

# Inhibitory Control During Sentence Reading in Dyslexic Children

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## ABSTRACT

The present study focused on the nature of the reading disability of children with the guessing subtype of dyslexia (who read fast and inaccurately). The objective was to separate the excitatory account of their reading disturbance (i.e., in guessers the words' resting levels of activation are oversensitive to semantic context) from the inhibitory account (i.e., guessers tend to react prematurely to (false) candidate words that are activated in the lexicon).

To disentangle the above accounts, guessers and normal readers were presented with a sentential priming task (SPT). In the SPT, subjects had to determine whether the final word of a sentence was semantically congruent or incongruent with the sentence, but had to inhibit their 'congruent' or 'incongruent' response in case of an occasionally presented pseudoword. To evoke guessing, each pseudoword closely resembled either a valid congruent or incongruent word. Guessing referred to prematurely accepting a pseudoword as a word that either appropriately or inappropriately completed the sentence. The extent to which subjects guessed at word meaning was evidenced by the false recognition rates (FRR) of the misspelled terminal words.

Analyses on the FRRs of the pseudowords showed that guessers had significantly more difficulty in suppressing the 'go tendency' triggered by the pseudowords. It was concluded that the impulsive reading style of guessers should be ascribed to a less efficient suppression mechanism rather than to excessive reliance on contextual information. Specifically, the data were explained by assuming that the availability of the pseudoword's *candidate* meaning activated the hand to respond with, and that guessers found difficulty in suspending this response until they analyzed *all* letters in the stimulus and they could be sure of its spelling.

## INTRODUCTION

Studies have shown that children with dyslexia represent a heterogeneous group comprising several subgroups (Satz & Morris, 1981). Although the notion of subtypes is widely accepted, the manner in which subgroups are identified varies. For example, each of the studies listed by Hooper and Willis (1989, pp. 42–44) used different

measures of achievement and cognition as the basis for group separation. In spite of this, Van der Schoot, Licht, Horsley, and Sergeant (2000, 2002) argued that the different subgroups that have been distinguished by several of the dual-subtype models – for example, Bakker's L and P type (1981, 1992); Van der Leij's guessers and spellers type (1983); Boder's dysphonetic and dyseidetic readers (1970, 1973); Lovett's accuracy and rate

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Accepted for publication: October 22, 2003.

disabled readers (1984) and Mitterer's whole-word and recoding subtypes (1982) – largely overlap and, in view of their reading *style*, seem to converge to two types of dyslexic children. The first type, henceforth referred to as *guesser*, manifests a fast and global reading style that is characterized by many substantive errors. Substantive errors are omissions, additions, substitutions, letter reversals, false word identifications (i.e., misreading one word as another) and other word mutilating errors that result in an inaccurate reading response. The second type, henceforth referred to as *speller*, reads slow and fragmented. In this subgroup of dyslexic children the identification of words is mainly based on an elaborate grapheme to phoneme translation process. Yet, the speller's style of reading is accurate in that it leaves the ultimate reading response intact.

At the word recognition level, the slow-accurate–fast-inaccurate dichotomy has been associated with indirect- versus direct-word approach (e.g., Licht, 1989; Van Strien, Bouma, & Bakker, 1993). In the indirect or phonological route, word identification is attained through generation of a phonological representation, formed by the stepwise translation of graphemes into phonemes. The direct or lexical route does not require an intermediate phonological code, since the use of specific orthographic codes enables direct access to word memory. Licht (1989), Licht and Van Onna (1995), Van der Leij (1983), and Van Strien et al. (1993) argued that guessers and spellers may predominantly rely on the direct and indirect word recognition strategy, respectively.

Clearly, the distinction between guessers and spellers differs from the classical distinction between developmental phonological and surface dyslexia (e.g., Castles & Coltheart, 1993; Stanovich, Siegel, & Gottardo, 1997). Whereas the former distinction refers to differences in reading style (fast-direct vs. slow-indirect), the latter distinction refers to differences in deficits underlying word recognition problems (phonological vs. visuo-orthographical deficits). Yet, spellers may be equated with surface dyslexics in that they are presumed to have difficulties using visuo-orthographic cues for fast whole word recognition (as a consequence of which they have to employ a

spelling-like approach). Guessers on the other hand, cannot be so easily equated with phonological dyslexics. Although guessers show a number of reading characteristics that are similar to the phonological dyslexia subtype, their fast, hasty reading style is not easy to explain.

### **Reading and Executive Function**

Van der Schoot et al. (2000) suggested that differences between guessers and spellers do not necessarily have to boil down to differences in computational skills required for efficient word recognition, and that the field of executive functioning (EF) may be a promising alternative for determining the underlying process deficit(s) in guessers and (possibly) spellers. There is a growing body of evidence that specific patterns of executive deficits exist in (subtypes of) dyslexic children. These deficits were reflected by poor response inhibition (Purvis & Tannock, 2000), poor flexibility of responding (Helland & Asbjornsen, 2000), poor inhibition of distractors and sequencing of events (Brosnan et al., 2002), increased Stroop interference (Evarett, Warner, Miles, & Thomsen, 1997), planning and organizational problems (Condor, Anderson, & Saling, 1995; Levin, 1990) and difficulties in selective and sustained attention (Kelly, Best, & Kirk, 1989). To explore the possibility that the impulsive reading style of guessers is linked to deficits in more basic executive processes responsible for the regulation of behavior, Van der Schoot et al. (2000) compared children with the guessing type of dyslexia with children with the spelling type of dyslexia on three aspects of executive functioning (EF): response inhibition, interference control, and planning. In agreement with the predictions, guessers were found to be impaired in their ability to inhibit inappropriate responding on all tasks that were used to assess the different EF measures, that is the stop signal task (Logan & Cowan, 1984), the Stroop task (Stroop, 1935), and the Tower of London task (Shallice, 1982), respectively. In a subsequent study in which event-related brain potentials (ERPs) were recorded during stop task performance, Van der Schoot et al. (2002) provided evidence that the inhibitory deficits in guessers can be attributed to dysfunctions in the fronto-central brain areas.

The crucial question that was raised by the Van der Schoot et al. (2000, 2002) studies was whether the executive-type deficiencies observed in guessers may also underlie their impulsive reading behaviors or that primarily a language-based disorder has to be assumed. Since the EF tasks did not tap critical elements of reading, no direct relationship between the guessers' executive dysfunctions and reading disturbance could be deduced from both experiments. However, the finding that fast-inaccurate readers can be differentiated from slow-accurate readers and normal readers on a variety of EF tasks, as well as the finding that the guessers' impairment in executive functioning is apparent not only behaviorally but also electrophysiologically, suggest that there is at least some type of association between them.

To further examine the nature of the association between the guessers' impulsive reading style and their executive deficits, Van der Schoot et al. (submitted) assessed the role of inhibitory control in a combined semantic categorization/lexical decision task (SCT). In the SCT subjects had to determine whether a word belonged to either of two semantic categories, but had to inhibit their response in case of an occasionally presented pseudoword (i.e., a nonword that is orthographically legal). To evoke guessing, each pseudoword closely resembled a valid category member. Guessing referred to prematurely accepting a pseudoword as a word, that is making a response with respect to the meaning of the letter string before *all* letters have been analyzed. Analyses on the false recognition rates of the pseudowords showed that guessers had significantly more difficulty in suppressing the 'go tendency' triggered by pseudowords than normal readers. It was concluded that the early availability of the pseudoword's *candidate* meaning activated the hand to respond with, and that guessers found difficulty in suspending this response until they analyzed all letters in the stimulus and they could be sure of its spelling.

### Logogen-Type Lexical Activation

For present purposes, it is important to recognize that the above account of the guessers' reading disturbance differed from Van der Schoot et al.'s original hypothesis but did not invalidate it. Their

original hypothesis was derived from a logogen-type lexical activation model (e.g., Coltheart, Curtis, Atkins, & Haller, 1993; Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001). Logogen-type lexical activation models share the conception of recognition units, or input logogens, which collect and sum evidence from sensory stimulation. Each of the input logogens corresponds to a word in the orthographic lexicon. This implies that the presentation of a target word induces the simultaneous activation of a set of lexical candidates, that is words that have sufficient orthographic features in common with the stimulus word. In logogen systems that operate in a cascaded fashion, these *partial* activations of words and word units in the orthographic lexicon (i.e., the Input Logogen System) cascade forward to the corresponding semantic codes in the semantic lexicon (i.e., the Cognitive System) and the corresponding phoneme units in the phonological lexicon (i.e., the Output Logogen System) (e.g., Coltheart et al., 1993). During the course of analyzing a word, partial graphemic information may therefore activate candidate meanings and candidate pronunciations. Logogen-type lexical activation models assume that the resting activation levels of the words' logogens are temporarily responsive to semantic context (e.g., Coltheart et al., 2001; Morton, 1982). For example, the 'starting point' for the lexical unit EAT would be heightened after the presentation of the words THE PIZZA IS TOO HOT TO rather than after THE PACKAGE IS TOO HEAVY TO. This way, these models account for the most famous empirical phenomenon of word recognition: the contextual facilitation/semantic priming effect (see Neely, 1991, for a review). Van der Schoot et al. (submitted) reasoned that information-collecting units with tunable resting levels of activation may account for the guessers' impulsive reading style if one assumes that in guessers, the resting activation levels of logogens are *over*responsive to semantic constraints. According to cascaded logogen-type lexical activation models, words whose logogens are highly activated at the moment of presentation require only a small amount of sensory information in order to induce activity at the semantic and phonological level. This may have inflated the guessers' false recognition rate in the SCT if one

assumes that activated candidate meanings primed the hand to respond with, and that guessers found difficulty in suspending this response until they analyzed all letters in the stimulus and they could be sure of its spelling. Unfortunately, the extent to which this was actually the case could not be inferred from the Van der Schoot et al. study. Therefore, it should be further investigated whether the guessers' reading disturbance can be attributed to logogens that are oversensitive to semantic context, to a less efficient suppression mechanism, or to a combination of both.

### The Present Study

In the present study, an attempt will be made to disentangle the above accounts by means of a sentential priming task (SPT). In the SPT, the subject had to decide whether a word was semantically congruent or semantically incongruent in a particular sentence context. However, subjects had to inhibit their response in case of an occasionally presented pseudoword. Each pseudoword closely resembled either a valid congruent word or a valid incongruent word. Due to this procedure, subjects were provoked to guess at word meaning, whereby guessing refers to prematurely accepting a pseudoword as a word that either appropriately or inappropriately completes the sentence. The extent to which subjects guess at word meaning is evidenced by the false recognition rate (FRR) of the misspelled terminal words.

It is presumed that in the SPT, the availability of the candidate meaning of a (pseudo)word activates the hand to respond with and that, in order to perform the task properly, subjects were required to inhibit, or delay, the selected response until all letters in the stimulus were analyzed. It is predicted that (1) congruent words would yield a faster mean reaction time (RT) than incongruent words, that (2) congruent pseudowords would yield a higher false recognition rate (FRR) than incongruent pseudowords, and that (3) congruent pseudowords would yield false recognition times (FRTs) that are at least as fast as the RTs to congruent words but faster than the FRTs to incongruent pseudowords. These predictions directly follow from the notion that the logogens

of words that are related to a semantic context have higher 'starting points' than the logogens of words that are unrelated to a semantic context. In order to retrieve a word's meaning from the semantic lexicon (i.e., Cognitive System) and make a decision with respect to its semantic appropriateness, subjects therefore needed to extract a smaller number of sensory attributes from a congruent terminal word than from an incongruent terminal word (prediction 1). At the same time, however, this increased the probability that the orthographic features of a slightly misspelled congruent word would provide this limited number and induce a false recognition error (prediction 2 and 3).

It should be noted that the way in which logogen-type lexical activation models account for the above type of semantic context effects is highly similar to the way in which a class of models referred to as automatic spreading-activation models account for them (e.g., Anaki & Henik, 2003; Collins & Loftus, 1975; Hill, Strube, Roesch, & Weisbrod, 2002). According to the spreading activation theory, concepts are represented by locations (i.e., nodes) in a semantic memory network. It is assumed that, when stimulus information activates a memory location, some of the activation automatically spreads to semantically related memory locations that are nearby in the network. The process of automatic spreading-activation and the process of logogen activation do not use attentional capacity and do not affect the retrieval of information that is unrelated to the context.

The primary focus of the present experiment concerns the Congruency (congruent pseudowords *vs.* incongruent pseudowords) by Group (guessers *vs.* normal readers) interaction, since the nature of this interaction provides information regarding the relative contributions of the excitatory account (i.e., guessers have logogens whose activation levels are oversensitive to semantic context) and inhibitory account (i.e., guessers tend to react prematurely to (false) candidate words) of the guessers' reading disturbance. To understand this, it should be recognized that the orthographic structure of both congruent and incongruent pseudowords would bias the subjects towards one word in particular, and that false

recognition errors to *both* types of pseudowords are expected to result from a failure to suppress the hand response that became activated as soon as the candidate meaning was extracted from the pseudoword. Since guessers are presumed to suffer from a less efficient response suppression mechanism, it is predicted that congruent pseudowords and incongruent pseudowords would induce more false recognition errors in guessers than in normal readers. In the congruent pseudoword condition, however, false recognition errors are not only hypothesized to result from orthographic priming (i.e., priming by the orthographic appearance of the word) but also from sentential priming (i.e., priming by the sentence context; prediction 2). Since the sentence context is presumed to *over-facilitate* lexical decisions on congruent pseudowords in guessers, the interaction between Congruency and Group is predicted to be overadditive. That is, the difference between the FRR in guessers and the FRR in normal readers should be larger for congruent pseudowords than for incongruent pseudowords.<sup>1</sup> Assuming that the guessers' impaired inhibitory abilities equally affected the performance on congruent and incongruent pseudowords, the residual group difference in the FRR to congruent pseudowords would then reflect the extent to which the resting activation levels of (the logogens of) words are more responsive to contextual constraints in guessers than in normal readers. On the other hand, the notion of overresponsive logogens would be invalidated if the difference between the FRR in guessers and the FRR in normal readers was to be found as large in the congruent pseudoword condition as the incongruent pseudoword condition.

## METHOD

### Subjects

Subjects were 10–12-year-old children who were recruited from two special schools for learning disabled

children and from one normal primary school. Learning disabled children whose reading disturbance could be attributed to emotional problems, socio-cultural factors or gross neurological deficits on the basis of school records, were not included in the sample. All children who participated ( $N=65$  for reading disabled and  $N=16$  for controls) were healthy and had normal or corrected to normal vision, and their IQ scores (obtained from school records) were in the normal range ( $IQ > 85$ ). None of the children was diagnosed as ADHD using DSM-IV criteria (American Psychiatric Association, 1994), nor did they participate (or had been participating) in ADHD treatment programmes.

### Assessment of Dyslexia

To assess current reading level, all children were administered a standardized Dutch word-reading test (Two-Minutes-Test (TMT); Brus & Voeten, 1973) which consists of lists of words that become progressively more difficult. The TMT score, the number of words read correctly in two minutes, was converted into a reading-age equivalent (RAE; Struiksma, Van der Leij, & Vieijra, 1989) reflecting the child's *actual* reading level expressed in the number of months of reading instruction (one year of instruction being equivalent to 10 months). The *expected* reading-age (ERA) is equivalent to the number of months that a child has received formal reading instruction. Since in The Netherlands a very systematic way of reading instruction is employed, the ERA-RAE difference enabled us to assess lag of reading performance almost at the level of a month. Children who lagged 15 months or more in reading (ERA-RAE) were considered to be dyslexic ( $N=62$ , 3 learning disabled children did not fulfill this criterion and were removed from the sample). Consequently, only those children were admitted to the subsequent classification procedure.

The ERA-RAE procedure goes beyond a simplistic chronological age-grade level discrepancy formula in that the *number of months of actual reading instruction*, and not chronological age, is used to define reading lag. In addition, the educational age-norms for average reading level were obtained in extensive standardization studies on reading in the Dutch population of primary school children.

All of the control children ( $N=16$ ) came from the normal primary school and their RAEs approximated their ERAs.

### Classification of Guessers

Subsequent to the TMT, the *dyslexic* children were given a standardized Dutch sentence-reading test (AVI; Van den Berg & Te Lintelo, 1977). This test consists of nine texts with increasing difficulty. The number of

<sup>1</sup>In addition, the guessers' mean RT to congruent words is predicted to be faster than the normal readers' mean RT to congruent words since it is thought to be composed of a relatively large number of 'lucky guesses'.

texts actually mastered (i.e., read within time and error limits) determines the child's mastery level of text reading.

The AVI was employed to classify the dyslexics as guessers on the basis of reading speed, the number of substantive errors (SE; e.g., omissions, additions, substitutions, letter reversals) and the number of time-consuming errors (TE; e.g., hesitations, stammerings, fragmentations, repetitions, corrections). In order to evoke a sufficient number of SE and TE errors, a text two levels above the child's mastery level was presented and assessed on reading speed and reading errors.

Reading speed (RS) was expressed as the total reading time divided by the time norm for the text \* 100, whereas reading error (RE) was expressed as the proportion of SE errors relative to the total number of errors (SE + TE). A child was classified as having the guessing type of dyslexia when:  $RS < 120$  and  $RE > 0.60$  (more than 60% of errors made were substantive errors). The classification criteria were adapted from Bakker and Vinke (1985) and Van Strien, Bakker, Bouma, and Koops (1990) and have been applied in many studies (e.g., Jonkman, Licht, Bakker, & Van den Broek-Sandmann, 1992; Patel & Licht, 2000; Van Strien, 1999). Using this classification system, we were able to classify about 26% of our dyslexics as guessers ( $N = 16$ ).

To assess hand preference (i.e., the characteristic preference that individuals show for one or the other hand for performing unimanual tasks), the children were rated with a hand preference questionnaire (Van Strien, 1992; scale ranges from -10 (left-handed) to +10 (right handed)).

Group characteristics are presented in Table 1. *Note.* *t* tests showed that guessers and controls neither differ in age,  $t(30) = 1.70$ , nor in handedness,  $t(30) = 0.14$ .

## Task and Stimuli

In the Sentential Priming Task (SPT), the child had to determine whether the final word of a sentence was semantically congruent or semantically incongruent with the rest of the sentence. For example, THE PIZZA IS TOO HOT TO . . . EAT would require a response with the left hand, and THE PIZZA IS TOO HOT TO . . . WALK would require a response with the right hand. However, subjects had to inhibit their response in case of an occasionally presented pseudoword. To evoke 'guessing', each pseudoword closely resembled either a valid congruent word or a valid incongruent word. In the congruent pseudoword condition, this means that the pseudoword was derived from the anticipated terminal word, that is the word that would harmonize with the unfinished sentence (e.g., JOHN EATS HIS SOUP WITH A . . . SPOOM). In the incongruent pseudoword condition, the pseudoword was a slightly misspelled version of a word that would be incongruent with the sentence (e.g., JOHN EATS HIS SOUP WITH A . . . ROBIM).

Both congruent pseudowords and incongruent pseudowords were constructed by changing only a single letter in a word. The deviant letter always occurred in the last segment of the pseudoword. We ascertained that the resulting letter strings were in conformance with the orthography of the Dutch language, so that decisions about lexicality had to be based on retrieval of lexical information rather than on shallower, that is nonlexical, criteria (e.g., illegal orthography).

The words from which the congruent and incongruent pseudowords were derived, were familiar 4–10 letter words. According to the Staphorsius–Krom–de Geus (1988) frequency list of word forms and letter positions (corpus size: 202,526; Staphorsius–Krom–de Geus, 1988), the average frequency of the words from which the congruent pseudowords were derived was 16.4, and the average frequency of the words from

Table 1. Characteristics for Each Reading Group.

	<i>N</i> (boys/girls)	Age	Hand preference <sup>a</sup>	Reading age <sup>b</sup>			Reading speed <sup>c</sup> (on AVI)	Error type <sup>d</sup> (on AVI)
				Expected	Actual	Difference		
Guessers	16 (9/7)	11.9 (0.6)	7.1 (5.4)	54.8 (4.8)	26.9 (3.3)	27.9 (6.7)	98.5 (8.8)	.66 (.06)
Controls	16 (6/10)	11.5 (0.7)	7.3 (4.9)	52.7 (5.2)	48.6 (6.8)	4.1 (9.1)	–	–

*Note.* Numbers in parentheses are standard deviations.

<sup>a</sup>Hand preference is rated on a scale ranging from -10 (left-handed) to +10 (right-handed) (Van Strien, 1992).

<sup>b</sup>Reading age is in months; 10 months equals 1 year of reading instruction. (The actual reading age is derived from the Two-Minutes-Test (TMT; Brus & Voeten, 1973)).

<sup>c</sup>Reading speed is expressed as  $100 * (\text{time needed}/\text{time norm})$ .

<sup>d</sup>Error type is expressed as  $N(\text{substantive errors})/N(\text{substantive} + \text{time-consuming errors})$ .

which the incongruent pseudowords were derived was 14.4. This difference in word familiarity was not significant,  $t(79) = 0.44$ . In addition, congruent and incongruent pseudowords did not differ in their averaged length (6.7 vs. 7.0 letters, respectively;  $t(79) = 1.20$ ). The sentences ranged in length from 3 to 7 words and were of the type '<subject> <verb> <direct/indirect object>'

In the SPT, each trial began with the presentation of the incomplete sentence, which was displayed for 2500 ms. Following the offset of the incomplete sentence, there was a 500 ms interstimulus interval to the onset of the terminal word/pseudoword. The word/pseudoword was displayed for 800 ms and immediately followed by a 300-ms masking stimulus (an '#####' array). After the mask signal, the screen was blank for a 2100 ms intertrial interval. A pilot study showed that a 800 ms stimulus duration was sufficiently long to recognize the word stimulus.

The unfinished sentences and the terminal words/pseudowords were presented in black-on-white and in the center of the screen. They were printed in lowercase letters with a 1.80 cm width and a 2.90 cm height.

## Design and Procedure

In the SPT, a total of four test blocks of 200 trials each were administered. After each block, a short break was scheduled. Prior to the first test block, the subjects were provided with 28 practice trials. Approximately, the SPT lasted 2 hr. After the experiment, the subjects received a present for their participation.

Terminal words requiring a Go response were presented on 80% of the trials: 40% of the words were congruent with the sentence and required a response with the left hand (CW condition, 320 trials), and 40% of the words were incongruent with the sentence and required a response with the right hand (IW condition, 320 trials). Terminal pseudowords requiring a NoGo response were presented on 20% of the trials: 10% of the pseudowords were derived from a congruent word (CP condition, 80 trials), and 10% of the pseudowords were derived from an incongruent word (IP condition, 80 trials).

The sequence of congruent words, incongruent words, congruent pseudowords and incongruent pseudowords was pseudo-randomized, and mapping of congruent and incongruent words onto response hand was counterbalanced across subjects.

Subjects were instructed to make a left hand response to terminal words that were congruent with the sentence and to make a right hand response to terminal words that were incongruent with the sentence. They were told to respond as quickly and as accurately as possible. After the Go task instructions, the NoGo task instruction was given. The subjects were explicitly

instructed to withhold their response whenever the stimulus item was a nonexistent meaningless word (i.e., a pseudoword).

## Apparatus

The stimuli were presented on a NEC Multisync 5FG monitor positioned at 70.00 cm from the subject's eyes. Subjects sat in a reclining chair. On either side of the bed a response box was positioned at an optimal location for each subject.

## Data Analysis

### Go Words

For each word type (congruent words vs. incongruent words) and subject group (guessers vs. normal readers), the following dependent measures were derived from the Go trials: mean reaction time (RT), standard deviation of RT (*SD*), percentage of errors (responding 'congruent' when an incongruent word was presented, or vice versa), and percentage of omissions (non-responses). The effects of 'Congruency' and 'Group' on the different dependent variables were examined in repeated measures analyses of variance (ANOVA), using an alpha level of 0.05.

### NoGo Pseudowords

For each pseudoword type (congruent pseudowords vs. incongruent pseudowords) and subject group (guessers vs. normal readers), the percentage of false alarms (%FA), the percentage of hand errors (%HE), and the false alarm reaction times (FA-RTs) were computed.

Subjects make a false alarm error when they respond 'congruent' to a congruent pseudoword, or when they respond 'incongruent' to an incongruent pseudoword. Subjects make a hand error when they respond 'congruent' to an incongruent pseudoword, or when they respond 'incongruent' to a congruent pseudoword. The focus of the present experiment is on the false alarm rates (i.e., false recognition rates (FRRs)) since they are believed to reflect the extent to which subjects guess at word meaning. As already pointed out, guessing refers to prematurely accepting a pseudoword as a word that either appropriately or inappropriately completes the sentence.

The effects of 'Congruency' and 'Group' on the different dependent variables were examined in repeated measures ANOVA, using an alpha level of 0.05.

## RESULTS

### Go Words

Analyses of variance with one between-subject factor (Group: guessers vs. controls) and one

within-subject factor (Congruency: congruent *vs.* incongruent) was conducted for the mean reaction time to the Go words (RT), the standard deviation of RT (*SD*), the percentage of errors, and the percentage of omissions.

With respect to RT, the result of the analysis of variance showed a main effect of Congruency,  $F(1, 30) = 59.97$ ,  $p < .001$ , signifying that congruent words yielded shorter reaction times than incongruent words. In both the congruent word condition and incongruent word condition, guessers were as fast as controls (Group effect:  $F(1, 30) = 0.01$ ,  $p = .90$ ; Group  $\times$  Congruency:  $F(1, 30) = 0.00$ ,  $p = .97$ ). Yet, guessers tended to be more variable in responding than controls (*SD* effect:  $F(1, 30) = 2.96$ ,  $p < .1$ ,  $\eta_p^2 = 0.09$ ).

Significant Group effects were obtained for percentage of errors ( $F(1, 30) = 17.31$ ,  $p < .001$ ; guessers made more hand errors than controls) and percentage of omissions ( $F(1, 30) = 5.35$ ,  $p < .05$ ; guessers made more omission errors than controls). In both subject groups, congruent words brought about more hand errors and fewer omission errors than incongruent words ( $F(1, 30) = 32.94$ ,  $p < .001$  and  $F(1, 30) = 28.40$ ,  $p < .001$ , respectively). As for the hand errors, the effect of Congruency was larger in guessers than in controls, as was reflected in the significant Group by Congruency interaction,  $F(1, 30) = 6.16$ ,  $p < .05$ .

Means and standard deviations of the dependent measures in each reading group are presented in Table 2.

### NoGo Pseudowords

The mean percentages of false alarms (FA) and hand errors (HE) for congruent pseudowords (CP)

and incongruent pseudowords (IP) in each subject group are displayed in Figure 1.

On the percentages of false alarms, a 2 (Group: guessers *vs.* controls)  $\times$  2 (Congruency: CP *vs.* IP) ANOVA was performed, treating Group as between-subject variable and Congruency as within-subject variable. The results of this analysis demonstrated a main effect of Group ( $F(1, 30) = 32.96$ ,  $p < .001$ ) and Congruency ( $F(1, 30) = 103.65$ ,  $p < .001$ ), signifying that guessers misidentified pseudowords as words more often than controls, and that incongruent pseudowords induced more false word recognitions than congruent pseudowords. Although the group difference in false alarm rate was larger in the IP condition (average increase of 39%) than in the CP condition (average increase of 28%) the interaction between Group and Congruency did not reach conventional levels of significance,  $F(1, 30) = 2.75$ .

In order to compare the false alarm rates with the hand error rates, we repeated the above analysis with Error\_Type (FA *vs.* HE) as additional within-subject variable. Pseudowords induced more false alarms than hand errors (Error\_Type:  $F(1, 30) = 197.42$ ,  $p < .001$ ), and, when averaged across levels of Congruency, the group difference in false alarm rate was larger than the group difference in the hand error rate (Group  $\times$  Error\_Type:  $F(1, 30) = 23.35$ ,  $p < .001$ ). In both reading groups congruent pseudowords induced more hand errors than incongruent pseudowords, and the difference between false alarm rate and hand error rate was particularly manifest in the incongruent pseudoword condition (Error\_Type by Congruency:  $F(1, 30) = 81.51$ ,  $p < .001$ ).

Table 2. Performance on the 'Go' words in the Sentential Priming Task (SPT).

	Congruent words				Incongruent words			
	Controls		Guessers		Controls		Guessers	
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
RT (Go words)	957.97	281.57	969.33	324.87	1154.33	295.65	1167.72	280.11
<i>SD</i> of RT	302.82	88.14	349.73	80.65	291.73	87.56	341.28	76.99
% of errors	5.35	4.32	14.18	7.94	2.47	1.79	6.91	4.64
% of omissions	1.18	1.04	5.91	7.57	3.10	1.89	7.77	8.61

Note. *M* = mean, *SD* = standard deviation, RT = mean reaction time to Go words; all times are in ms.



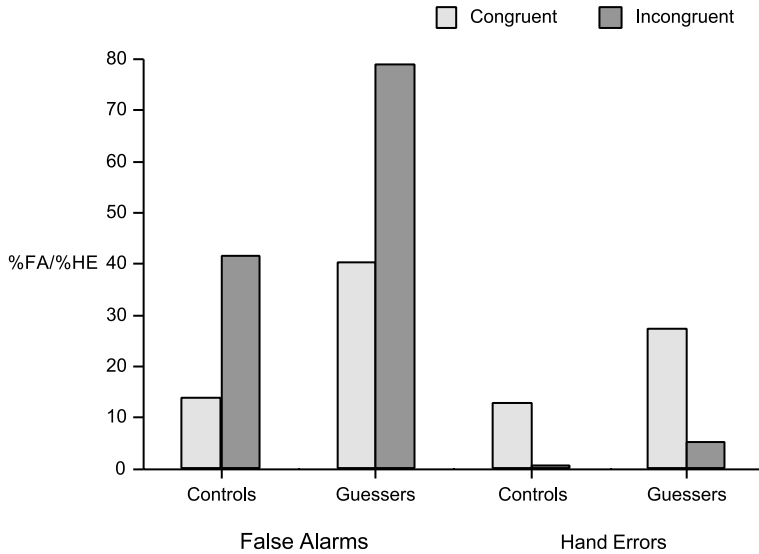


Fig. 1. The mean percentages of false alarms (%FA) and hand errors (%HE) for congruent pseudowords and incongruent pseudowords in controls and guessers.

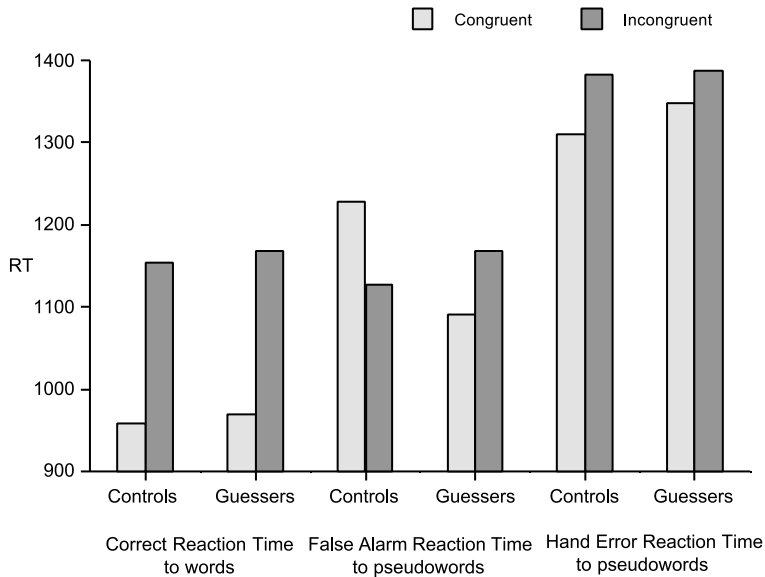


Fig. 2. The correct reaction times to congruent and incongruent words, and the false alarm and hand error reaction times to congruent and incongruent pseudowords (RT = reaction time).

Along with the correct response times to the correctly spelled words, the false alarm-reaction times (FA-RTs) and hand error-reaction times (HE-RTs) to congruent pseudowords and incongruent pseudowords are displayed in Figure 2.

As can be seen from Figure 2, the difference between mean FA-RT and mean RT varied as a function of Congruency. Whereas incongruent pseudowords and incongruent words yielded similar response times, the false recognition

times to congruent pseudowords were slower than the correct recognition times to congruent words. This effect was reflected in the significant Congruency by Response\_Type interaction,  $F(1, 30) = 6.99$ ,  $p < .05$ , in an analysis of variance with Group as the between-subject factor and Congruency (CP vs. IP) and Response\_Type (RT vs. FA-RT) as within-subject factors. The effect was manifest in both guessers and normal readers (Group  $\times$  Congruency  $\times$  Response\_Type:  $F(1, 30) = 1.22$ ). From Figure 2, it can be seen that incongruent pseudowords evoked comparable FA-RTs in guessers and in controls, but that congruent pseudowords evoked shorter FA-RTs in guessers than in controls. However, a post hoc analysis conducted on the FA-RTs showed that the interaction between Group and Congruency did not reach conventional levels of significance,  $F(1, 30) = 1.36$ .

The reaction times that accompanied the hand errors (HE-RTs) were slower than the correct RTs and FA-RTs in both the CP condition and the IP condition. This combined effect was reflected in the significant Congruency by Response\_Type interaction,  $F(2, 30) = 3.56$ ,  $p < .05$  in an analysis of variance with Group as between-subject factor and Congruency (CP vs. IP) and Response\_Type (three levels: RTs vs. FA-RTs vs. HE-RTs)<sup>2</sup> as within-subject factors. The effect was apparent in both guessers and controls.

## DISCUSSION

The main objective of the present study was to explain the fast and inaccurate reading style of children with the guessing type of dyslexia. The inhibitory account of their reading disturbance asserts that guessers tend to react prematurely to (false) candidate words that are activated in the lexicon. The excitatory account of their reading disturbance claims that in guessers, the (logogens of) words have activation levels that are over-sensitive to semantic context.

In order to disentangle the accounts, guessers and normal readers were presented with a sentential priming task (SPT). In the SPT, subjects had to determine whether the final word of a sentence was semantically congruent or incongruent with the sentence, but had to inhibit their 'congruent' or 'incongruent' response in case of an occasionally presented pseudoword. To evoke guessing, each pseudoword closely resembled either a valid congruent or incongruent word. In the evaluation of the results, the effects of congruency on reaction time (in case the stimulus was a word) and false recognition rate/false recognition time (in case the stimulus was a pseudoword) will be discussed first. Then, the effects of group on the dependent variables will be discussed. These effects will be evaluated both separately and in combination with the congruency factor.

The effects of congruency on RT, FRR and FRT are not easy to explain. As predicted by a logogen-style activation framework, congruent words yielded shorter RTs than incongruent words. This finding can be accounted for by assuming that words that are related to a semantic context have higher 'starting points' than words that are unrelated to a semantic context (Coltheart et al., 2001; Meyer & Schvaneveldt, 1976; Morton, 1982). In order to make a decision with respect to a word's semantic appropriateness and lexical status, subjects therefore needed to extract a smaller number of sensory features from a congruent word than from an incongruent word. However, this line of reasoning also predicts that the orthographic features of a slightly misspelled congruent word are more likely to provide this limited number than a slightly misspelled version of an incongruent word. Hence, congruent pseudowords were predicted to produce *more* and *faster* false word recognitions than incongruent pseudowords. In addition, the false recognition times to slightly misspelled congruent words (i.e., congruent pseudowords) were predicted to be as fast as the correct recognition times to correctly spelled congruent words. Clearly, the FRR/FRT data contradict these predictions, since congruent pseudowords produced *fewer* false word recognitions than incongruent pseudowords and produced false recognition times that were *slower* than the correct recognition times to congruent

<sup>2</sup>It should be noted that in the IP condition, 12 control children and 3 guessers made no hand errors, as a consequence of which the average HE-RTs were based on only 4 and 13 subjects, respectively.

words and, in controls, the false recognition times to incongruent pseudowords.

### **Expectancy-Based Semantic Priming**

Together, the data suggest the operation of a semantic priming mechanism other than the one described above. A post hoc explanation that may be more compatible with the results is that – in addition to automatic processes – priming has also come about due to strategic processes mediating expectancies (see Anderson, 1983; Becker, 1980, 1985; Brown, Hagoort, & Chwilla, 2000; Posner & Snyder, 1975; Stanovich & West, 1979, 1981). Unlike the automatic priming mechanism, the expectancy mechanism acts slow and requires a person's conscious attention. The expectancy theory asserts that subjects who are engaged in a single-word semantic priming paradigm (e.g., Neely, 1977) or sentential priming paradigm (e.g., Stanovich & West, 1983) use the word-prime/sentence-prime to prepare themselves for the most likely target. They do so by directing a limited-capacity processor to the memory location of the expected stimulus. Significantly, this mechanism 'inhibits the retrieval of information from unexpected locations because the limited-capacity processor must be shifted to a location some distance away in the memory network so that information can be read out' (Stanovich & West, 1979, p. 78). Since in the present experiment the incomplete sentences were highly predictive of the target word, it is likely that the expectancy mechanism became implicated in the subjects' performance.<sup>3</sup>

### **Congruent and Incongruent Word Condition**

It is presumed that, in the congruent word condition, the expectancy mechanism facilitated performance on all trials on which the actual target matched the expected target. In the incongruent word condition, the expectancy mech-

anism caused an inhibitory effect as the limited-capacity processor had to be moved from the expected location in the semantic memory network to the location of the unexpected target. The operation of these controlled processes mediating expectancies are reflected in the RT difference between congruent words (short RT) and incongruent words (long RT). It should be realized, however, that this does not exclude the possibility that the operation of automatic spreading-activation processes contributed to the RT effect as well (by facilitating performance on congruent words).

### **Congruent Pseudoword Condition**

The expectancy theory predicts that on most trials in the congruent pseudoword condition, the subjects were prepared for the pseudoword's 'base word' in that the memory location of the word the pseudoword was derived from was pre-activated at the moment of stimulus presentation. Since a congruent pseudoword was prepared by changing only a single letter in the anticipated word, a fast inspection of the stimulus' overall orthographic structure was sufficient in order for the subjects to conclude that the target was congruent, even though they were still ignorant of whether the target was correctly spelled (and actually required a 'congruent' response) or incorrectly spelled (and required no response). Presumably, being cognizant of the congruent status of the target stimulus activated, or primed, the hand to respond with. To perform the task properly, subjects were required to postpone the 'congruent' response until all letters in the stimulus were analyzed. Only then, they could resolve on whether to actually execute (in case of a word) or abort (in case of a pseudoword) the response.

From the notion that subjects wasted little time in establishing that the overall orthographic structure of the actual target matched the overall orthographic structure of the expected target, it follows that they could turn all their attention to the necessary letter-by-letter analysis *shortly after* the presentation of the target stimulus. Moreover, the subjects who discovered that the deviant letter always occurred in the last part of the stimulus may have adopted the strategy to first zoom in on the final fragment of the target word they prepared

<sup>3</sup>It should be emphasized that the slow-acting expectancy mechanism had time to operate only because we employed a relatively long sentence-duration and a relatively long time interval between the processing of the sentence and the onset of the target word (see Stanovich & West, 1979, 1981).

themselves for. These subjects may have come across the deviant letter in the congruent pseudoword even sooner. Both argumentations may explain the finding that, in controls, slightly misspelled congruent words induced a false alarm on only 13% of the trials. Guessers, on the other hand, misidentified a congruent pseudoword as a word on 42% of the trials. This finding can be taken to reflect an impaired ability to suppress the 'congruent' response until all letters in the stimulus were analyzed.

The relatively long FA-RTs to congruent pseudowords in controls and guessers suggest that both subject groups were reluctant to reject a congruent terminal word they prepared themselves for, even if they noticed a possible 'deviancy' in its spelling. Suppose, for example, the pseudoword SPOOM was presented after JOHN EATS HIS SOUP WITH A . . . . It is conceivable that the dominant availability of SPOOM's candidate meaning (i.e., the meaning of SPOON) interfered with, or slowed down, the judgment of the final letter. The long FA-RTs support the idea that subjects 'double-checked' the misspellings in the expected congruent terminal words. In controls, this extra check was of use since they successfully rejected a congruent pseudoword on the vast majority of trials. In guessers, on the other hand, the extra spellings check was often 'interrupted' by the execution of the candidate hand response, that is the hand response that was activated by the availability of the meaning of the word the pseudoword was derived from. The idea that guessers were impaired in the ability to inhibit this activation until they were sure of the spelling of the word/pseudoword is supported by a post hoc *t* test, indicating that the FA-RTs to congruent pseudowords in guessers were significantly faster than the FA-RTs to congruent pseudowords in controls,  $t(30) = 0.74$ ,  $p < .05$ .

### Incongruent Pseudoword Condition

How does the expectancy theory account for the finding that subjects produced more false alarms in the incongruent pseudoword condition than in the congruent pseudoword condition, and that, unlike the FA-RTs to congruent pseudowords, the FA-RTs to incongruent pseudowords were as fast as the correct RTs to the words they were derived

from? The expectancy theory makes two predictions. First, the limited-capacity processor started off at the wrong location in the semantic memory network in case of both an incongruent word and incongruent pseudoword. Second, subjects could not base a congruent/incongruent decision on a shallow inspection of the overall orthographic structure of the stimulus. In the congruent word/pseudoword condition, the stimulus' overall orthographic appearance immediately informed the subjects that the actual target matched the expected target, and that, therefore, the target required a 'congruent' response *unless* it was incorrectly spelled. In the incongruent word/pseudoword condition, the overall orthographic appearance did not give away the congruent/incongruent status of the stimulus; it only informed the subjects that the actual target did not match the *expected* target. However, this did not exclude the possibility that the target was a congruent word (or pseudoword), albeit not the one they prepared themselves for.

Thus, after having established that the overall structure of the actual target *differed* from the overall structure of the expected target, subjects still needed to evaluate the incongruent pseudoword's semantic content (congruent or incongruent) and lexical status (word or pseudoword). Since an incongruent pseudoword was prepared by changing a single letter in an incongruent word, a second look at the stimulus' overall orthographic structure biased the subjects towards the incongruent pseudoword's base word. However, in order for the subjects to retrieve the meaning of the incongruent pseudoword's base word (and determine its semantic inappropriateness), the conscious-attention mechanism first needed to shift the limited-capacity processor from the expected location in the semantic memory network to the location of the word the incongruent pseudoword was derived from. From the congruent-incongruent effect on the RTs to words, it can be inferred that such a 'long-distance move' in the memory network took up a considerable amount of time. Correspondingly, subjects needed more time to determine the 'incongruent status' of an incongruent pseudoword than the 'congruent status' of a congruent pseudoword.

Like the 'congruent' response in the congruent pseudoword condition, it is assumed that the 'incongruent' response in the incongruent pseudoword condition became available before uncertainty regarding the lexical status of the stimulus was resolved (at least, on the majority of trials), and that subjects needed to suspend the 'incongruent' response until all letters in the stimulus were analyzed. The FRR/FRT data indicate that the subjects were careless in doing so. In controls and guessers, incongruent pseudowords induced a high false recognition rate, and in both reading groups, the reaction times that accompanied the false alarms were as short as the reaction times to (correctly spelled) incongruent words. Together, these data suggest that on a large number of trials subjects neglected the letter-by-letter analysis of the stimulus (necessary to make the word/pseudoword decision) after they had established its 'incongruent status'. Apparently, subjects made a 'word' decision as soon as the limited-capacity processor arrived at the memory location of the incongruent pseudoword's base word and they determined its semantic inappropriateness. It can be argued that subjects were careless (i.e., fast and inaccurately) in making the subsequent word/pseudoword decision because they realized that they already wasted a lot of time in displacing the limited-capacity processor in the semantic memory network and making the congruent/incongruent decision.

A more general version of this conception of the speed-accuracy relationship has been advanced by the so-called deadline model of reaction time (e.g., Ruthruff, 1996; Sanders & Rath, 1991). In short, this model assumes that subjects who are engaged in a choice reaction task adopt a time deadline and respond whenever processing time passes this deadline. Since the processes that preceded the final spelling check of the stimulus took up more time in the incongruent word/pseudoword condition than in the congruent word/pseudoword condition, it is conceivable that subjects experienced speed stress at the start of the spelling check especially in the incongruent word/pseudoword condition. In this condition, subjects may therefore have speeded up the necessary letter-by-letter analysis at the expense of accuracy. At least, this would explain the

finding that incongruent pseudowords were repeatedly misidentified as the words they were derived from, as well as the finding that the FA-RTs to the incongruent pseudowords were as fast as the correct RTs to incongruent words.

Although both reading groups paid insufficient attention to the lexical decision process in the incongruent word/pseudoword condition, normal readers were at least able to suppress the 'incongruent' response on 60% of the trials. Guessers, on the other hand, found substantially more difficulty in suppressing the 'go tendency' triggered by the overall orthographic structure of the incongruent pseudowords, since they successfully inhibited the 'incongruent' response on only 21% of the trials. On 79% of the trials, they prematurely accepted an incongruent pseudoword as the incongruent word it was derived from.

### Guessers Versus Normal Readers

Thus, in both the congruent word/pseudoword condition and incongruent word/pseudoword condition, the poor performance of guessers can be attributed to a less efficient suppression mechanism, that is to an impaired ability to suppress an 'congruent' or 'incongruent' response until all letters in the word stimulus were analyzed. The conclusion that guessers tend to react prematurely to (false) candidate words receives support from the Van der Schoot et al. (submitted) study. In the semantic categorization task, they found that NoGo pseudowords induced substantially more false word recognitions in guessers than in controls.

Significantly, the pattern of FRR/FRT results invalidates the hypothesis that in guessers, the activation levels of the words' logogens are *over*-responsive to semantic context. This hypothesis incorrectly predicted that, when compared to controls, the performance of guessers would be fast (i.e., fast RTs/FA-RTs) and inaccurate (i.e., high FRR) especially in the congruent word/pseudoword condition. Contrary to this prediction, the results showed that (in both subject groups) congruent pseudowords produced *less* false word recognitions than incongruent pseudowords and that the group difference in FRR and RT was as large in the incongruent word/pseudoword condition as in the congruent

word/pseudoword condition. Accordingly, we have to conclude that the guessers' high false recognition rate on the SPT should be ascribed to a less efficient suppression mechanism rather than to excessive reliance on contextual information.

This leaves us with two questions: how can our findings be integrated with the literature on semantic cortical activation in dyslexic children and why are guessers characterized by fast and inaccurate on reading aloud tasks.

Studies using event-related brain potentials (ERP) and magnetoencephalography (MEG) have revealed a negative component with a peak latency of about 400 ms after word presentation (N400), which increases in amplitude with the amount of unexpected semantic information a word contains (Helenius, Salmelin, Service, & Connolly, 1998, 1999; Marinkovic et al., 2003; Osterhout & Holcomb, 1995). The N400 is generally viewed as reflecting a processor of semantics in especially the left superior temporal cortex (Brown & Hagoort, 1993; Helenius et al., 1998; Holcomb, 1993). In sentential priming tasks, dyslexic subjects have shown delayed N400 peak latencies (Brandeis, Vitacco, & Steinhausen, 1994) and smaller N400 amplitudes (Helenius et al., 1999) when compared to control subjects. Interestingly, dyslexic readers showed a weak cortical activation especially to semantically inappropriate sentence-ending words that began with the same letters as the most expected word (Helenius et al., 1999). This finding may well be the electrophysiological manifestation of the tendency to prematurely accept a correctly beginning word (or, in our case, pseudoword) for the one that is expected. Future research will be needed to further examine this possibility.

Why do guessers read impulsively on reading aloud tasks such as the AVI? Reading aloud tasks require subjects to simply name words. That is, they are required to compute the phonological code of the words the text consisted of. Their reading style can be explained by assuming that there is a continuous flow of information from the orthographic lexicon to the phonological lexicon (i.e., by assuming that the *partial* activations of words, and word units, in the orthographic lexicon cascade forward to the corresponding phoneme units in the phonological lexicon) and that, as a

consequence, a word may become available as a vocal response before all of its sensory features have been analyzed. Since such a 'candidate pronunciation' might be wrong, the response need to be stored in a response buffer (Coltheart et al., 2001) until subjects are sure the correct word would be read out. At present, we argue that guessers find difficulty in doing so. That is, guessers may read impulsively because they are impaired in the ability to delay a vocal response until all sensory features of a word are analyzed, and the proper word can be read aloud.

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