the range of scores for variable 2, the average fixation time in milliseconds, equaled 211.5 to 294.4, with a M-value = 242.8. As mentioned above, the kurtosis of this variable was very high, whereas the skewness statistic equaled 0.919. In other words, data were considered to be within reasonable limits for acceptance with regard to further analyses. Regarding variables 3 and 4, the range of scores for variable 3, the number of progressive saccades varied from 50 to 98, with an average score that equaled 75. The comparable data for variable 4, the number of regressive saccades, were for the range of data: 2 to 47, and M = 19.4. To sum up: A relatively large dispersion of individual scores was observed for each of the measures of the four eye movement parameters. A comparison of the stability of the four parameter scores for the Ss under research will follow.

Since reading speed was chosen as one of the most important variables in the current study, it was reasonable to consider variables 5–7 as a group to be commented upon and compared in connection with data presented in Tables 1 and 2. Variable 5 represented data obtained by the OBER-2 system while administering T 1 to the Ss. In this silent reading test, the range of

Table 1. Individual scores, M-values for variables 1–9. Variables 1–7 are measures of eye movement parameters achieved by the OBER-2 system (silent reading T 1). Variables 8–9 are measures related to T 3 (oral reading). N = 20. Variable 1: Recognition span, i.e., average number of words in a fixation; Variable 2: Decoding fraction, i.e., average fixation time in milliseconds; Variable 3: Number of progressive saccades to find 'new' text; Variable 4: Number of regressive saccades to reread text; Variable 5: Reading speed in silent reading (T 1), i.e., number of words read per minute; Variable 6: Reading speed in silent reading (T 2), i.e., number of words read per minute; Variable 7: Reading speed in oral reading (T 3), i.e.,number of words read per minute; Variable 8: Reading fluency in oral reading (T 3); Variable 9: Reading error in oral reading (T 3)

Subj	Var 1	Var 2	Var 3	Var 4	Var 5	Var 6	Var 7	Var 8	Var 9
1	1.21	236.9	83	36	170.9	186.4	138.5	6.0	6.0
2	1.06	255.1	95	47	125.2	121.3	100.7	20.0	15.0
3	1.57	211.5	64	13	280.7	297.3	140.9	10.0	18.0
4	1.62	218.9	62	11	291.4	287.0	139.7	10.0	12.0
5	2.00	233.9	50	6	336.3	217.1	143.3	2.0	2.0
6	1.52	220.5	66	26	234.5	165.8	133.0	10.0	10.0
7	1.36	250.5	74	36	174.4	185.4	98.9	6.0	7.0
8	1.36	250.5	74	12	219.4	183.3	138.5	7.0	12.0
9	1.03	254.2	98	35	143.0	144.7	105.9	8.0	12.0
10	1.10	231.3	92	6	209.6	114.6	135.1	5.0	2.0
11	1.29	256.3	78	19	190.1	166.7	118.7	20.0	13.0
12	1.15	252.4	88	34	154.9	112.6	117.9	20.0	16.0
13	1.12	232.9	90	14	196.8	164.2	149.7	8.0	21.0
14	1.62	237.1	62	7	280.7	270.5	144.5	8.0	6.0
15	1.24	240.5	81	24	191.8	169.2	133.0	9.0	16.0
16	1.31	259.7	77	22	188.9	93.5	137.4	2.0	7.0
17	1.13	238.5	89	12	197.4	185.4	151.1	5.0	7.0
18	1.73	243.0	58	12	272.0	230.8	148.4	7.0	3.0
19	1.76	294.4	57	13	221.7	126.0	115.4	9.0	5.0
20	1.62	238.4	62	2	301.5	239.1	144.5	5.0	6.0
M	1.39	242.8	75	19	219.1	183.0	131.8	8.9	9.8

individual scores was equal to 125.2–336.3 with an average score of 219.1. T 2, also a silent reading test and performed in the same manner as T 1 but with a different text, exhibited a range of scores = 93.5 to 297.3. It followed that the M-value equaled 183.0. In other words, the Ss' average reading rate when doing T 2 was somewhat slower in comparison with their reading speed in T 1. As the T 2 text was shorter than the one used for T 1, an acceptable explanation might be found in the children's different familiarity with the subject and/or structure of the texts used for the two tests. Whereas T 1 and T 2 were silent reading tests, T 3 was an oral reading test. The range of scores in T 3 equaled 98.9–151.1, and the average score was 131.8. The Ss in general read considerably slower in the oral reading test compared to their reading performance (rate) in silent reading. It should also be noted that larger dispersions of scores were registered for the Ss' silent reading performances than for their oral reading behavior. The finding will be further commented on below.

The data from the third and final group of variables in Table 1, variables 8 and 9, both refer to the oral reading test (T 3). Variable 8 represents measures of the Ss' reading fluency whereas variable 9 was defined to be reading errors observed during the oral reading process (T 3). It should be remembered that the higher the scores in the two variables, the poorer were the performances. Regarding variable 8, the range of scores was observed to be 2 to 20, with an average score equaled to 8.9, while for variable 9, errors in oral reading performances, the range of scores was between 2–21 with the M-value equaled to 9.8. It should be pointed out that the distributions of scores for variables 8 and 9 were most satisfactory with regard to the normality principle.

In the present study, comparisons of scores achieved in the nine variables were important, both on the individual level (performances on variables 1 to 9) and on the sample level (comparing M-values for the same variables). Thus, without doing statistical tests it might be instructive to consider the individual reading rate scores on T 1 and T 3 for the five Ss who achieved the highest T 1 scores, on one side, and the five Ss with the lowest T 1 scores on the other. Going back to figures in Table 1 one finds that Ss 5, 20, 4, 14, and 3 had the highest scores on the silent reading test, i.e., 336.3, 301.5, 291.4, 280.7, and 280.7, with M = 298.1. The scores of the same Ss in oral reading were as follows: 143.3, 144.5, 139.7, 144.5, and 140.9, with M = 142.6. In other words, only 3 other Ss had T 3 scores in the same range, namely, Ss 17, 13, and 18. When examining the five Ss with the lowest scores on T 1, Ss 2, 9, 12, 7, and 16, they achieved these scores: 125.2, 143.0, 154.9, 174.4, and 188.9, with M = 157.3. The same Ss obtained the following scores on T 3: 100.7, 105.9, 117.9, 98.9, and 137.4, with M = 112.2. Five other Ss were in the same range: Ss 10, 6, 15, 11, and 19. It can thus be stated that a relatively high degree of stability was found in the scores both for the five best and the five poorest Ss when comparing their performances in silent and oral reading.

Table 2. Intercorrelations among eye movement parameters (T 1), speed in silent reading (T 2), and criteria on oral reading (T 3). N = 20. Variable 1: Recognition span; Variable 2: Average fixation duration; Variable 3: Number of progressive saccades; Variable 4: Number of regressive saccades; Variable 5: Speed in silent reading (T 1); Variable 6: Speed in silent reading (T 2); Variable 7: Speed in oral reading (T 3); Variable 8: Fluency in oral reading (T 3); Variable 9: Errors in oral reading (T 3)

	V 1	V 2	V 3	V 4	V 5	V 6	V 7	V 8
V 2	−08							
V 3	−98**	10						
V 4	−57**	25	57**					
V 5	87**	−45*	−86**	−81**				
V 6	58**	−62**	−61**	−48*	75**			
V 7	34	−54*	−35	−74**	64**	48*		
V 8	−32	18	31	48*	−43	−19	−52*	
V 9	−45*	−17	41	35	−37	−02	−16	58**

** $p < 0.01$.
* $p < 0.05$.

Correlations

Table 2 presents product-moment (PM) correlations among the variables in T 1 through T 3. When analyzing and commenting on figures in the correlation matrix, it seems reasonable to do so in relation to the problems in the study. Variables 1–4 in the correlation matrix are measures of the eye movement parameters chosen first and foremost for testing their individual relations with reading speed in the same test (T 1), but also to check their interrelationships, and their relations with reading data obtained in T 2 and T 3.

The figures in Table 2 indicate that variable 1, average number of words in a fixation, correlates significantly (r = 0.87) with variable 5, reading speed. Similarily, variable 2, average fixation time, as well as variables 3 and 4, the number of progressive and regressive saccades respectively, all correlate negatively with speed in silent reading (T 1). When negative relations are found, the results are meaningful as shorter fixation time and fewer progressive and regressive saccades are expected with the good rather than the poorer readers. It is, therefore, not surprising that the majority of the intercorrelations among the eye movement parameters measured in the study are significant findings in Table 2.

Interestingly, variables 1 through 5 also are substantially related to reading rate in T 2, the second silent reading test chosen for the project. The findings are all in line with the results reviewed and commented on above. It is noteworthy that a high and significant correlation is found between variable 5

(T 1) and variable 6 (T 2), i.e. *r* = 0.75, which can be taken as a high and acceptable reliability measure for the main test, T 1.

What can be said about the correlations between the individual eye movement measures and variables 7 to 9? Figures in Table 2 indicate that recognition span (v 1) correlates negatively with errors in oral reading, variable 9 (*r* = –45), which means that the higher number of words in a fixation is negatively related to the frequency of errors in an oral reading performance. In line with this finding, it can also be noted that the number of regressive saccades (v 4) correlates significantly with the score of fluency in oral reading (*r* = 48) (the higher fluency score, the poorer performance). Furthermore, both the average fixation time (v 2) and the number of regressive saccades (v 4) correlate negatively with reading rate in oral reading (v 7).

Finally, some remarks can be made with regard to the inter-correlational data for reading speed in the three reading tests. It has already been noticed that high correspondences were observed between the reading rate scores in T 1 and T 3 for the five Ss with highest and the five Ss with lowest scores on reading speed on T 1. When the comparable data for the whole sample are taken into account, it can be confirmed that significant correlations are available in Table 2 between silent reading (variable 5) and oral reading (variable 7) with *r* = 0.64, and also between silent reading (variable 6) and oral reading, *r* = 0.48. Hence, the two remaining correlations which show up as significant results in Table 2, namely, the negative correlation between speed in oral reading (v 7) and the fluency scores in the same performance (v 8), and the substantial finding between fluency and errors in reading (v 8 and v 9), *r* = 58, complete the inter-correlational picture of the variables in a plausible and acceptable way.

Multiple regression analyses

Two multiple regression analyses, one analysis using speed in silent reading (v 5) as dependent measure and one using speed in oral reading (v 7) as the criterion variable, were carried out in order to examine the prediction values of the individual eye movement parameters and their total prediction with regard to each of the two dependent measures. In other words, the same (linear) model was applied for both analyses. The data from the two analyses could be compared concerning the four eye movement parameters chosen for the study. The coefficient of determination is not only an indicator of total prediction of the independent variables in the regression analysis, it also indicates the goodness of fit tested by a F-test. R^2 also shows how much variance in the dependent variable is explained by the model. Since the results of the two regression analyses showed good fit of the linear model, no attempts were made to use alternative regression models.

Although relatively few independent variables should be used in a multiple regression analysis with 20 Ss, it seemed meaningful and legitimate to include all of the four eye movement parameters in each of the two analyses because they all were considered potential predictors for reading speed. Stepwise procedures were used for both analyses. No outliers were revealed in the two multiple regression analyses.

Table 3 contains multiple regression data based on the Ss' test performances in doing T 1 and T 3. In the first analysis (prediction study), the Ss' rate in silent reading was used as the criterion variable. It should be noted that $F_{3\ 16} = 285.3$, $p < 0.001$. In the second analysis, where the Ss' speed in oral reading was the dependent measure, the $F_{3\ 16} = 8.3$, $p < 0.01$. In other words, the linear model was found significant in the first as well as the second prediction study.

Special attention should be paid to the individual parameters tested and found to be significant predictors for Ss' reading rate in T 1 and T 3. During the first analysis, three of the four eye movement parameters could predict reading speed individually, that is, both v 1, recognition span (number of words in fixation), v 2, average fixation duration, and v 4, number of regressive saccades, were found to be significant predictors, with $t_{19} = 4.91$, $p < 0.001$; $t_{19} = –9.86$, $p < 0.00.1$; and $t_{19} = –10.08$, $p < 0.001$ for speed in silent reading. It is noteworthy that v 4, the number of regressive saccades while reading, could predict reading rate strongly (with a negative *t*-value, of course). In the second analysis, two of the four parameters were found to be significant, individual predictors for speed in oral reading, that is, v 2, average fixation duration, and v 4, number of regressive saccades, with $t_{19} = –2.42$, $p < 0.05$; and $t_{19} = –3.84$, $p < 0.001$. Thus, the empirical results of the two multiple regression analyses have indicated close relations between individual measures of the majority of the eye movement parameters sampled for the study and reading speed both in silent and oral reading tasks. In the analyses, two of the parameters, v 2 and 4, seemed to play an important role in predicting the children's reading speed performances.

Discussion and conclusions

Recent research has focused on the characteristics of eye movements and eye movement control in reading. Data from the eye movement studies have also been utilized to infer something about the process of reading, that is, what the eye movements can tell us about reading (Rayner 1995). Despite the information which has now become available with regard to factors influencing fixation time in reading a word or a sentence (e.g., word frequency, contextual constraints, semantic relations between words in sentence, and

Table 3. Results of multiple regression analyses based on children's test performances in the prediction studies. Criterion variables: Speed in silent reading (T 1) (first prediction study), and in oral reading (T 3) (second prediciton study). Predictor variables: Eye movement parameters in T 1. Figures for total prediction and significant individual predictors are presented. N = 20

Criterion variables	Predictor variables	R	R^2	Regr. SS	MS	F	*t*	*p*
v 5 Reading speed (T 1)	All 4 predictors	0.993	0.984	62175.4	15543.8	285.3		0.001
- - - " - - -	v 1 Rec. span						4.91	0.001
- - - " - - -	v 2 Av. fix. t.						−9.86	0.001
- - - " - - -	v 4 No. reg.sacc.						−10.08	0.001
v 7 Reading speed (T 3)	All 4 predictors	0.830	0.607	3486.7	871.7	8.3		0.001
- - - " - - -	v 2 Av. fix. t.						−2.42	0.029
- - - " - - -	v 4 No. reg.sacc.						−3.84	0.002

lexical ambiguity), few, if any studies, have examined the relations between central eye movement parameters and reading speed which was emphasized in the reported study.

Reading speed is an important criterion of reading competence. Research on the relationship between eye movement parameters and reading speed, therefore, might identify information that would explain to some extent why some people read ordinary texts at an unacceptably slow speed. When doing research on the relations between eye movement parameters and reading speed, it was thought important to check the total prediction value of the parameters as well as their individual predictions about silent and oral reading before an experiment could be organized for examining causation relations between the target variables. If such relations were tested and observed in correlation studies in future experiments, one might concentrate on causality regarding central eye movement parameters and speed variables in reading when using different kinds of texts for various problems within the same subject matter. This line of research could be systematically performed for different subject matters as well, and thus expand empirical information concerning the relation between eye movement parameters and divergent criteria on reading.

Once again, it should be clarified that the point of departure in the present study was children's reading speed, and the intention was to investigate whether a sample of eye movement parameters were related (and thus could predict) to the children's reading speed. The purpose of the study would, therefore, be a determinating factor for the sampling of parameters/measures of children's eye movements topical for the reported study. Four parameters were considered to be important for the total and individual predictions of children's reading rate with two of them being associated with the eye fixations. Thus, it was assumed that the recognition span, that is, the number of words in a fixation, would be an adequate and valid measure related to reading speed. Similarly, it was assumed that the average fixation time would be another valid indicator correlated with children's reading rate. Likewise, the total number of progressive and regressive saccades were assumed to affect children's reading rate, and were thus chosen and used as the third and fourth parameters of the eye movements involved in reading. The variable reading speed was defined to be the number of words read per minute. Finally, it was assumed that the level of difficulty (comprehension) of the three texts was fairly equal in the tests used in collecting data for the study.

According to previous research, it was reasonable to expect significant correlations between each of the four parameters/measures of eye movements and reading speed, yet, no hypotheses were formulated and stated in line with the expectations. For instance, as to our expectations, slow (poor) readers were expected to have high frequencies of progressive as well as regressive fixations in their reading performances. Moreover, it was predicted that this category of readers would also have small recognition spans in their reading, and their average fixation time would be long. Data achieved from the present study clearly showed significant correlations between each of the four eye movement parameters and silent reading speed. Similar findings for the average fixation duration occurred also for oral reading speed. Since significant correlations were observed among the three measures of reading speed, the empirical evidence for substantial total predictions of the four eye movement variables concerning reading speed both in silent reading (T 1) and oral reading (T 3) were in keeping with data in the correlation matrix.

When interpreting data from the multiple regression analyses, it was important to know that significant inter-correlations among the four eye movement variables (v 1–4) were revealed for only three of the six correlation coefficients (cf. Table 2). According to these findings, it could be stated that no serious problems of colinearity would occur in the two regression analyses (a phenomenon verified in the statistical analyses as well). The results of the regression analyses indicated significant relations between the parameters: recognition span, average fixation duration, number of regressive saccades and speed in silent reading. The average fixation duration, and the number of regressive saccades were also substantially related to speed in oral reading (cf. Table 3). Based on the reviewed findings from the correlation matrix and the two multiple regression analyses the following conclusions could therefore be drawn: First, the sample of eye movement parameters selected for the current study seemed to have been a reasonable choice for finding significant variables with substantial relations to children's reading speed, particularly in their silent reading. Second, besides the significant total prediction of the four eye movement measures with respect to reading speed, the average fixation time and number of regression saccades were the most efficient, individual predictors for speed in silent as well as oral reading. Support for these findings can be found in earlier studies where it was confirmed that cognitive and linguistic variables play an important role for eye movement parameters in reading behavior (Hyönä et al. 1995; Rizzolotti et al. 1987; Vauras et al. 1992).

Some questions (related problems) were raised in conjunction with the main problem of the reported study, namely, whether or not speed in silent reading is closely related to speed in oral reading. Similarily, we intended to scrutinize whether or not reading fluency (oral reading) was related to reading speed, on one hand, and if errors in oral reading were correlated with reading speed, on the other. In the present study, interesting correlation data were observed in these areas. Thus, further research should be carried out in order to investigate the educational implications within the problem area. From an educational point of view there might be a stressing point to learn to what extent the curricula and methods of reading should emphasize oral vs. silent reading training.

Although the M-values, that is, the average number of words read per minute, for the three reading tests differed to some extent (T 1 = 219.1, T 2 = 183.0, and T 3 (oral reading) = 131.8), the inter-correlations among the three reading test performances were all significant findings (correlations coefficients = 0.75, 0.64, and 0.48). As the level of difficulty was assumed to be equal for all three texts used as task variables in the reading tests, it seems reasonable to conclude that a high degree of stability in the three reading speed performances of the children sampled as subjects was disclosed in the study. In general, the results indicated that the reading speed performance of a 12 year old child doing an oral reading test in general also will indicate his/her speed in silent reading, and vice versa. In connection with this conclusion, based on general statistics, it seems reasonable to mention that both intra-individual and inter-individual differences could be observed from data in Table 1. Even though no case studies were carried out in the data analyses, the researchers were aware of the diversities in the test performances of the children under investigation, the intra-individual differences for some Ss in particular. Without treating these findings specifically, the diagnostic values of such data with reference to educational practice should not be underestimated. Furthermore, we want to show the reader that data concerning fluency and errors in oral reading may also give additional information.

Even though a significant correlation was revealed between fluency and error scores in the children's oral reading performances, figures in Table 2 indicated that few substantial relations existed among variables 8 or 9 (fluency – reading errors) and remaining variables under investigation. Significant correlations were revealed in two cases only: between scores of reading fluency and frequency of errors in oral reading (r = 0.58), and between reading fluency and speed in oral reading (r = –0.52). These findings are plausible and meaningful as they suggest that poor reading fluency (high score) is related to (1) a high frequency of reading errors in oral reading tasks, and (2) a need for a relatively long time, for example, taking many longer pauses, when reading a text orally. The negative correlation observed between fluency and general reading speed (in the same reading task) does not call for special interpretation as fluency in reading can hardly be carried out without a certain degree of speed performance. The empirical information in this area should indicate that the criteria of fluency as well as errors in oral reading can be used for further research on this type of reading studies (oral reading). When assessing the correlational findings in Table 2, it should also be kept in mind that few measures were used for each of the functions under research, and further, that the sample of Ss in the reported study was relatively small.

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