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Sensory and Cognitive Determinants of Reading Speed

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Fast readers and average readers were tested on four tasks. Neither peripheral letter identification nor susceptibility of foveal letter identification to patterned masking differed between the two groups. However, fast readers appear to pick up more information per fixation on structured textual material, as indexed by a forced-choice test. Furthermore, the average fast reader had a greater span of apprehension for unrelated elements. It appears that faster readers are able to encode more of the contents of each fixation, whether or not higher order linguistic structure is present. The results are inconsistent with the view that reading speed is dependent solely on the reader's ability to infer or fill in missing information.

Since researchers began studying the process of reading, the problem of determining why some people can read faster than others has attracted considerable interest. Although numerous researchers have looked into the matter or speculated upon it, there is little indication of any success in isolating the processes and factors which determine reading speed. The present investigation represents a first step toward that goal. It is our hope that isolating the processes or factors which contribute to reading speed will lead to a clearer understanding of the reading process.

Ordinarily, reading is defined as the acquisition of the intended meaning from written symbols (McLaughlin, 1969). However, the term "reading" has been used to refer to a number of different processes. People can process text differently depending on their reason for reading (McConkie, Rayner, & Wilson, 1973), and will not necessarily acquire the intended meaning of the material being read, even though their eyes may stop within a few degrees of visual angle of every word. While a number of techniques have been developed which purport to increase the user's reading speed through the use of skimming, rhythmic finger sweeping, rapid visual search, or some combination of these methods, many of these techniques do not permit the reader to acquire an adequate understanding of the material read (Taylor, 1965) and consequently do not constitute reading as defined here. We will restrict this investigation to a consideration of processes which are adequate to give the reader a high level of comprehension of what he has read, as indexed by a strict comprehension test.

The earliest studies of the reading process (cf. Huey, 1908) indicate that reading takes place during fixations or pauses of the eye, separated by very brief eye movements or saccades. Reading speed is, therefore, dependent on the number and duration of the fixations per unit of text. Taylor (1965), summarizing the results of several eye movement studies, noted that more effective readers make fewer fixations per page. These findings suggest that faster readers are able to

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deal with a larger amount of text during each fixation. In support of this view, Gilbert (1959) found a positive correlation between speed of reading and the ability to report the words contained in briefly presented phrases; the performance of the fastest 25% of the readers was significantly better than the performance of the slowest 25% of the readers.

The problem is to explain why faster readers can identify more words correctly from each fixation. We will distinguish two general possibilities: The faster reader has superior sensory processes which make available to higher level processes more of the visual information on the page at each fixation; or the fast reader has an advantage at a cognitive level, allowing him to make superior use of information made available by the sensory processes. Although reading is primarily a cognitive task, at least two sensory factors could contribute to an increase in the amount of visual information available at each fixation: (1) The number of words recognized from a briefly presented phrase may depend on the length of time that information is available for processing. This, in turn, may depend on the temporal resolution of the perceptual system, since each fixation is preceded and followed by other fixations which provide pre- and post-exposure masking. Hence, if the temporal resolution of the rapid reader's perceptual system is superior, he should be able to read more at one glance. To test the system's temporal resolution we measured the threshold for correctly identifying a single letter presented in the fovea under conditions of pre- and post-exposure masking by a patterned mask. This task will be called the single letter threshold task. (2) Fast readers may identify more words from each fixation because they are able to pick up information from a wider spatial area. Thus, the degree to which information can be extracted from peripheral areas may well be an important determiner of reading speed. To measure the size of our subjects' spatial span, we presented pairs of letters separated at various distances from the center of fixation and tested accuracy of report. This task is called the letter separation task.

Although it is certainly possible that fast readers have greater sensory processing capabilities, the major determiners of reading speed are probably more cognitive in nature. Two possibilities to consider are: (1) Fast readers may be able to apprehend a larger number of units—be they letters, words, or phrases—from the information available from a single fixation. To measure the span of apprehension, free of influences of higher level language structure, we measured the number of letters which fast and average readers could recall from a briefly presented string of unrelated consonants. This task will be called the unrelated letter task. (2) Faster readers may be better able to use sensory information in conjunction with knowledge of linguistic structure in forming a representation of the contents of each fixation. If this, and only this, ability differentiates fast readers from slower readers, none of the tasks thus far described would reveal any advantage for fast readers, even though the fast readers would show an advantage of reporting the content of the structured phrases and sentences used by Gilbert (1959). Within the domain of this possibility, there are two quite distinct subpossibilities: (a) For all readers, only a small amount of visual feature information is picked up on each fixation. What differentiates fast readers from slower readers is the fast reader's ability to fill in or guess the missing parts of the message from knowledge of linguistic structure and contextual cues. (b) For all readers, a great deal of information is made available to higher level cognitive processes on each trial. What differentiates the fast reader from the slower reader is the fast reader's superior ability to integrate that information into an organized conceptual structure with the aid of knowledge of linguistic structure and contextual cues.

Many researchers have taken the position that the faster reader simply guesses better than the slower reader from sparse visual information (Smith, 1971; Hochberg & Brooks, 1970; Mattingly, 1972; Goodman, 1970; Mackworth, 1972; Morton, 1964; Schiffman, 1972).

Any model of reading which attributes differences in reading speed solely to differential guessing from context must predict that in a recognition task in which context cannot be relied upon to facilitate correct guessing, performance of fast readers should equal performance of slower readers, all else being equal. The unrelated letter task is one such task. However, this task is somewhat removed from what is involved in normal reading. To determine whether fast readers are simply guessing better in a sentence reading situation, we can measure how much information readers extract from briefly presented sentences using a probe forced-choice test (following Reicher, 1969). In our adaptation of this test, the subject is given a choice between two words differing by a single letter, where one word occurs in the sentence presented but both choices fit the sentence context. For example, a subject may be presented with the sentence

Sally wore a plain scarf

and then tested with the choice

Sally wore a plain/plaid scarf.

If fast and slower readers pick up equal visual information, their performance should be equal. If, however, the faster reader is able to pick up more information, he should perform more accurately. This task is called the forced-choice task.

To address the possibilities we have raised, fast and average readers were first tested in a free report task following Gilbert (1959) to show that, indeed, we were tapping the processes responsible for Gilbert's effects. Then both groups were given the four tasks described above.

In selecting subjects, we assessed comprehension, as well as speed. No subject was included in either group unless he scored at least 70% on a comprehension test, insuring that he was in fact reading as defined above. The reading material and comprehension tests were prepared with considerable care in an attempt to obtain an accurate estimate of the subject's reading performance. Often the subject matter of reading tests used in assessing reading speed may be more familiar to some subjects than to others. The result is inflated speed estimates for those subjects. Comprehension tests constructed of multiple-choice questions are especially sensitive to differences in the prior knowledge of the subjects. Alternative answers can be eliminated and more accurate guesses made without recourse to any knowledge gained from the test passage. To avoid these problems, we tested reading on a passage on an unfamiliar topic, and required written short answers to our test questions, to reduce the possibility of guessing the correct answer.

METHOD

All subjects who were contacted to participate in the experiment were tested for reading speed and comprehension (Reading Test), and for ability to report the contents of a briefly presented five-word sentence (Free Report Task), in an initial session lasting up to 40 min depending on the subject's reading speed. Subjects whose performance placed them in either the average or fast groups (see Subjects) returned for a second session in which they performed, in order, the first half of the Forced-Choice Task, the Letter Separation Task, and Threshold Task, and the second half of the Forced-Choice Task. A break of approximately 3 min separated the tasks in the second session, which lasted approximately 50 min. A third session included the Unrelated Letter Task along with further experiments not reported here.

Reading Test

The reading test consisted of a short article of 4286 words, "The Trojan Hearse," by Isaac Asimov (1975). The passage dealt with asteroids. This topic area was chosen to be unfamiliar to as many subjects as possible.

Subjects were told that the purpose of the reading test was to obtain an estimate of their actual reading speed. Subjects were instructed to read the passage as fast as possible, consistent with good comprehension, and were warned that afterwards they would be given a comprehension test.

The comprehension test consisted of 10 short-answer questions and was completed by each subject immediately after reading the passage. Subjects were instructed to write a brief answer to each question. No time limit was placed on the comprehension test. Answers were scored from a key written by the experimenter. To determine whether the questions could be answered without reading the material, 10 graduate students who had not seen the article were given the comprehension test and were instructed to answer as many questions as possible, making guesses when necessary. The average number of questions correctly answered was only .9 out of 10.

Subjects

Our design called for six readers in the average range (200–300 words per minute) and six readers who could read considerably faster with good comprehension. Subjects from the normal reading group were recruited by posting a sign-up sheet. The first six subjects obtained from this source who satisfied all of the following restrictions were used: (a) no courses in astronomy and no admitted background knowledge about asteroids beyond the knowledge that asteroids are small bodies orbiting between Mars and Jupiter; (b) 70% correct performance on the comprehension test; and (c) a reading speed between 200 and 300 words per minute. Twelve subjects were tested before six satisfying all these constrains were obtained.

Subjects for the fast reader group were solicited via sign-up sheets, advertisements in campus publications, and recruiting within the psychology department. Twenty-eight subjects were tested. The six of these with the fastest speed who passed restrictions (a) and (b), above, were used in the experiment. The speeds of these readers ranged from 451 to 855 words per minute. Two of these fastest six were psychology graduate students; the rest were undergraduates.

All subjects who typically wore corrective lenses were required to wear them in the experiments. Each subject was given either course credit or $1.88 per hour, whichever he preferred.

Apparatus and Materials

Stimuli were presented in a modified two-field Polymetric Tachistoscope with Sylvania F4T5/D fluorescent lamps illuminating each channel. Modifications included a more durable timing circuit and an extension of the viewing distance to 81 cm. The reverse field of the tachistoscope was illuminated whenever the stimulus field was not, with pre- and post-exposure masking provided by an array of overlapping Xs and Os. The mask extended one space above and below each stimulus. In the free report, forced-choice, and unrelated letter tasks, the mask extended one space beyond the left and right boundaries of the stimuli. For the peripheral span and single letter threshold tasks, the mask extended to the edges of the field, several spaces beyond the widest span used. The luminance of a blank white card was approximately 192 candelas per square meter in the stimulus field, and 185 candelas per square meter in the masking field. All stimuli were typed using a 10 pitch IBM selectric typewriter with carbon ribbon and a Courier 72 element on white 5 × 8 in. cards.

General Procedure

In all of the experimental tasks, the subject sat looking into the tachistoscope and fixated the center of the masking pattern. Instructions stressed that the tasks were difficult and would require full attention on each trial. When he felt he was ready for each trial, the subject pressed a foot switch and 300 msec later the stimulus was briefly exposed. In all but the threshold task, stimuli were presented for 200 msec. The 200-msec duration is in the lower range of normal durations of fixational pauses in reading, which averages about 250 msec (Taylor, 1965; Abrams & Zuber, 1972).

Free Report Task

The free report stimuli consisted of five-word sentences of the forms Noun Verb Article Adjective Noun and Noun Verb Preposition Article Noun. The first noun was always a first name. For example, one sentence was *Dan fixed the flat tire*. All the sentences were complete and made sense. The sentences were 19 to 21 letters in length (mean 20.25), and subtended approximately 4.3° of visual angle. All stimuli were typed in lowercase beginning with a capital letter. The sentences were centered around the center of the masking field. Subjects were shown five practice sentences followed by 20 test sentences presented in random order.

For each trial, subjects were instructed to fixate on the center of the masking pattern and try to see the whole sentence. After each exposure subjects wrote down, on a form provided, as much of the sentence as they could. Subjects were instructed to write down any letters they saw whenever they recognized letters without identifying the whole word.

Letter Separation Test

The stimuli consisted of 72 pairs of uppercase letters formed from all combinations of two different letters from the set A, B, C, E, F, G, H, M, N. The letters were chosen to be confusable, making the discrimination more difficult. Spatial separations of 11, 17, 25, and 31 letter spaces (2.29, 3.37, 4.76, and 5.87°, respectively) were used with the midpoint coinciding with the fixation point. There were 18 pairs at each separation, with each letter occurring twice on each side of center. In addition, 12 practice items, three at each separation, were constructed by randomly assigning 12 of the test pairs to a different separation.

The set of possible letters was displayed at the top of the field before and after each trial to ensure that all subjects were aware of the sample set. After each trial, subjects wrote down, on a form provided, which letter was presented on the right and which letter was on the left of fixation. Subjects were instructed to guess if they were not sure, selecting only letters from the sample set. The 12 practice trials were followed by the 72 test pairs presented in random order.

Single Letter Threshold Test

The stimuli were single capital letters presented at the center of the stimulus field. There were 36 stimuli, four each of the letters A, B, C, E, F, G, H, M, and N. The list of letters was displayed at the top of the pre- and post-exposure field as in the letter separation task. Each subject was instructed to fixate the center of the masking pattern, and to respond verbally by saying the letter he saw, or that he did not see a letter. The threshold was approached using a modified binary search method, starting at 20 msec. The threshold was taken as the average of the last 20 trials.

Unrelated Letter Test

Each of the unrelated letter strings consisted of eight letters randomly chosen from the set of consonants. Each string was typed in capitals, centered in the presentation field, and subtended an angle of 1.38°. The list contained five practice stimuli and 20 test stimuli. After each exposure, the subject wrote down eight letters in any order, guessing if necessary.

Forced-Choice Test

As in the free report task, sentences were of the form Noun Verb Article Adjective Noun and Noun Verb Preposition Article Noun. Sentences were made in pairs, and the first noun was always a first name. The sentences in the same pair differed by one word; both words made sense in the sentence and differed by only one letter. For example, one pair was

Kevin fired/hired a new worker.

The sentences were all 21 letters in length and subtended 4.3°. Each sentence was typed in normal lowercase type with the first letter of the first word capitalized. There were 18 pairs in each of four critical word positions (first, second, fourth, and fifth word) divided into three groups of six with the critical letter in initial, medial, and final positions within the word. The set of sentence pairs was separated into two lists of 72 items, with one item from each pair in each list. Half of the subjects in each group saw one member of each pair (List A), and half of the subjects saw the other member (List B). The two lists were balanced for the number of correct choices which were the upper and lower members of the choice pair at each word position. Six practice items, at least one at each critical word position, were also constructed.

Each sentence was shown for 200 msec. After each exposure, the subject looked over the top of the tachistoscope to view the choice alternatives typed at the top of the stimulus card. The entire sentence was given with the two alternatives at the critical position as in the example given above. The subject indicated his choice by writing down the alternative he thought was in the sentence, guessing when not sure. Subjects had the practice sentences followed by 36 of the test sentences at the beginning of the second session, and the remaining 36 sentences at the end of the session.

RESULTS

Table 1 summarizes each subject's performance on the reading test and the several experimental tasks. Subjects are arranged in order of increasing effective reading speed (speed times comprehension).

Subjects' free reports were scored for the percentage of letters, words, and whole sentences reported correctly. One-tailed t tests (corrected for nonhomogeneity of variance) showed that the fast readers reported significantly more letters, words, and whole sentences than did the slow readers, $t(6) = 3.68$, $p < .005$, $t(10) = 2.99$, $p < .005$, and $t(10) = 3.02$, $p < .005$, respectively. The overall mean of 69.7% words correctly reported is comparable to the 72% mean found by Gilbert (1959). The percentage of letters correctly reported increased with effective reading speed, $r = .74$, $p < .01$. Similar correlations were obtained for the other measures. The scattergram in Fig. 1 suggests a curvilinear relationship between reading speed and free report accuracy.

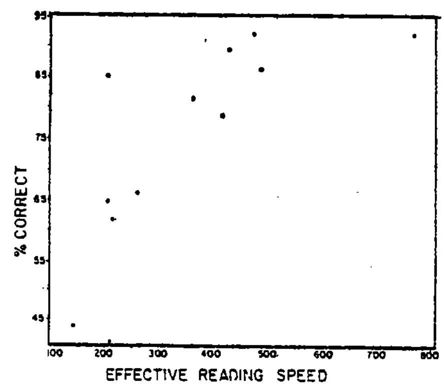

FIG. 1. Percentage of letters correctly reported in Free Report Task plotted against Effective Reading Speed in words per minute.

The results for the two sensory tasks show no difference between fast readers and normal readers. In the single letter threshold task, thresholds for the fast reader group, 49.3 msec, and the slow reader group, 52.7

TABLE 1

INDIVIDUAL SUBJECT RESULTS[a]

Subject	Speed	Compre-hension	Effective reading speed	Free letters	Report words	Senten-ces	Threshold	Overall span	Unre-lated letters	Forced-choice
JC	206	70	144	43	37	0	64.5	79	53	57
MS	242	85	206	86	83	40	54.0	94	47	82
MW	257	80	206	65	63	15	49.0	81	52	65
PS	299	70	210	41	36	0	50.5	77	50	68
EM	268	80	215	62	61	20	44.0	88	57	76
JS	286	90	260	66	66	20	54.5	88	59	79
$\bar{X}$	260	79	207	61	58	16	52.7	85	53	71
MT	451	80	361	82	74	25	46.5	88	71	79
CG	525	80	420	78	70	15	50.5	73	63	75
SH	615	70	430	90	88	50	50.2	81	66	79
GS	528	90	475	93	89	45	57.0	88	66	79
FM	542	90	487	87	83	40	42.0	85	61	81
BG	855	90	769	93	87	50	49.5	92	57	83
$\bar{X}$	586	83	490	87	82	39	49.3	85	64	79

[a] All numbers are percentage correct except Speed and Effective Reading Speed (words per minute) and Threshold (milliseconds).

msec, were not significantly different, $t(10) = 1.00$, $p > .1$. The small difference between means appears to be due to one subject (JC) in the slow group who had a higher threshold; otherwise the distributions look identical, and the correlation with effective reading speed is $r = -.29$, $p > .1$. In the peripheral span task, fast readers did not differ significantly from slow readers in the number of correct responses made at any of the four peripheral span separations, $t < 1.0$ in all cases, or in the mean performance collapsed over all separations, $t = .48$. These results are shown in Fig. 2. The two subjects making the fewest errors at the widest spatial span were in the slow group.

In the unrelated letter task, the fast readers reported the letters 11% more accurately than the slow readers, $t(10) = 4.19$, $p < .005$. Accuracy in the unrelated letter task had a modest correlation with effective reading speed, $r = .48$, $p = .06$, and the number of letters correctly reported in the free report task, $r = .52$, $p < .05$.

In the forced-choice task, the fast readers were 8.1% more accurate than the slow readers, $t(5.87) = 1.99$, $p < .05$. The number of correct forced choices correlated highly with the number of letters correct on the free report, $r = .85$, $p < .001$, and to a lesser extent with effective reading speed, $r = .61$, $p < .05$.

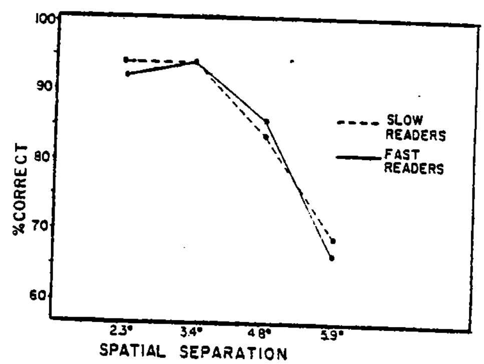

FIG. 2. Percentage of letters correctly reported in Letter Separation Task for each spatial separation. Means for fast readers and slow readers are plotted separately.

Discussion

The results of the free report task replicate the results found by Gilbert (1959); faster readers reported more letters correctly from a five-word sentence presented for a duration approximating the average duration of a reading fixation. The percentage of correctly reported letters, words, and, indeed, whole sentences increased dramatically with increasing reading speed. This effect demonstrates once again that faster readers are able to pick up more information from each fixation.

The present experiment found no evidence that either of the two sensory factors considered are the determinants of superior reading speed or superior performance in the free report task. Fast readers' thresholds for identifying single letters did not differ from slow readers' thresholds. Thus, the results suggest that the fast reader's ability to deal with more information from each fixation is not due to reduced susceptibility to the masking effects of prior or subsequent fixations.

The breadth of field from which the reader can utilize visual information was approximately the same for the fast-reader group and the slow-reader group. Apparently the advantage fast readers enjoy in the free report is not due to an ability to identify letters farther into the periphery. One possible explanation for the lack of influence of peripheral span on the amount of information dealt with at each fixation, is that the necessity to devote resources to comprehending the material reduces the amount of material which can be attended to at each fixation (Taylor, 1965). Consequently, any advantage of greater peripheral sensitivity would be useless when a sequence of words must be organized into some sort of stable conceptual structure.

The peripheral span results should not be taken as evidence that fast readers and average readers use peripheral cues equally well in the guidance of eye movements during reading. We doubt that the use of peripheral cues is dependent solely on the reader's visual span; it presumably depends as strongly on the amount of processing capacity he has to spare for dealing with sensory information available from the periphery. If, as we will suggest below, rapid readers are more efficient processors of the contents of each fixation, they may well have spare capacity left over for the superior use of peripheral cues to guide eye movements for subsequent fixations.

Although peripheral span and susceptibility to masking do not appear to differentiate fast from average readers, we cannot rule out the possibility that other sensory factors may help determine how much information can be dealt with by the reader from each fixation. A possibility not explicitly tested in the present experiment is sensitivity to lateral masking of adjacent letters in the stimulus. Bouma (1973) found evidence for lateral visual interference in the identification of letters in words and unrelated letter strings. Fast readers may be less sensitive to lateral masking effects of adjacent letters, allowing them to identify more letters at each fixation. If, however, lateral masking and temporal masking are mediated by the same neural mechanisms (Weisstein, 1968), this would seem unlikely given our failure to find a difference in temporal masking.

The results of the forced-choice task support the hypothesis that fast readers are able to form an accessible representation capturing more of the visual information present in each reading fixation. Fast readers identified more words correctly when the choices differed by a single letter and both choices fit the sentence context. Hence, fast readers must be picking up more information about the critical letter than are the slow readers. We can thus eliminate the hypothesis which states that faster reading is solely due to an ability to guess missing information in the sentence based on contextual cues and knowledge of the language.

The difference in performance for individual fast readers and slow readers in the forced-choice task is not as distinct as in the free report task. This is to be expected, since the number of observations involved in the forced-choice test is not large. Even so, it is noteworthy that the one slow reader (MS), who was as accurate as the median fast reader in the free report, fell in the same position in the forced-choice task. This subject may be a potential fast reader who is currently reading slower than her capabilities would permit. Alternatively, she may lack some processing skills which are needed for integrating information across fixations.

Although we are rejecting the hypothesis that differences in reading speed are due solely to differences in ability to fill in incomplete information, we do not wish to exclude the possibility that filling-in plays an important role in reading. Both fast readers and slow readers identify a higher percentage of letters in the free report task than the percentage of correct forced choices, corrected for guessing, would predict. Filling in letters correctly on the basis of contextual constraints may well be responsible for some of this discrepancy.

The unrelated letter task permits us to ask whether the fast reader's advantage in free reports and forced choices is due to an ability to process more elements regardless of higher order structure. The answer appears to be at least a partial yes. Fast readers were more accurate than slower readers in reports of unrelated letters. However, the correlation between free report and unrelated letter performance was only moderate, in spite of the low variance in each of these measures, and was much lower than the correlation between free report and forced-choice performance. Thus, superior unrelated letter performance alone does not appear to account completely for free report performance, or reading speed. One interesting possibility is that a greater-than-normal span of apprehension is necssary for fast reading, but, in addition, fast readers must also possess the capability to integrate more perceived elements into an organized conceptual representation.

Conclusion

A number of researchers have expressed the view that tachistoscopic recognition tasks are static, impoverished situations which do not implicate the higher-order processes required in reading (Fisher, 1975; Rayner, 1975; Taylor, 1957, 1965). This view is justified in the sense that many processes operating during reading, such as the control of eye movements, the guidance of visual search, and the integration of information into a meaningful conceptual structure cannot be investigated in a tachistoscopic situation. The work of Rayner (1975), McConkie and Rayner (1975), and Fisher (1975) in situations more closely approximating normal reading, represent important steps toward fuller understanding of these processes. However, the present experiment indicates that tachistoscopic procedures are useful for investigating some of the processes which are fundamental to rapid reading.

Our results suggest that faster readers are capable of encoding more information for higher-level conceptual processes to organize into a conceptual representation from each fixation. The availability of more information may well facilitate the utilization of contextual contraints, resulting in more efficient use of partial information. At the same time, greater efficiency of encoding of visual information could free limited processing resources to deal with the conceptual content of what is read and to guide eye movements to a useful place to begin the cycle anew.

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