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Training of Perceptual Unit Processing in Children With a Reading Disability

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A reading intervention program based on a computerized instructional system developed by Frederiksen was conducted over an 8-week period. The program was aimed at developing expertise in detecting multiletter units within words, which is an important reading skill component. The program was adjusted to the features of the Dutch language and tested on a sample of 33 nine- or ten-year-old children with reading difficulties. The participants were subdivided based on reading strategy: fast guessing or spelling. We hypothesized that perceptual coding and decoding skills would be improved by the training program. We also predicted that fast guessing readers would learn to detect letter units and to read words more accurately and that spelling participants would increase their speed. The children were matched to form an experimental group and a control group. Various test tasks were administered to determine both direct training effects on detection of multiletter units in words and transfer of training to other components of reading ability. The results showed increased perceptual coding skills for children in the training group compared with the control group. The children in the experimental group not only recognized (trained as well as new) multiletter units in words more quickly but also showed faster word decoding. A tendency toward a differential effect on reading strategy was found regarding word decoding only. In this respect, spellers tended to profit more from the speed training than did fast guessers from the accuracy exercise.

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In many cultures, the ability to read is considered basic to everyday functioning. Therefore, children who suffer from reading problems need to be helped. The often disappointing results of many approaches to remediation should not preclude continued effort in this area. This article reports on a remediation study, starting from the widely accepted premise that, without rapid processing of words, fluent reading is problematic. The study was based on a promising instructional system developed by Frederiksen, Warren, and Rosebery (1985). The most basic program from that system was employed in this study. The program aims to improve speed, accuracy, or both of recognition of multiletter units in words and, at the same time, to maintain accuracy and speed, respectively. In previous research, this component of the reading process has been shown to represent a particular source of difficulty for poor readers (Frederiksen, 1982). Frederiksen et al. reported on the rather impressive progress made by students with reading problems who were trained by this program. However, the study involved only a small sample of students, and no control group was used. Furthermore, the participants were high school students. This study investigated the effects of the multiletter recognition program of Frederiksen et al., employing a control group and larger samples of younger students.

Although our theoretical understanding of the reading process is still far from complete, a few decades of research have yielded many interesting findings. A selection of the theoretical positions and some recent advances are first presented here. Subsequently, a choice justification and a short description are given of the remediation program and the groups of participants used in this study.

INDIVIDUALS WITH A READING DISABILITY AND SUGGESTED AREAS OF DEFICIT

Research on reading has focused on issues representing various levels of the reading process, ranging from perceptual to semantic. Various factors have been thought to be specifically linked to reading disability (RD). Stated in broad categories, a deviation in brain lateralization development (Bakker, 1982), visual spatial processing deficits (DiLollo, Hanson, & McIntyre, 1983), verbal deficits (Vellutino, 1979) or a combination of visual and verbal deficits, inefficient working memory functioning (Torgesen, 1985), and automatization failure (LaBerge & Samuels, 1974; Perfetti & Lesgold, 1977) have been mentioned as underlying causes for inadequate reading. In addition, the issue of the existence of one or more kinds of deficits in different children has been addressed. This issue has not been settled yet. Both single and multiple causations of reading disability have been advocated (for single causations, see Shankweiler & Crain, 1986; Vellutino, 1979; for multiple causations, see Pirozzolo, 1981; Snowling, 1991).

Recently, evidence has accumulated regarding a phonological coding deficiency as one major cause of reading failure (Bradley & Bryant, 1983, 1985). A study by Olson, Wise, Conners, Rack, and Fulker (1989) is particularly significant in this

context, because their results point to genetic origins of the lower phonological coding abilities among RD children. Besides a deficit in phonological awareness, however, many poor readers also show an impaired memory span (Torgesen & Houck, 1980). As demonstrated by Baddeley and his colleagues in their model of working memory (Baddeley, 1986), this aspect of memory functioning draws heavily on a phonological component and plays an important role in reading.

In the past decade, the working memory model has gained wide acceptance. In this model, working memory is conceptualized as a modular system for temporary storage and information manipulation. It involves a controlling central executive system, which operates to regulate the processing of material in working memory. The central executive is assisted by subsidiary *slave systems*, which have a storage function. The phonological loop is one of these slave systems. It is responsible for the maintenance and rehearsal of speech-based material. The loop consists of a short-term phonological store that is capable of holding such material and an articulatory control process that maintains and refreshes information in the store. In contrast to auditory information, which has direct access to the phonological store, visually presented material has to be recoded by the articulatory control process before it can be registered in the store.

Based on this conception, Baddeley (1990) argued that an impaired memory span for verbal material may represent a kind of phonological deficit. He pointed out that it is not clear yet whether the underlying deficit of RD is one of phonological awareness apart from memory, phonological rehearsal in memory, or perhaps some other common underlying factor.

Processing limitations in working memory may represent such a common factor. Shankweiler and Crain (1986) addressed the issue of a deficit in phonological mechanisms versus processing limitation. Although they recognized that the empirical evidence is enough to locate the source at the phonological level, they pointed out that it is quite possible that a processing limitation in working memory restricts the use of otherwise intact phonological structures. They argued that an account in terms of inefficient processing in working memory has the advantage of explaining more of the basic but diverse facts in the symptom complex of the poor reader.

The findings of DiLollo et al. (1983) are interesting in this respect. DiLollo et al. showed evidence not only of slower rates of visual information processing in RD children but also of prolonged visual persistence. Visual persistence refers to the lingering visibility of an image following stimulus disappearance. The visual system of these children seems to require an unusually long period of time to recover from neural aftereffects of stimulation. This may easily result in interference with the next stimulus, implying incomplete processing or lack of integration of stimuli. DiLollo et al. argued that the same principle may apply to auditory information. Recent results of Yap and Van der Leij (1993a) supported that point of view. They found an impaired rate of processing among RDs, even for nonlinguistic information. According to DiLollo et al., the results of the impairment

could take a variety of forms because congestion and degradation of information may occur at various levels of processing. Thus, an excessively slow information processing and recovery rate at one or more processing stages can also be considered the possible common underlying factor mentioned by Baddeley (1990).

A linkage with automatization failure as an explanation of RD is possible here. It is conceivable that inefficient processing skills will impede automatization of basic processes that should normally proceed rapidly to make fluent reading possible. Proponents of automatization failure as an explanation of RD (e.g., LaBerge & Samuels, 1974; Perfetti & Lesgold, 1977; Spear & Sternberg, 1987) maintain that, in RDs, a component subskill of reading (notably word decoding) is poorly automatized, leading to consumption of attentional resources that would otherwise have been available to higher order components such as comprehension. Recently, Nicolson and Fawcett (1990) made it plausible that a more general automatization deficit is involved here, which tallies with the arguments of DiLollo et al. (1983).

A REMEDIATION PROGRAM: TRAINING OF PERCEPTUAL UNIT PROCESSING

Although there are still some questions regarding the cause of RD, it follows from the preceding discussion that, according to many authors, RD is associated with a less efficient basic skill, that is, word decoding rather than just with higher order deficits such as poor comprehension (see also Spear & Sternberg, 1987). Such a theoretical point of view suggests that remediation should be directed first at an early stage of processing.

One remediation program on this aspect that appeared to be successful comes from an instructional system developed by Frederiksen et al. (1985). Their system is based on a componential approach of the reading process, according to which reading is viewed as a set of interactive component processes. Readers are assumed to differ in the degree to which components have become automatized. Frederiksen (1982) studied eight such components and selected three of them as the most suitable for training. A set of three training programs was developed, all aimed at automatizing a particular skill component of reading. The idea was that this would reduce the drain on attentional processing resources posed by these components, making the resources available to higher order reading processes, just as in normal skilled reading.

The program that was chosen for this study is the most basic one, the one that is instrumental in processes of word analysis, pertaining to the perception of multiletter units in words. With preservation of accuracy, speed of recognition of multiletter units in words is highly stimulated in this training system. Conversely, with preservation of speed, accuracy is encouraged. It was expected that developing skill in recognizing multiletter units would help to improve word decoding performance.

It should be mentioned that such a remediation program could also be successful if reading performance is constrained by some factor other than perceptual coding skill. For instance, as indicated in the foregoing, many RD children have a limited memory span. Unfortunately, an impaired memory span in itself is hardly susceptible to improvement. However, a properly chosen remediation program may compensate for these constraints by circumventing the memory limitations. Baddeley (1986) recognized this and recommended that remediation should be done by encouraging the chunking strategy, that is, processing multiletter units instead of letters one at a time. Chunks should substantially increase the amount of material that can be held in phonological memory, eventually aiding comprehension. Thus, the strategy recommended by Baddeley also boils down to exercising perceptual coding skills, which was the aim of the present program. Training this skill to a level of greater efficiency would relieve the working memory of at least some extra burden, thereby freeing capacity for other components of the reading process.

The program used in this study, most kindly provided by Frederiksen, was designed to improve the speed or accuracy with which readers recognize common multiletter units within words. The program was adjusted for this study to the characteristics of the Dutch language and examined on a sample of RD children. Using a microcomputer, the program was presented as a game with a car race theme. The game provided training by recognizing 40 of the most frequent multiletter units in language.

Efficient perceptual coding was stimulated as follows: Children were presented with a target (a two- or three-letter) unit and had to determine whether or not this unit was present in words that were shown successively. Automatization of multiletter unit recognition was promoted by practicing intensively at increasing speed. Accuracy, however, was also required, because only a few errors were allowed. The program provided immediate feedback on both speed and accuracy. The task difficulty was adjusted to each child's individual level of performance.

In addition to words with "to-be-trained" units, words were also presented that did not contain the trained multiletter unit. These were either distractor words with fillers highly similar to the test words in terms of unit resemblance (e.g., "ger" as distractor word for "gen") or dissimilar words of comparable word length. The distractors were meant to incite discrimination.

However, generalization was thought to be important too. Because RD children tend to concentrate on the initial letters of a word (Harris & Sipay, 1975), an additional aim of the program was to teach children to distribute their attention over the whole word. Therefore, multiletter units were placed equally often at the beginning, middle, and end of a test word (e.g., for "gen": *genetic*, *regency*, and *collagen*). This training facet was expected to improve general reading strategy. In addition, many different multiletter units ($n = 40$) were presented during training, with a maximum of 96 words for each of these units. This extensive exercise was also meant to increase the chance of generalization. To

examine whether generalization occurred, a posttest was administered in which both trained and new multiletter units were given. In addition, transfer to higher level reading skill components was evaluated, which was assessed by several kinds of word decoding tasks. These tasks included both words and pseudowords, with either normal or very short exposure times. The reason for using the latter task is that speed of recognition is of crucial importance here. Speed of recognition can be considered a measure of the degree of automatization of word decoding. Pseudowords were added to rule out the possibility of direct word recognition.

NEW FEATURES OF THIS STUDY

Unlike the study of Frederiksen et al. (1985), in this study, in addition to the training group, a matched control group was formed, which received a control training program. Furthermore, a larger sample of participants was used (17 instead of 5), and children of elementary school age were used as opposed to the high school students in the Frederiksen study. Another new feature was that, prior to training, a subdivision was made among children, based on their reading strategy. The training program was evaluated for fast guessing as well as for spelling readers.

RD children seem to process multiletter units poorly and to use strategies such as letter-by-letter spelling or whole-word guessing instead. These habits reflect the two methods of word processing that are described by so-called dual-route models of reading (Perfetti, 1985). Unfortunately, RD children execute both routes inefficiently. Subtypes have been recognized based on stable strategy preferences (e.g., Bakker, 1982). Readers with a spelling strategy prefer the safe but laborious way of attaching sounds to single letters and show a lack of speed. In contrast, fast guessing readers are inclined to read the whole word rapidly, with insufficient processing of information. As a result, they are deficient in accuracy. Normal readers do not use inefficient strategies. Instead, it may be assumed that they are able to read unfamiliar words by processing units in between and including single letters and whole words.

In general, training the fast recognition of multiletter units could teach RD children of both subtypes mentioned to develop the strategy that is used by normal readers. A specific advantage of this program was that guessing participants were corrected by encouraging them to pay attention to all parts of a word and to keep their number of errors within certain constraints. Spelling participants, on the other hand, learned to improve their speed without losing accuracy.

EFFECTS OF TRAINING

The general hypothesis of the study was that developing skills in recognizing multiletter units in words would eventually help to improve word decoding performance by increasing the efficiency of coding orthographic information. This hypothesis can be specified.

First of all, a direct training effect was expected on perceptual coding skill. Training the ability to process multiletter units instead of letters one at a time implies chunking. Chunks are information units consisting of associated elements. They are knowledge dependent. That is, new multiletter units first have to be learned before they can be perceived as a chunk. This knowledge has to be developed by extended practice. It was hypothesized that RD children would show better detection of the exercised multiletter units following training.

Besides recognizing multiletter units that have been practiced repeatedly, efficient reading also involves application of strategies to process unfamiliar words and units properly. With regard to the effect of the program on the detection of untrained multiletter units, one could argue that no generalization is to be expected. Because the multiletter units are stored in memory as knowledge about chunks, only words containing the trained multiletter units would be read faster and more accurately. Yet, better knowledge about specific chunks does not necessarily preclude the additional learning of a general perceptual coding skill or strategy. The effect of learning may depend on the way the multiletter units are presented.

If the multiletter units always appear in the same position in the words presented and if they are always pronounced identically (e.g., "gen" in the words *gentle* and *general*), perhaps only generalization to words with the same multiletter units in the same position is to be expected, analogous to the results of training experiments with the repeated presentation of "orthographic neighbors" such as *land* and *band* (Van Daal, 1993; Van Daal, Reitsma, & Van der Leij, 1994).

If, on the other hand, the position of the multiletter units varies in different words, including subtle differences in pronunciation (e.g., "gen" in *genetic*, *regency*, and *collagen*), the children learn to distribute their attention over the orthographic characteristics of the whole word. Here, children may adopt unit detection as a general strategy. Frederiksen et al. (1985) found evidence to support this supposition. Like the Frederiksen et al. study, this study was designed to encourage distribution of attention across positions within a word. In addition, the program provided exercise with many different units, each one placed in many different words. These aspects of the design of the current program were hypothesized to be the way to stimulate a more efficient strategy of multiletter processing that could be generalized to untrained multiletter units. If so, transfer to more general reading skills than multiletter unit detection could be anticipated as well. Thus, transfer of training to the higher level reading skill components of word and pseudoword decoding was also expected. That is, increasing the availability of multiletter unit knowledge following training would improve decoding of (pseudo)words with trained units. Training would also improve the reading of words with untrained units, however, because of the hypothesized development of a more efficient general skill regarding multiletter processing.

Finally, a training program that emphasizes the balance between accuracy and speed of multiletter processing was thought to be beneficial to both RD children with a spelling strategy and RD children with a guessing strategy. Spelling

participants learn to process units at a higher level than single letters and to heighten their speed without losing accuracy. Guessing participants are corrected by encouraging them to pay attention to all parts of a word and to keep their number of errors within certain constraints.

To summarize, a reading intervention program was conducted in which perceptual coding of multiletter units was trained. Before and after training, a series of criterion measures was administered in order to assess direct training effects on perceptual coding of multiletter units in words as well as transfer of training to reading ability as measured by (pseudo)word decoding skills. The training program was incorporated into a game that was aimed at increasing the speed of response without increasing the rate of errors. Immediate feedback was given on both speed and accuracy, and the task difficulty was adjusted to the individual level of performance of each participant. A detailed description of the program is given in Frederiksen et al. (1985). The training program was expected to:

1. Improve the perceptual coding skills of children in the experimental group in a multiletter detection task over those of children in the control group;
2. Enable the participants to generalize this training effect to multiletter units that were not included in the training program;
3. Show transfer of training to the ability to decode words and pseudowords;
4. Improve performance in flashword reading tasks in which (pseudo)words are presented visually for a very short time;
5. Improve accuracy of perceptual coding and (pseudo)word decoding skills among readers with a fast guessing strategy; and
6. Improve speed in these skills among readers with a spelling strategy.

DESIGN

In this training experiment, children with reading disabilities were given perceptual unit training as developed by Frederiksen et al. (1985). The children were 9 or 10 years old. Seventeen children participated in the training condition, and 16 children formed a control group. Both groups could be subdivided according to reading strategy preference (i.e., fast guessing or spelling), which was assessed for each child separately in advance. The training focused on fast and accurate detection of multiletters in words. This component of the reading process can be considered as a precursor of efficient word decoding. The instructional system was also designed to correct the poor reader's tendency to attend only to the beginning of words. That is, it was directed at improving the distribution of a child's attention over the whole word in word reading. Each child received 30 min of individual training or a control task session of the same duration for a total of 16 times. Various test tasks were administered before and after these training sessions.

Prior to the experiment, a participant selection procedure was performed. Children were screened with a current Dutch reading test that determined the technical reading ability of the children on word level (EMT). Reading strategy was measured by a specific procedure on reading tests that determined the technical reading ability on text level (AVI). A detailed description is given in the materials section. Based on the scores of these tests, children with reading problems and a clear preference strategy were selected. The selection tests were administered once, in a preliminary assessment procedure.

Several test tasks were employed in order to test the various hypotheses of this study. Children in the experimental group were expected to show better perceptual coding skills after training than children in the control group. A unit detection task was used to determine a direct training effect. Besides trained multiletter units, new units were also presented in the unit detection task. Thus, the supposed generalization effect of training to untrained units could also be determined by this task.

In order to test the hypothesis of the transfer of training to a higher level of the reading process, the decoding of words, a test task was administered. This was the word task, in which words had to be read out loud. In this task, increased availability of multiletter unit information as a result of training was expected to improve word decoding skill with words containing trained letter groups. In addition, it was thought that a more general skill would be developed, increasing the ability of word reading. The pseudowords, with nonlexical letter combinations, were included because of the advantage that the results are free here from the influence of varying degrees of familiarity of words. With pseudowords, phonological decoding is necessary because the words have never been combined before and direct word recognition is impossible. A second test task was administered (i.e., the flashword task) that was similar to the word task. However, the word task had unrestricted exposure times of the words, whereas the exposure times in the flashword task were very short, in order to test speeded (pseudo)word decoding ability. Thus, in the flashword task, the hypothesis of transfer of training to word reading was tested on speeded word decoding.

Hypotheses regarding training effects on children with different preferential reading strategies were tested on both unit detection and word reading tasks.

Children of the control group received training on a pair of control tasks. These were a mathematical exercises task and a task containing motor finger exercises. With these tasks, the control group was trained regarding both the cognitive and the motor aspect of the training program. Mathematical exercises served as a counterpart of training in a reading subskill, whereas motor exercises were given to equal the amount of experience in quick button pressing between the experimental and the control groups.

Except for both reading tasks employed for participant selection, all tasks were computerized. The tasks are described in the Materials section.

Adjustment of Tasks to the Characteristics of the Dutch Language

In the study of Frederiksen et al. (1985), students were trained in identifying the 60 most frequent multiletter units in the English language. Multiletter units are groups of letters that can be pronounced. In Frederiksen et al.'s experiments, these multiletter units were embedded in different existing words and were divided equally over different positions within these words. Words were also presented in which the trained multiletter units did not occur.

For this study, from Van Berckel, Brandt Corstius, Mokken, and Van Wijngaarden (1965), we selected the 50 most frequent multiletter units of the Dutch language (see the Appendix). The selected multiletter units were used for the training task and for the unit detection task. The units consisted of either two or three letters. Both in the training task and in the unit detection task an equal amount of two- and three-letter units were used. There were 25 two-letter and 25 three-letter units, divided into trained (5 two-letter and 5 three-letter units), untrained (5 two-letter and 5 three-letter units), and additional units (trained, but not used in the unit detection task: 15 two-letter and 15 three-letter units). The units are given in the Appendix.

The classification of the words is as follows. For each unit, 96 stimulus words were selected. Forty-eight words comprised the unit. In these words, the unit appeared at the beginning ($n = 16$), in the middle ($n = 16$), or at the end ($n = 16$) of the word, regardless of whether the units would coincide with or comprise a syllable or straddle syllables. The other 48 words did not contain the unit. These were divided into 24 fillers that were highly similar to the test words with a trained unit (in terms of unit resemblance and word length), and another 24 fillers that were clearly dissimilar except in word length. All words were selected from a frequency investigation of Dutch children's literature (Staphorsius, Krom, & De Geus, 1988). The most current words were chosen, with a word length varying between 8 and 18 letters.

METHOD

Materials

Reading Tasks

The EMT (Brus & Voeten, 1979) is a Dutch reading task to determine technical reading ability on word level. It is a standardized measure of increased speed of word reading with a high reliability ($r = .89$). The test requires the child to read within 1 min a list of unrelated words of increasing difficulty. The reading score is the number of words read aloud correctly within 1 min.

The AVI (Van den Berg & Te Linteloo, 1977) is a Dutch test to determine technical reading ability on the text level. The test consists of nine cards with texts. The cards correspond to nine levels of reading ability. Each card has its own error and speed limits. Besides the normal assessment procedure, in this study, the children also had to read a text two levels above mastery level to determine whether a child had a clear preference strategy for guessing or spelling. For each child, the percentages of time-consuming and substantive errors relative to the total error numbers were computed, as well as a time quotient expressing the child's reading speed (actual reading time/AVI time limit $\times$ 100). A time quotient was used because the AVI paragraphs differ in duration. Participants were classified as spellers if more than 60% of the errors were of the time-consuming type, if their time quotient exceeded a value of 125, or both. Guessers were classified as such if more than 60% of the errors were substantive errors, if their time quotient was less than 125, or both (see Bakker & Vinke, 1985).

Training Task

The purpose of the training task was to stimulate automatization of identifying multiletter units in words. A computer was used to present the words. In these words, children had to detect the presence or absence of a target unit. Following each response, the children were given immediate feedback on their speed and accuracy (number of errors). The program was presented as a series of games with a car race theme. For the children, in each game the goal was to increase their speed until a goal speed was reached while keeping the number of errors within an acceptable range.

During each game, one specific unit was trained. The training of a unit could consist of several runs. Each unit was trained until the participant had won a run for that unit (i.e., reached the target speed). Thus, the total number of runs depended on the number of repetitions a child needed for a unit.

The display formats in the training task are depicted in Figure 1. At the beginning of a game, the unit to be identified, an initial speed, and a goal speed were presented on the screen. After pressing the space bar, the game started. The display showed the target unit at the top. Five error lights were located directly below the target unit. The stimulus words (maximally 96) appeared one after another in a window at the center of the display. A speedometer, positioned below the display window, showed the initial speed, the goal speed, and the intermediate speed for that run. By pressing one of two (yes or no) response buttons, the child indicated whether or not the target unit was present in a word. A correct response resulted in heightening the current speed with a small step of 2 words per minute (wpm) and the extinction of an error light, if any error lights were burning. An incorrect or too slow reaction (i.e., not within the display time, which was determined by the current speed), resulted in the illumination of an error light and a current speed reduction with one step (2 wpm). If the goal speed was reached and no more than four subsequent errors were made, the

child had won the race, and a "Win" display with a flag was shown. If there were more than four subsequent errors, too slow reactions, or both the message "Crash, better luck next time" appeared on the screen, which then gradually became red (see Figure 1).

The procedure of the training task is represented in Figure 2. Children started with an initial speed of 10 wpm and a goal speed of 60 wpm. Each time the child reached the goal speed for a target unit, the game was over, and a new game with the next target unit was started. Whenever the goal speed was reached, 10 wpm were added to the start and the goal speed of the next run. If the child did not reach the goal speed, the game continued. The next run with the same target unit was presented. For each new run, the initial speed and the goal speed were determined, depending on the speed mastered during the previous run. When the run ended below half of the goal speed, the initial speed and the goal speed of the next run were diminished by 10 wpm. When a run ended at half that speed or higher, but below the goal speed, the same initial and goal speed were presented again.

The training task consisted of games with 40 target units (see the Appendix). First, 10 units were administered that were also presented during the unit detection task. After reaching the target speed, each unit was presented once again, using a higher speed (> 10 wpm). Then, regardless of whether the player won or lost this latter run, a new game started.

Following training with these first 10 units, 40 units (the 10 already trained and 30 other units) were presented randomly. Each unit was exercised until the target speed was reached. There was a fixed time schedule. The children were trained 16 times, each time for 30 min. The total number of games a child played depended on the number of runs a child needed for each unit.

FIGURE 1 Display formats in the car race game.

FIGURE 2 Flowchart representing the dynamics in the car race game.

Control Tasks

Mathematical exercises. To control the effects of intensive training as such, the children of the control group received instruction and computerized practice in mathematics. There were different programs on different levels. Each child worked on his or her own level. The programs were add and subtract, multiplication, multiplication tables, and exercises on division and lengths.

Motor finger exercises. To diminish the difference in "motor finger exercises" between the training and control group, the control group was also trained in pushing a button as quickly as possible. A target figure of 10 cm was presented on the screen. Participants had to remember it. The task started by pressing the space bar. Figures that were either identical or nonidentical to the target figure were presented sequentially at a high speed (100 msec). The children had to push the "+" button if the figure was identical to the target figure; otherwise, they had to push the "-" button. Errors or slow reactions (not within the stimulus presentation time) activated a sound signal. The children worked 10 min with these tasks in each training session.

Criterion Tasks

The unit detection task was similar to the training task, except that no feedback was given and only one run per unit was presented. Below a target unit, the stimulus words were presented one by one in a window at the center of the display. By pushing one of two buttons, the participant indicated whether the word contained the unit. The task was self-paced: When a button was pushed, the word disappeared from the screen. The presentation time depended on the individual response speed, with a maximum of 6 sec. The reaction time (RT) was measured from the beginning of the presentation of a word to the moment a participant pushed a button. Both trained ($n = 10$) and untrained ($n = 10$) units were presented (see the Appendix). The unit detection task consisted of 20 runs. Each unit was embedded in 30 different words. These were 18 target words (words containing the unit), 6 fillers similar to target words, and 6 fillers dissimilar to target words. The position of the units was distributed over the target words to avoid positional likelihoods. The words were presented in random order.

In the word task, words were presented to the child one by one on the computer screen. Each word had to be read aloud. The task was self-paced, with a maximum exposure time of 6 sec. At the beginning of the reading response, the trainer pushed a button, causing the word to disappear. The RT was the time from the beginning of the word presentation until the trainer pushed the button. During the task, 64 words were presented randomly. The words varied in the number of letters (4 to 6), the frequency of occurrence in language (high or low), and the presence or absence of a trained unit in the word. The second part of the task resembled the first part. However, instead of words, 64 pseudowords were

employed. These were constructed from existing words that were selected according to the same criteria as the words in the first part of the task. Letters were replaced by other letters to form phonetically correct nonexisting words.

The flashword task contained both words and pseudowords. The words and pseudowords were randomly presented one at a time, and the child had to read them aloud. Words were selected with a high frequency of occurrence in the Dutch language. The words consisted of 1 or 2 syllables, and a trained unit was present in half of the words. The pseudowords were constructed from real words in which one or two letters were replaced so that phonetically correct nonexisting words were formed. A total of 32 words was given, half of which were presented for 200 msec and the other half for 100 msec. The task started with the 200-msec presentation, followed by the 100-msec presentation. Immediately following this flashed presentation, the stimulus word was masked to prevent an afterimage.

Participants

Children with reading disabilities participated in the research. They came from two LOM-schools. LOM-schools are special schools for children with a primary learning disability who have an average intelligence and show severe learning disabilities without any gross sensory or neurological deficits (for a review of the Dutch system of special education, see Van der Leij, 1987). The children were 9 or 10 years old. On the basis of a technical reading score (EMT) according to school data, 49 children with reading problems were selected. Next, two reading tests, the EMT and the AVI were administered to these children to update the data on level of reading ability. The AVI was also used to determine the preference strategy (guessing or spelling) of the children. Based on these data, 33 children were selected who were at least 2 years behind their normal peers on both the EMT and the AVI score and who had a clear preference strategy. There were 12 guessers and 21 spellers. Of these children, a training group and a control group were formed, each with guessers and spellers matched according to reading level, age, and IQ (Wechsler Intelligence Scale for Children-Revised according to school data). A review of mean age and IQ is given in Table 1.

Procedure

Each child participated in 24 half-hour sessions twice a week. Eight sessions were spent on the tests and 16 on the training or control task. All children were trained and tested by one experimenter. Children were trained two at a time in a quiet room at school. Each school was visited for about 3 months.

During the first session, the EMT and AVI were administered. The children selected were given the unit detection task in the second session. During the third session, the word task was presented; the flashword task was presented during the fourth. Following the test tasks, either the training or control task,

TABLE 1
Mean Age, IQ, and Number of Guessers and
Spellers in the Experimental and Control Groups

	<i>Experimental</i>	<i>Control</i>
Guessers		
Age	9 years, 8 months	9 years, 7 months
IQ	106	102
<i>n</i>	6	6
Spellers		
Age	9 years, 10 months	9 years, 8 months
IQ	101	99
<i>n</i>	11	10

dependent on the group to which a child was assigned, was presented during 16 training sessions. Finally, the criterion tasks were readministered, and the children received a present for their participation.

RESULTS

Method of Analysis

The training results were examined by analyzing the effects of the program on performance on the criterion measures. These included the unit detection task, the pseudoword and word task, and the flashword task. Multivariate analyses of variance (MANOVAs) were conducted for these tasks. Participants were matched in advance on reading level, age, and IQ. These matching variables were not incorporated into the analysis. The dependent variables were the mean number of correct responses and the mean RTs for correct responses. Effects of training were determined in general by evaluation of interaction effects between participant group and assessment time. Results will be presented separately for each hypothesis, as formulated at the end of the introduction section.

Training was expected to improve the perceptual coding skills of children in the experimental group in a multiletter unit detection task over those of children in the control group.

Table 2 shows the data on RT and accuracy of the unit detection task. Factors for the MANOVA included group (experimental, control), preference strategy (guessing, spelling), and assessment time (pretest, posttest). In support of the hypothesis, the interaction between group and assessment time proved to be significant, $F(2, 28) = 14.63$, $p < .01$. The univariate test showed that the effect

TABLE 2
Reaction Time (RT) and Mean Percentage Correct per
Group on the Unit Detection Task Before and After Training

	<i>Experimental</i>	<i>Control</i>
RT (msec)		
Before	1,476	1,530
After	865	1,204
% correct		
Before	80.0	76.5
After	85.7	77.8

Note. Data are based on 10 trained and 10 untrained units.

was due primarily to the RT, $F(1, 29) = 25.58$, $p < .01$. As expected, the experimental group performed faster on the unit detection task after training than did the control group. No other significant interactions emerged. Prior to training, no significant difference in performance between the experimental and the control group appeared to exist.

All main effects were significant. The univariate test showed that the main effect of preference strategy, $F(2, 28) = 3.36$, $p < .05$, could be ascribed to accuracy, $F(1, 29) = 6.04$, $p < .05$. Spellers were more accurate than guessers, which is in line with their strategy. The main effect of group, $F(2, 28) = 4.87$, $p < .05$, was caused by the RT, $F(1, 29) = 9.49$, $p < .01$, with the experimental group performing faster than the control group. The main effect of assessment time was also significant, $F(2, 28) = 311.23$, $p < .01$, due to accuracy, $F(1, 29) = 644.51$, $p < .01$, as well as to RT, $F(1, 29) = 198.93$, $p < .01$. Accuracy increased and RT decreased from pretest to posttest performance. Mean RT and accuracy data are presented in Table 3.

Both the main effect of group and the main effect of assessment time can be specified by the interaction between group and assessment time already mentioned, which confirmed the hypothesis, at least as far as speed is concerned. It can be concluded that, as a result of the training program, trained participants performed at a significantly higher speed in the unit detection task than did the control group.

TABLE 3
Reaction Time (RT) and Mean Percentage Correct on the Unit
Detection Task for Assessment Time, Group, and Strategy

	<i>Assessment Time</i>		<i>Group</i>		<i>Strategy</i>	
	<i>Before</i>	<i>After</i>	<i>Experimental</i>	<i>Control</i>	<i>Guessers</i>	<i>Spellers</i>
RT (msec)	1,503	1,029	1,171	1,367	1,171	1,320
% correct	78.3	82.0	83.0	77.2	77.5	81.7

Note. Data are based on 10 trained and 10 untrained units.

The training was expected to enable the participants to generalize this training effect to multiletter units that were not included in the training program.

Similar to the procedure just described, a MANOVA was done for the factors group, preference strategy, and assessment time for the untrained units. Mean RT and accuracy data are presented in Table 4.

As predicted, the MANOVA showed a significant interaction between group and time, $F(2, 28) = 6.58, p < .01$. The univariate test showed that this was due to the RT, $F(1, 29) = 9.54, p < .01$. In comparison with the control group, the experimental group performed faster on untrained units following training. Thus, the hypothesis that the effect of training would generalize to untrained units was confirmed. Again, no other interactions were significant.

The main effect of group was significant, $F(2, 28) = 3.71, p < .05$, which can be ascribed to the RT, $F(1, 29) = 6.01, p < .05$. All in all, the experimental group had a lower RT than the control group. There was also a significant main effect for preference strategy, $F(2, 28) = 3.79, p < .05$. This was due to the RT, $F(1, 29) = 4.99, p < .05$. Guessers were faster than spellers. The main effect of assessment time was also significant, $F(2, 28) = 91.68, p < .01$. The univariate test showed that this was due to the RT, $F(1, 29) = 143.12, p < .01$. Posttest performance was faster than pretest performance. Mean RT and accuracy data are presented in Table 5.

In short, the analysis showed that the training effect generalized to new units. The trained participants obtained a faster perceptual coding skill, which they applied to untrained units.

Transfer of training was expected regarding the ability to decode words and pseudowords.

Table 6 shows the RT and accuracy data of the word task. A MANOVA was carried out for these data. Factors that varied in the analysis included group

TABLE 4
Reaction Time (RT) and Mean Percentage Correct per Group on the
Untrained Units of the Unit Detection Task Before and After Training

	<i>Experimental</i>	<i>Control</i>
RT (msec)		
Before	1,551	1,591
After	932	1,229
% correct		
Before	69.6	67.3
After	71.0	67.6

Note. Data are based on 10 untrained units.

TABLE 5
Reaction Time (RT) and Mean Percentage Correct on the Untrained Units
of the Unit Detection Task for Assessment Time, Group, and Strategy

	Assessment Time		Group		Strategy	
	Before	After	Experimental	Control	Guessers	Spellers
RT (msec)	1,571	1,076	1,242	1,410	1,225	1,380
% correct	68.5	69.5	70.5	67.4	66.4	70.5

Note. Data are based on 10 untrained units.

(experimental, control), strategy (reading, guessing), assessment time (pretest, posttest), type of word (real, pseudo), and presence of trained unit (present, absent).

Transfer of training to (pseudo)word decoding should be manifested in an interaction between group and assessment time. This interaction did not reach significance. Thus, the conclusion is that training did not result in more efficient decoding of (pseudo)words.

Except for group, all main effects were significant. The univariate test showed that the effect of assessment time, $F(2, 28) = 15.14, p < .01$, was due to accuracy, $F(1, 29) = 7.47, p < .05$. In the posttest, all children read more accurately. The main effect of strategy, $F(2, 28) = 5.17, p < .05$, was caused by RT, $F(1, 29) = 6.14, p < .05$. Guessers always performed faster than spellers on the word reading task. There was also a significant main effect for type of word, $F(2, 28) = 63.77, p < .01$, caused by both accuracy, $F(1, 29) = 69.93, p < .01$, and RT, $F(1, 29) = 28.66, p < .01$. Real words were read faster and more accurately than pseudowords. The main effect of unit, $F(2, 28) = 9.16, p < .01$, was due to accuracy, $F(1, 29) = 17.79, p < .01$. Words with a trained unit were read more accurately. Mean RT and accuracy data are presented in Table 7.

Between-group differences prior to training were checked, and it appeared that there were no significant prior differences between the experimental group

TABLE 6
Reaction Time (RT) and Mean Percentage Correct per
Group on the Word Task Before and After Training

	Experimental	Control
RT (msec)		
Before	2,308	2,231
After	2,083	2,232
% correct		
Before	64.1	62.5
After	68.0	68.0

Note. Data are based on 64 pseudowords and 64 words.

TABLE 7
Reaction Time (RT) and Mean Percentage Correct on the Word
Task for Assessment Time, Strategy, Type of Word, and Unit

	Assessment Time		Strategy		Type of Word		Unit	
	Before	After	Guessers	Spellers	Real	Pseudo	With	Without
RT (msec)	2,271	2,155	1,917	2,508	2,071	2,501	2,272	2,300
% correct	63.3	68.0	61.9	68.0	72.7	58.8	67.7	63.8

Note. Data are based on 64 pseudowords and 64 words.

and the control group on the word reading task. To summarize, the results on the word reading task, the hypothesis of transfer of training to (pseudo)word decoding could not be confirmed.

Training was expected to improve performance in flashword reading tasks in which (pseudo)words are presented visually for a very short time.

Performance on the flashword task was evaluated by one dependent variable, that is, number of correct responses. For this variable, an ANOVA was conducted to test the hypothesis of transfer of training to the higher order skill of speeded (pseudo)word recognition. Factors of the ANOVA were group (experimental, control), strategy (guessing, spelling), assessment time (pretest, posttest), and type of word (real, pseudo).

Table 8 presents the results of the flashword task. The analysis showed, as predicted, a significant interaction between group and assessment time, $F(1, 29) = 4.67, p < .05$. Following training, the trained children performed significantly better than the control children.

Moreover, the effect of strategy was significant, $F(1, 29) = 10.61, p < .01$. Guessers performed better on this task (see Table 9). Again, the effect of assessment time was significant, $F(1, 29) = 9.06, p < .01$. Posttest performance (31.8% correct) was better than pretest achievement (37% correct). Finally, the

TABLE 8
Mean Percentage Correct per Group on (Pseudo)Words
of the Flashword Task Before and After Training

	Experimental	Control
% correct		
Before	29.4	34.4
After	38.2	35.8

Note. Data based on 16 words and 16 pseudowords.

TABLE 9
Mean Percentage Correct for the Guessers and Spellers
on Real and Pseudowords of the Flashword Task

	<i>Guessers</i>	<i>Spellers</i>
% correct		
Real words	63.5	42.7
Pseudowords	20.0	16.8

Note. Data based on 16 words and 16 pseudowords.

interaction of strategy and type of word was significant, $F(1, 29) = 8.76$, $p < .01$, indicating that the improved performance of guessers was found especially in real words.

In short, the results on the flashword task demonstrated the hypothesized effect of training. Trained participants were better able to read words that were presented during a very short time than participants in the control group. The effect yielded overall, but in particular for real words for guessing participants. The results point to transfer of training to a higher order reading skill.

Training was expected to improve accuracy of perceptual coding and (pseudo)word decoding skills among readers with a fast guessing strategy as well as speed in these skills among readers with a spelling strategy.

The unit detection task and the word task were used to measure the training effects for children from the trained group with different preference strategies.

Unit detection task. Factors of the MANOVA were the preference strategy of the trained group (guessing, spelling) and assessment time (pretest, posttest). Table 10 shows the RT and accuracy data for guessers and spellers on the unit

TABLE 10
Reaction Time (RT) and Mean Percentage Correct for the Trained Guessers
and Spellers on the Unit Detection Task Before and After Training

	<i>Experimental Group</i>	
	<i>Guessers</i>	<i>Spellers</i>
RT (msec)		
Before	1,322	1,561
After	769	918
% correct		
Before	75.5	82.5
After	82.8	87.5

Note. Data based on 10 trained and 10 untrained units.

detection task. From this table, it can be seen that guessers tended to improve their accuracy, and spellers tended to decrease their RT somewhat more following training, although overall both groups seemed to work more accurately and rapidly following training. However, the expected interaction of strategy and assessment time, univariate for RT and accuracy, was not significant. Thus, the guessers did not work more accurately compared with the spellers, and the spellers did not improve their speed more than the guessers did as result of training.

The main effect of strategy, $F(2, 14) = 4.50, p < .05$, was significant. The univariate test showed that this was due to the accuracy, $F(1, 15) = 9.09, p < .01$. Overall, the spellers worked more accurately than the guessers. There was also a main effect for assessment time, $F(2, 14) = 174.15, p < .05$. The univariate test showed that this yielded both for accuracy, $F(1, 15) = 353.53, p < .01$, and for RT, $F(1, 15) = 43.28, p < .01$. All trained children detected the units more accurately and rapidly following training. There were no other significant effects. The results are consistent with the full analysis of this task, including the control group, as reported in the results on the first hypothesis.

Word task. For this task, too, the data were analyzed for both preference strategies. The factors for the MANOVA were strategy of the trained group (guessing, spelling), assessment time (pretest, posttest), type of word (real, pseudo), and presence of a trained unit (present, absent). RT and accuracy data are given in Table 11.

The MANOVA showed a tendency toward statistical significance for the interaction between strategy and assessment time, $F(2, 14) = 3.65, p < .10$. Following training, the spellers tended to read more accurately and rapidly. Table 11 illustrates that their increase in RT resulted in approximately equal speed between spellers and guessers after training. In the univariate test, however, neither of the dependent variables reached significance.

There was no significant main effect for strategy, but the main effect for assessment time proved to be significant, $F(2, 14) = 14.24, p < .01$. The univariate

TABLE 11
Reaction Time (RT) and Mean Percentage Correct for the Trained
Guessers and Spellers on the Word Task Before and After Training

	<i>Experimental Group</i>	
	<i>Guessers</i>	<i>Spellers</i>
RT (msec)		
Before	2,172	2,383
After	2,095	2,076
% correct		
Before	60.9	65.6
After	62.5	71.1

Note. Data based on 64 pseudowords and 64 words.

test showed that this was attributable to both accuracy, $F(1, 15) = 4.99, p < .05$, and RT, $F(1, 15) = 3.98, p < .10$. Participants worked more accurately following training and tended to work faster. Moreover, of the main effects, the type of word was significant, $F(2, 14) = 44.13, p < .01$, due to both accuracy, $F(1, 15) = 69.02, p < .01$, and RT, $F(1, 15) = 12.86, p < .01$. Real words were read faster and more accurately than pseudowords. The main effect of presence of a trained unit was not significant. These results are not completely consistent with the full analysis of this task, including the control group, as reported with the results on the third hypothesis. Here, all main effects except for group were significant. Although logically one would expect both analyses to be consistent, in practice inconsistencies nevertheless do occur.

The interaction between word type and presence of a trained unit was significant, $F(2, 14) = 4.82, p < .05$, due to accuracy, $F(1, 15) = 9.25, p < .01$. The interaction indicated that real words without a trained unit were read relatively accurately. The meaning of this result is not clear.

The results can be summarized as follows: The hypothesis concerning differential advantages of training for spellers and guessers could not be confirmed regarding perceptual unit coding. The unit detection task showed that both groups improved their accuracy as well as their speed in multiletter unit detection following training. Thus, although improvement did occur, it was not a differential one. The results on the word task also did not quite support the hypothesis. The only weak effect that merits mention here is that spellers seemed to profit somewhat more from training than guessers did. Spellers tended to increase their speed and accuracy in word reading more than guessers. Following training, they were more accurate and as fast as guessers.

DISCUSSION

Although it may not be the whole story, efficient word decoding is a very central process in reading. As Stanovich (1981) noted, researchers of vastly different persuasions agree that words must be processed rapidly for fluent reading to occur. Difficulties at the level of word reading are generally found in poor readers. It was argued that this lower level problem should be remediated by training basic components of word reading. Perceptual coding of multiletter units instead of single letters was chosen as a starting point in this study. In a study by Frederiksen (1982), this aspect of efficient encoding of multiletter units within words was identified as one important component, furnishing a basis for optimal functioning of higher order components. The program developed by Frederiksen et al. (1985) for training this component proved to be successful in their study. Because the sample in the Frederiksen et al. study was very small and their study lacked appropriate experimental controls, its validity is limited, and the findings clearly need to be replicated. This study more extensively investigated the program's potential use for remediation.

First, the intervention program was adjusted to the characteristics of the Dutch language. Next, the program was conducted over an 8-week period with a group of RD children, while a control group received pseudotraining. The study yielded some interesting differences between the trained group and the control group. In short, the effects were mainly an improvement in speed of perceptual coding skills in the training group.

The first goal of the study was to determine whether children with reading difficulties would show increased perceptual coding skills as a result of training. A direct learning effect was observed on the unit detection task, which was used to assess the identification of multiletter units in words. Following training, the trained children performed better on this task than did the control group, especially regarding speed. This training effect was not limited to trained units but actually concerned untrained units as well. Thus, the training effect also generalized to new multiletter units. This points to the development of some general skill for faster perceptual coding of multiletter units by training. It shows that an explanation of the effect of the training program cannot be restricted to the learning of specific chunks or multiletter units. A general strategy seems to be learned. Presumably, this is a strategy in which participants are more inclined than before the training period to code multiletter rather than single letter groups.

As for further application of the program, it should be noted that children are likely to profit most from this newly acquired "vocabulary" of multiletter groups if these are current letter combinations that frequently occur in language as syllables. Two other facets of the training program also deserve some attention. The results on generalization indicate that the trained skill not only involves specific multiletter units but also a general improvement in the perceptual coding of orthographical information in a word. In this respect, an important feature of the program seems to be that a variety of multiletter units were used, which had various positions in many different words. This was intended to stimulate generalization. The training task also contained words with similar, but not identical, multiletter units compared with the ones to be detected. This forced the children to observe the words accurately.

Fast detection of multiletter units is considered to be an important contribution to quick and accurate reading of words because it reduces the number of information units that have to be processed. Clusters are being processed instead of single letters. In addition, fast detection of letter groups reserves part of the available capacity for the control of information processing for other simultaneously necessary processes of reading and understanding texts. The expectation was, therefore, that training would not only affect the detection of multiletter units within words but that it would also contribute to effective reading. Thus, the question was whether words would be read more quickly and accurately after training. Two transfer tasks were employed to examine this issue. On the word task, no differences were found between the performance of the trained and the control group following training. Compared with the control group, however, the

trained group did improve its ability to read (pseudo)words in the flashword task after training. The latter result does not seem to be in keeping with the first one. How can this be explained?

In research on intelligence, a measure known as the inspection time (IT) is used (Vernon, Nador, & Kantor, 1985). The IT reflects the time needed to recognize an item that is masked immediately following presentation. The IT is considered a measure for the decoding speed. In the flashword task, very short presentation times and immediate masking were applied. Therefore, analogous to the IT, the task can be regarded as an indication of the decoding speed of words. To what extent the words are recognized correctly will depend on the appropriateness of the child's perceptual coding speed. Because of the time limit, the number of correct answers is the indicator of the decoding speed in this task. The fact that guessers, who work at a higher speed than spellers, performed better on this task, supports this interpretation. The results of the flashword task can therefore be taken to indicate that training fosters rapid (pseudo)word decoding.

Why then was this transfer of training to word decoding not found in the word task? In contrast to the flashword task, the number of correct responses in the word task does not indicate decoding speed because there was always enough perceptual coding time: Each word remained visible until it was read. Speed is measured by RT here. Although the RT means of the word task pointed in the expected direction, the differences did not reach significance. Perhaps this was due to the RT measurement procedure in this task. The experimenter pushed the RT button as soon as the participant started word pronunciation. It is not inconceivable that this method of recording a sensitive measure such as RT resulted in some improper variance, leading to nonsignificant effects. Some support for this interpretation comes from the study by Frederiksen et al. (1985) in which a voice key was used and transfer of training to the word task was found. In contrast, a study by Yap (1993), who used similar methods, failed to show a transfer effect.

A second explanation may be put forward. It may be that, when the task requires quick decoding of words, such as when the words are flashed, the children are forced to read at their highest speed. If, on the other hand, the task is self-paced, with words remaining visible until they are read, less effort may be invested in the speed of reading. If this interpretation is correct, it would mean that the flashword task, more than the word task, measures competence rather than performance.

Be that as it may, the findings on the flashword task point to faster word reading as a result of training. This again supports the idea of a general strategy being learned, in which multiletter rather than single letter units are coded. Multiletter coding is a more efficient strategy because it reduces the amount of time it takes to decode a word.

The training effects for both groups of readers with different strategies—guessers and spellers—were evaluated separately. Based on their preferential

strategy, the children were selected in advance. Because the training was meant to improve both accuracy and speed, a difference in training results was expected between trained children with a spelling strategy and those with a guessing strategy. It was hypothesized that spellers would increase particularly their speed, whereas guessers would improve their accuracy.

First of all, it should be noted that, because of the relatively small number of guessers in the study, the results on differential effects should be taken with some care. With this in mind, the following can be reported: The results on the unit detection task at first sight may give the impression of a tendency toward faster and more accurate performance for spellers and guessers, respectively. However, accuracy also improved in the control group. This leaves only the improvement of speed as a possible training effect. The difference in speed gain between children with opposed preferential strategy was not significant. The conclusions are that, compared with guessers, spellers did not improve their speed and that guessers, as compared with spellers, did not work more accurately in recognizing units in words.

On the word task, results for spellers and guessers showed a small differential training effect. Spellers tended to profit more from training than guessers did. Following training, their speed equaled the speed of guessers. This is understandable if the effect of training, as supposed, operates by relieving working memory. By their strategy, guessers avoid an overload of working memory in word reading more than spellers do. They try to solve their insufficient reading ability by quickly guessing what is written. Guessing may place some burden on working memory but not as much as in spelling, where processing is slow and at a level of single letters. Here, all previous letters have to be retained while a word is decoded simultaneously. Thus, in terms of Baddeley's (1986) working memory model, especially for spellers, learning to detect multiletter units is profitable in word decoding. Faster detection affects not only speed of word decoding but also accuracy, because it reduces the chance of losing information. This is what tended to occur in this study.

In contrast to spelling, fast guessing is a holistic approach. The effect of training should be a more analytical strategy. However, guessers did not improve on accuracy more than spellers did. Apart from the interpretation on the results of the spellers given earlier, an explanation could be that the training program is, in general, better suited to training speed than to improving accuracy. In hindsight, it may be the case that the program emphasizes speed. Accuracy has to be kept within some range, whereas the primary goal is to increase speed.

We conclude this discussion with a few final remarks. How do the results of this study compare with the study of Frederiksen et al. (1985)? Unfortunately, it is hard to make a direct comparison. Frederiksen et al. trained a total of only 5 students of an older age, without controls. They found evidence for all hypotheses tested in this study. In contrast to the study by Frederiksen et al., a control group was included in this study. From the interactions between group

(trained or control) and time of testing (pretraining and posttraining), some proper training effects could be deduced, which have already been described. The addition of a control group appeared to be useful because this group also showed some performance improvement, albeit sometimes less than the trained group. The improvement of the controls suggests that some of Frederiksen et al.'s results may have been wrongly ascribed to an effect of the training program, because their results were not corrected for this progress.

Although we were unable to confirm all hypotheses, the training results that were obtained are encouraging, especially in light of the fact that the children in this study were only trained for a total of 8 hr during a 3-week period. In further research on this task, the number of training sessions should be extended. In addition, the issue on the long-term effects of training on the detection of multiletter units requires investigation. In a recent study by Yap (1993) with a similar training program, no retention effects were shown after a period of 2 months. Furthermore, the fact that transfer to word reading was less than expected may indicate that learning with the program was context dependent (i.e., restricted to the task that was trained). In future research, therefore, the training for RD students should perhaps be combined with a program focused on generalization of learned skills to the normal, nonexperimental reading situation. In order to determine the optimal duration of the training period, and to avoid unnecessary training, it should be determined regularly whether a child has reached a level of automatization (Yap & Van der Leij, 1993b).

Determining whether a level of automaticity has been reached is not without problems, however, because it is not quite clear what processes underlie automatization. According to the traditional view, automatization is thought to decrease the necessity of attention, leading ultimately to fast and effortless processing (e.g., Hasher & Zacks, 1979; Shiffrin & Schneider, 1977). This view, however, does not specify a learning mechanism. Other, memory-based models describe automatization as a transition from slow computations to direct memory retrieval. Performance is automatized when it proceeds by direct-access, single-step retrieval from memory rather than by way of some computational process (Logan, 1988). The recent experimental findings of Compton and Logan (1991) support such a model in which, during automatization, both retrieval and computational processes are started. The process that first produces an answer "wins the race." Automatization involves an increase in associative strength between input and response. Once automatized, direct memory retrieval in a single step is possible.

In this conception, an impaired automatization among RD children would mean that the computational process of reading single letters rather than chunk activation wins the race in producing a response. Several possibilities remain then. An RD child may be biased toward the computational process of single-letter reading, perhaps because he or she relies on that strategy out of habit. It may also be the case that the associative strength between chunk and response increases

too slowly. As a result, direct memory retrieval of chunks would be time-consuming for RD children. As explained in the introduction, a slow increase of associative strength tallies with DiLollo et al.'s (1983) idea of a general slowing of information processing, which could occur at various stages of processing. In support of the resulting slow retrieval of chunks, retrieval deficits have been mentioned as an underlying factor of RD (Cooper & Regan, 1982; Jackson & McClelland, 1979). In this way, retrieval problems could be seen as related to automatization failure. The training program employed in this study may have worked by promoting chunk formation and thus circumventing the computational process of single letter reading, by enhancing the quality of the retrieval process, or both. Both methods would promote efficiency of working memory functioning. The exact mechanism remains a matter for future research.

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APPENDIX

Units Presented in the Unit Detection Task and the Training Task

Only unit detection task^a

(untrained units)

5 two-letter units	ie	el	as	la	to
5 three-letter units	ang	een	tel	die	ver

Both unit detection task and training task^a

(trained units)

5 two-letter units	ak	eg	an	me	re
5 three-letter units	erk	eer	del	nie	ven

Only training task^b

15 two-letter units	am	al	ar	ee	en
	et	id	is	ui	or
	op	ne	se	te	ze
15 three-letter units	oor	aan	and	ond	ent
	ing	ede	ere	sch	tie
	gel	len	men	ter	der

Note. Total no. of units = 50.

^an = 10. ^bn = 30.