From Reading to Neurons

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Chapter 3

An Information-Processing Account of Reading Acquisition

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Introduction

The dangers of structuralist simplification are amply illustrated by those who grasp at parallels between acquired and developmental disorders. Curiously, even scientists of otherwise unimpeachable mental habits have lapsed when the temptation of drawing equivalences between acquired and developmental dyslexia have presented themselves (Ellis 1984; Marshall 1984). However, a label such as *deep dyslexia* has a full definition not in terms of a precise list of symptoms (Coltheart, Patterson, and Marshall 1980 not withstanding) but by its contrastive force in a more or less agreed upon information-processing framework (Morton and Patterson 1980; Patterson 1981; Shallice 1981). One may find a group of children with symptoms that more or less correspond to those found in a prototypical acquired deep dyslexic, but what does it do to term those children "developmental dyslexics"? The similarities are spurious, arising, as they do, from the structure of the material (in this case reading material) rather than from the structure of the disorders.

There are a number of reasons for pointing forcefully to the aberration just described. The first, and one that will occupy the major part of this chapter, is that it negates the truth that "the most obvious thing about development is that there is change" (Frith 1986a, p. 70). To this one can add that the most obvious thing about developmental disorders is that they affect development. It seems to me that any intellectual stance that obscures these truths is on the wrong track. Developmental disorders must be treated in their own right, and this means separately from acquired disorders.

A second reason for separating developmental and acquired disorders is that to do otherwise can lead to errors of inference. Of particular interest is the error of the following pattern. Suppose one has a developmental theory in which it is hypothesized that a particular disorder, leading to the absence of a skill, *s*, results from the absence

of a specific ability, *a*. Suppose one found a group of adult patients with acquired disorders such that the ability *a* was missing. Whether or not these patients had *s* preserved would tell us something about the localization of the neural substrate underpinning *s* and *a* but could have nothing to say concerning the *developmental* relationship between the two. Yet, consider the following from Ludlow (1980), who was examining the issue of whether impaired language development could be the result of auditory processing deficits. Against the proposal she adduces her own finding that patients with Huntington's disease sometimes have severe auditory-processing disorders without having any language disorder (Ludlow et al. 1979). She continues, "*Thus*, auditory processing disorders . . . are probably not the basis for the language problems" (p. 158). Of course, what may be the case for the Huntington's patients, whose language functions were established many years before they suffered a deficit of auditory processing, has no bearing on whether normal language *acquisition* depends over time on an intact auditory-processing system.

The fallacy in Ludlow's argument is fairly obvious. More dangerous, because it is more concealed, is the futility of discussions as to the reality of developmental dyslexia based on collections of test results. These become translated into "syndromes" that can look like syndromes with different etiologies. Thus, Marshall claims, "the syndromes of developmental dyslexia will accordingly be interpreted as consequent upon the selective failure of a particular adult component (or components) to develop appropriately, with relatively intact, normal (adult) functioning of the remaining components" (1984, p.46). Marshall believes that such precepts can form the basis of a "rational" taxonomy of developmental disorders. Bryant and Impey (1986) believe that such arguments can be countered by finding normal readers with the same pattern of test results as the supposed developmental deep and surface dyslexics. Both sides of the discussion ignore the developmental facts of the children in question and allow the debate to obscure the nature of the underlying psychological processes. As the debate stands, it can continue as long as one side or the other can find a dyslexic or normal reader with more and more extreme patterns of performance on particular tests. But the debate is actually about the developmental trajectory, which cannot be addressed by producing a profile of individual readers, howsoever complete, at one single moment in development.

In this article I hope to point to some relationships between acquired and developmental dyslexics by examining the information-processing implications of Frith's framework for reading acquisition.

These relationships will then be derived through comparisons of processes rather than behavior.

Frith's Framework

No serious student of developmental dyslexia can afford to be ignorant of the work of Uta Frith (e.g., 1985, 1986). In this article I can do no more than summarize the essential aspects of her thinking. What she required was a model "that can help bridge the gulf between the child who scribbles and the highly literate adult" (Frith 1986, p.72). Her proposals, therefore, are developmental. She assumes that it is sufficient to consider three basic strategies for dealing with the written word that the beginner has to master. These strategies are called *logographic, alphabetic,* and *orthographic.* Frith is concerned partly with the processing differences associated with these three strategies, but more importantly, with the fact that they follow in sequence and to a large extent are developmentally contingent (Morton 1986). By this I mean that later strategies cannot be attained unless prior ones have been achieved at a certain level of mastery. All I intend to do here is to give a brief outline of Frith's ideas. For additional evidence the reader is referred to Frith 1985. First of all, I will give an overall view of the framework. In the second part of the chapter I will take each stage in turn and give an information-processing interpretation.

Frith believes that normal reading acquisition cannot be understood fully without also taking into consideration the acquisition of spelling. The three strategies, then, are to be seen as strategies for both reading and spelling.

Logographic

In the logographic phase words seem to be recognized independently of each other. Indeed, it seems plausible to think of each word as being identified by an idiosyncratic schema. While it is the case that individual letters typically enter into the recognition, it is also the case that not all the letters in a word are crucial, and in some instances nonalphabetic information appears to be crucial. Typically, the first letter acts as a salient feature, but irrelevant detail too can be incorporated into the recognition schema. Thus, a child may only be able to read the sign ESSO when the letters are surrounded by the familiar oval (Augst 1986). Similarly, a child will respond with "Harrods" when presented with "Hrorasd" or "HaRroDs" (Coltheart 1986). The extent to which the logographic way of reading is elaborated depends upon the age at which the child is taught to read and the method by

which he is taught. Such things may have consequences that are a matter only of degree. This remains to be established. In all cases the child will be able to use some of what he has learned in logographic writing. In the normal course of development logographic reading and logographic writing display equivalent peculiarities. The child who could read ESSO only with the oval around it could only write it with the oval around it. In addition, only the initial letter may be crucial; the other letters may be in any order or even omitted. This is characteristic of this phase of learning. Yet it is clear that the child has learned something of the essential features of the writing system, since it would be exceptional for them to employ signs other than letters in their constructions.

Alphabetic

Frith believes that the child's earliest alphabetic attempts are to be seen in writing. The alphabetic strategy depends on analyzing words into component letters and phonemes and devising rules for mapping the two onto each other. The main difference between alphabetic and logographic modes of operation is that in the former the order of the elements is absolutely crucial. The beginning of the alphabetic phase is characterized by the inability of children to read back what they have written. Read (1971) has given a number of examples of this. For example: 2 DADDY I EM SRY TAT U R SIC (To Daddy: I am sorry that you are sick). What seems to be happening is that the child's first efforts at decoding the writing system involve the use of two codes under the child's control: phonological representation of words and written letters. A child may say any sequence of phonemes she wishes, playing around with sets of words and matching them to letters. The child attempts an analysis of the segmental structure of her own speech, sometimes arriving at a phonetic analysis rather than a phonemic analysis (Read 1971).

The precise nature of the dependency of alphabetic reading upon alphabetic writing remains to be elaborated. That there is such a dependency, at least at the beginning of the alphabetic stage, is shown by dissociations between reading and writing. Thus, Read (1971) identified precocious writers who could not read back their own writing. And Bryant and Bradley (1980) found cases in which reading by sight coexisted with writing by sound. At this time a regular word may be spelled correctly (alphabetically) but not recognized, while an irregular word may be recognized (logographically) but not spelled correctly. As alphabetic reading ability develops, the situation changes, and the child is able to pronounce all regular words cor-

rectly, but she may lose the ability to recognize irregular words that used to be in her vocabulary.

Orthographic

The orthographic strategy is the construction of recognition units above the alphabetic level. This enables the morphemic parts of words to be recognized instantly. The resulting processing units correspond to what I have called "logogens" (Morton 1969, 1979, 1980; Morton and Patterson, 1980); they are referred to as lexical units in other models. In Frith's framework the orthographic stage occurs in reading well before it becomes established in writing. Most English children are fluent readers of quite complicated material at a time when they are habitually making regularization errors in their writing. Indeed, many adults (including the author) never completely established an orthographic writing system even for quite common words.

The Development of an Information Processing System

Mention of "stages" in what follows should not lead the unwary reader into believing I am suffering from "incipient Piagetization" (to quote Jacques Mehler at the Florence conference). In traditional, a stage models the stages themselves are times of stability when the child rests as it were, after the latest achievement. In contrast, the stages in Frith's framework and in the information processing model proposed here are identified by the elements of *maximum* change. As should already be clear, I do not suppose that once a new strategy has been set in train, there will be no more development in the old one. Rather, the contingencies in normal development are found at the level of detail. Thus, one learns to read ESSO logographically, and while one is learning to read other words logographically, the logographic writing of ESSO can proceed. The force of the contingent relationships among the stages emerges when, as in the case of dyslexics, change does not occur, and the next stage cannot be reached. Then the subsequent stage is blocked as well. Thus, if a child is incapable of segmenting his own phonological representations, he will not be able to proceed to the alphabetic stage of writing. In the strongest form of the model, then, the alphabetic stage of reading and the two orthographic stages will be forever out of reach. In practice it might be possible to adopt an idiosyncratic strategy that enables the obstacle to be bypassed, though there is not much evidence that this is possible for organic dyslexics. On the other hand, children who struggle with reading and who are either relatively slow in their development

or for some reason cognitively blocked can be helped so that they overcome the obstacles (see Bryant and Bradley 1985).

On Method

The finishing point for this exercise in development is a model of the adult literate. That this model resembles the logogen model I have previously proposed is no coincidence. In the logogen model units in which morphemes are recognized give one access to not only a phonological lexicon but also semantics. The orthographic strategy depends on the existence of such units. It is natural to speculate on how the schema by which a word is recognized at the logographic level is replaced by the orthographic recognition unit. Is it, for example, that the representation, crude and lacking precise indication of the required order of the elements, is gradually refined as the child has experience with print? In this way of thinking, a logographic representation resembles minilogogens mapping in the adult way directly into the semantic organization built up in conjunction with speech. I reject this idea for a number of reasons, of which the most relevant are as follows:

- It appears to be the rule that when children who have developed a sight vocabulary begin to read, they suddenly cease to recognize words they could previously respond to appropriately. If logographic representations were simply elaborated by increasing the input specification but maintaining the same mapping semantics, we would not find such discontinuities.
- Words have a special meaning in special scripts even for adults. Thus, *Coca-Cola* may be orthographically the same as what we see on the red and white can, but it fails to exploit the special representation that the advertised script has set up.
- As we shall see later, classical developmental dyslexics make "semantic" errors in reading without any displaying the slightest suspicion of verbal semantic problems.

Accordingly, I am proposing that logographic recognition units map directly onto object semantics rather than verbal semantics. That is, words learned early resemble pictures, but later words do not. Before proceeding with my elaboration of the information-processing model, I will briefly describe what I intended by the distinction between the two kinds of semantics.

Picture Semantics and Verbal Semantics

The separation of verbal semantics from picture, object, or visual semantics is not new. It has occurred in my own work in the context of

naming disorders (Morton 1985) and in the work of Seymour (1979), Shallice (1981), Beauvois (1982), and Riddoch and Humphreys (1987).

I will make no attempt here to give a complete definition of the roles of the two kinds of semantic systems. Nor will I do more than hint at the kind of evidence available that supports the division.

At the most basic level, object semantics can be seen as mediating between the visual world and action. The functions include functions similar to what Gibson (1979) calls *affordances*. The idea here is that we can react to objects, parts of objects, or features of the environment without passing through a stage of verbalization, hypothesis formation, or other problem-solving-like activities. It is thus that we can sit upon solid surfaces without identifying them as parts of tables, windowsills, or walls. Other such visuomotor primitives for an object would be the property of being a container and the property of having something that can be used as a handle that can be picked up in an appropriate way.

One line of evidence in favor of separating the two kinds of semantics comes from analyses of the abilities of stroke patients. One of the cleanest examples is the patient M. P. reported by Beauvois (1982) and Beauvois and Saillant, (1985). Beauvois characterizes this patient as having a disturbance between her visual and verbal semantics, though her visual semantics and her verbal semantics each operated normally. Beauvois carried out verbal, visual, and visuoverbal tests in which color was the relevant feature.

The definition of verbal test was one in which the stimulus, the response, and the intervening processes required for the subject to perform the task were all verbal. There were two tests of this kind. In one of them the patient was required to answer questions of the form "Which category does the word *blush* belong to: brown, red, or yellow?" In the second verbal test the patient was asked to produce a color name from a verbal description in cases where the color name did not correspond to the color of an object. Thus, "What is the other name for *Jambon de Paris?*" elicited the reply "*Jambon blanc,*" which is a pale pink. Similarly, the color name commonly associated with envy can only be ascertained through verbal systems. M. P. performed at ceiling levels on these tests and on other purely verbal tests.

The visual tests were designed to exclude the need for verbal mediation, and for this reason M. P. had an adhesive plaster stuck on her mouth during the tests. In the first test she was presented with pairs of pieces of colored wool and had to decide simply whether they were the same or different. In the second test she had to point out the correctly colored picture of an object from among five pictures of the same object. To increase the purely visual component, the stimuli in-

cluded traffic signs, of which people have poor verbal knowledge. M. P. performed at near ceiling levels on these tests. In conclusion, M. P. appeared to have normal visual color processing, as well as normal knowledge of the colors of objects. We will see whether it is reasonable to think of such knowledge as semantics.

There were two kinds of visuoverbal tests. In one set the stimulus and response came from different modalities. Thus, there was a test of color naming and a test where the patient had to name the appropriate color for a line drawing of an object. The verbovisual equivalents were pointing to a color patch in response to the name or to a request like "Show me what color a cherry is." On these tests M. P.'s performance averaged 29 percent. She could not point out the color of a cherry, made very gross errors in pointing to colors (e.g., pointing to brown instead of "bright blue" and saying that a carrot should be "green").

In the second class of tests the stimulus and response were in the same modality, but the means of mediating between the two was in the other modality. When asked questions like "Tell me what color a gherkin is," which was presumed to involve visualization, M. P. could answer only 8 of 20 correctly. There was a large decrement on a test of picking out the "correctly" colored object, in which the correct response was an inappropriate color of the correct name. In a third series of tests M. P. showed a decrement in responding to the color of "snow". Here the stimulus and response were both verbal, but she was encouraged to use a visual strategy. Purely visual tests in which verbal mediation was encouraged resulted in a similar decrement.

If one has doubts as to the felicity of the term "semantic" for the purely visual tasks, there should not be much question when one considers M. P.'s failure on the cross-modal tasks. The ability to visualize the appropriate color of an object on verbal demand certainly cannot be termed perceptual by any normal definition. The storage and retrieval of information that can be translated into the word "green" has the properties in the color domain that we are looking for. If the reader objects to "semantic," suggestions for an alternative term are welcome.

Evidence similar to that provided by Beauvois is provided by Riddoch and Humphreys (1987). They present data from the patient J. B. This patient appears to have an unimpaired verbal system, since he performs 100 percent correctly when asked to provide a name to an auditory definition. However, his naming of everyday objects fell below 50 percent correct. With knife, fork, and spoon he accessed the three names of these implements, but he performed at chance levels in deciding among them. But when asked to make an appropriate

gesture at these objects, he not only makes a correctly discriminating action but also makes it with the correct hand (left hand for the fork and right hand for the spoon and knife, J. B. being British). The knowledge that enables the correct action to be performed is accessed by the object but is apparently not available in the search for the correct name. Let this do as an operational indication of the distinction between object semantics and verbal semantics.

Note that if we grant that the chimpanzee possesses semantic knowledge and hold that the species has no language, we have perhaps an equivalent, and certainly a parallel, organization to picture semantics. As to the nature of the organization of this knowledge we have only scattered clues. Suffice it for the moment to remark that we have no reason to suppose other than the roughest equivalence between the two semantic systems. It is not the case that for each node in picture semantics there is a node in visual semantics into which it projects (or the equivalent statement in the metaphor of your choice). When I am presented with a picture of Fido, while my verbal system has instructions to retrieve the basic-level term *spaniel*, my pictorial system may send it a message that is only interpretable as *dog*. The resulting reconciliation can be classified by an experimenter as an error.

Stage 1a—Logographic Reading

When a child begins to read, there are a number of processing elements already established. These are shown in Figure 3.1. In this figure and in subsequent figures the cognitive systems comprise all the cognitive apparatus not specifically mentioned elsewhere. The two shown elements of the cognitive systems are the two kinds of semantic processes: picture semantics (*p*) and verbal semantics (*v*). Picture semantics has input from systems concerned with the world of objects and has an output connection concerned with mediating action. At the beginning of the logographic-reading stage the child has already developed a speech system. This includes processes that have to do with both speech recognition and production. On the recognition side there is a categorization system, which I have called elsewhere an authority-input logogen system. This produces a phonological representation of lexical items, which can be unpacked, modified, and turned into motor instructions in the response buffer. These speech processes connect with semantic representations that are noncontroversially called verbal semantics. The child also has established a categorization system for pictures and objects, which accesses object semantics, as discussed in the preceding section. This

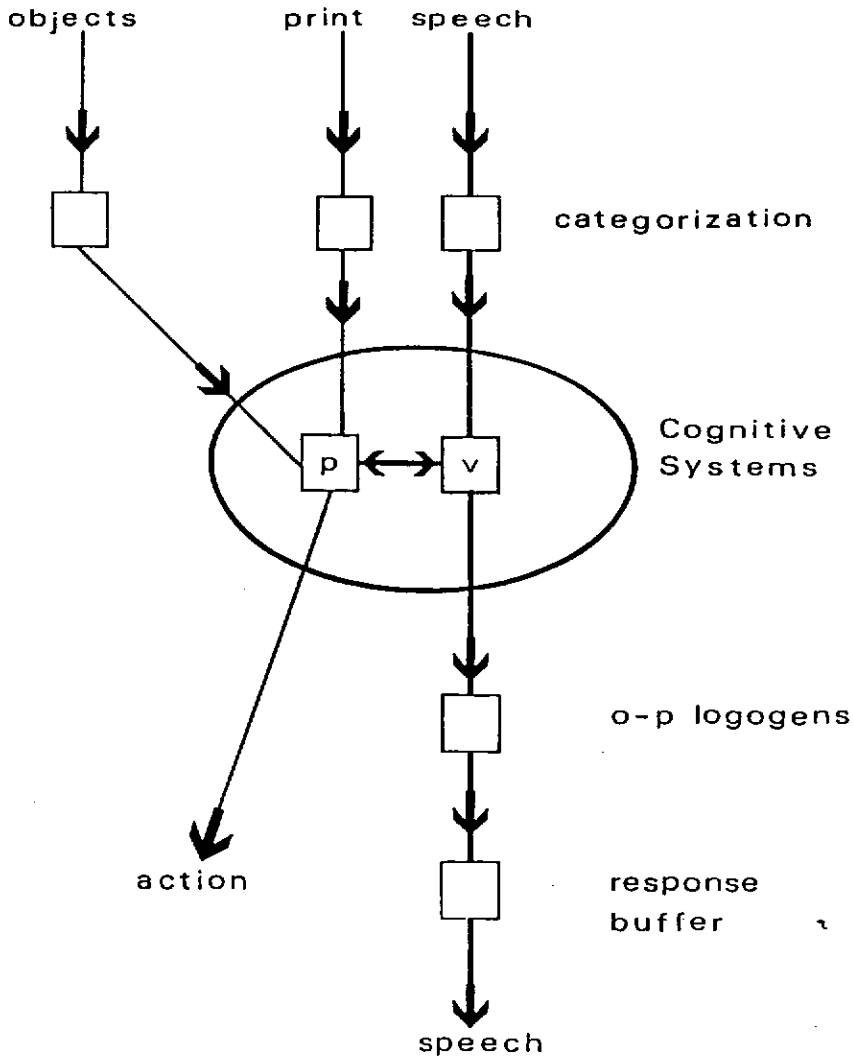

Figure 3.1
Stage 1*a*. An information-processing model of a child during Frith's (1985) logographic-reading stage. Only those processes relevant for the processing of single words and objects have been depicted. In this and subsequent figures p represents pictorial semantics and v represents verbal semantics. O-p (output) logogens contain the phonological specifications necessary for speaking individual words. The special feature of this model is that logographic reading is equated with picture recognition and accesses pictorial semantics rather than verbal semantics. This stage is characterized by growth in the categorical representations of print.

semantic system also has the facility to control action, as shown in figure 3.1.

We can imagine that a child discovers that printed words correspond to meanings and equates this correspondence to that obtaining between pictures and meaning. For this reason the result of categorizing a word should lead to access to picture semantics. When the child comes to recognize words without a simple referent, the nature of the organization of picture semantics itself is changed.

Another consequence of the child's processing words in the same way as pictures is that it makes sense of his indifference to quite major changes in the form of the word. In the same way drawings of the same cat can differ greatly from each other, since the cat itself undergoes major changes in projected form as it moves around. The picture of the cat may show four paws, but there may be only two or three visible. Similarly then, why should it be important that all the letters in a word should be represented all the time? And if a lemon has to be yellow to be a lemon, should not COCA-COLA *have* to be red and white to be Coca-Cola?

The logographic-reading stage has not been studied very extensively in normal children, largely because it lasts for such a short time and contains such a small vocabulary. One of the few studies is Seymour and Elder 1986. My colleagues and I currently conducting a study of this phase, and in table 3.1 I present the responses of Thomas, aged 4. One can see that his vocabulary is reasonable, though the response of "pull" to *yellow* might seem a little extraordinary. But it is no coincidence that both words have a double *l*, which may act as the salient feature. In table 3.2 are Thomas's responses to the same words misspelled. He almost does as well with these stimuli as with the words, and he can now read *yellow*. Particularly revealing is his response to *liltle*. The stimulus satisfied the general description of "little" but failed in some particular. Again, presumably not by co-

Table 3.1
Thomas's responses

Stimulus	Response
milk	"milk"
child	"camel"
house	"house"
blue	"blue"
grandfather	"grandfather"
little	"little"
yellow	"pull"

Table 3.2
Thomas's responses

Stimulus	Response
grodftehr	"gr . . . grandfather"
honse	"house"
mlik	"milk"
yollwo	"yellow"
chld	"cat"
bleo	"blue"
liltle	"*Little*. No that's not *little*, not two *ts*. *Lift*."

incidence, the double *t* is salient for this child, and the fact that it is now *ltl* rather than *ttl* is just a little disturbing to him. His response is rather like saying that it can't be a cat because it is wagging its tail.

Stage 1b—Logographic Writing

At some point while the child is building up a vocabulary of logographic words (what many people call a "sight vocabulary"), she begins writing. The child's own name is the most favorite word, and that is learned by copying from a sample. Later on, children try to write other words, especially ones they have learned to recognize. Most of these words are not perfect copies, and so must be based on representations that the child has herself created. The form of these representations is likely to be idiosyncratic to a certain extent, but the few children whose early written output has been studied share the feature that letter order apart from the initial letter can be varied. One imagines that the representation consists of a collection of letters (in contrast to a list, which would preserve the order) selected according to some perhaps aesthetic criteria.

In other cases the criteria might be exhaustive sampling, as in the following examples from Scheerer-Neumann (1987): Hanno, a preschooler, wrote *papa* either correctly or as APAP. He wrote *opa* (the familiar form for grandpa) as OPA, APO, or OAP. He is reported to be equally happy with any of these forms.

Further analysis must await more extensive data. What is clear is that at this stage there must be an accumulation of information on the set of letters. This would be used when the child is creating new written forms. In addition, there will be a set of representations of the items in the written vocabulary. In figure 3.2 I have termed the latter the lographemic store, though it is probably best to regard the term *store* as one of convenience only, rather than to think of some discrete

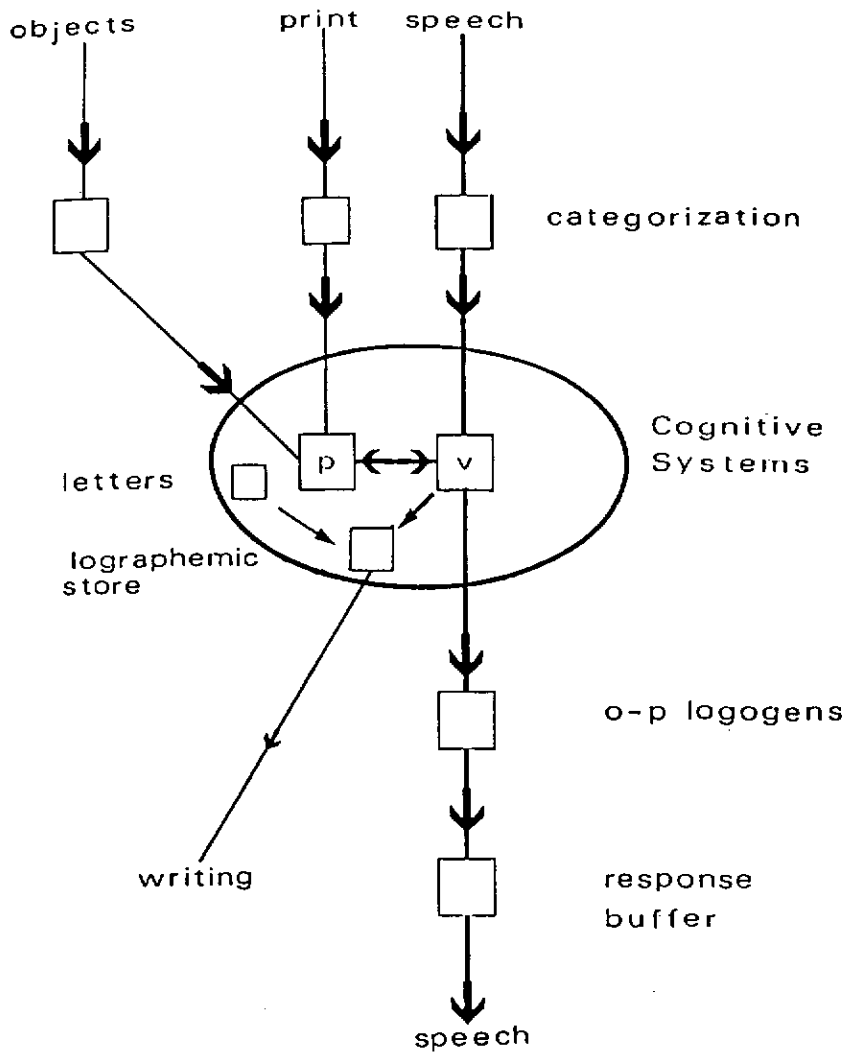

Figure 3.2
Stage 1*b*. An information-processing model of a child during the logographic-writing stage. Experience with print has led to a store of knowledge about letters. This is being used in the creation of lographemic representations, the growth of which characterizes this stage. Classic developmental dyslexics are frozen at this stage.

storage location or a system resembling a logogen system. In fact, lographemic knowledge is likely to consist of a set of discrete records.

In figure 3.2 the small arrow connecting letter knowledge with the lographemic store is intended to indicate a *source* of information over the long term, rather than short term information processing. Note also that action output from pictorial semantics has been omitted in order to simplify the figure.

Stage 2a—Alphabetic Writing

Logographic writing is eventually replaced by alphabetic writing. What is happening during this stage is that the child gains access to her own phonological representations and is able to isolate individual phonemes within them. This is an absolutely essential step, because

of the way our writing system works. Alphabetic scripts represent speech sounds at the level of the phoneme. With nonalphabetic scripts this stage would be very different.

There are a number of options available to us in accounting for how the child is able to isolate individual phonemes. These options are dependent upon the details of the model and will not be discussed further here. All of these options involve processes that follow the output lexicon in speech production. After individual phonemes are isolated, they have to be mapped onto written letters. This requires setting up phoneme-grapheme rules. These I have shown in figure 3.3 as being fed from the response buffer, though there is other processing involved. Clearly the phoneme-grapheme rules will use the letter knowledge that has been accumulating.

The process of phonemic segmentation is the most important single aspect of learning to read. Rozin and Gleitman (1977) write, "The child's insufficient access to the segmented nature of his own or another's speech . . . is the major cognitive barrier to initial progress in reading." A large proportion of backward readers are stuck at the logographic stage, though they can relatively easily be helped over the barrier by a well-directed program of remediation (Bryant and Bradley 1985; Bradley and Bryant 1985). As we will see in the final section, a class of developmental dyslexics that Frith terms *classical dyslexics* have a more serious problem in moving into the alphabetic phase.

In the early part of this stage, the child's productions are minimal. Here are some examples from Scheerer-Neumann (1987): TT for *Tante*, HS for *Haus*, LP for *Lampe*, KF for *Kaffee*. It is important to note that the child knows that he has not been able to put down all the sounds in the word. In addition, at this stage the child can rarely read the words that he has written, as I have already noted.

In the alphabetic stage of writing, words that might have been correctly written by the child in the logographic phase (as occasionally happens) may now be incorrectly written. An example from Scheerer-Neumann (1987) is her son's writing his own name. His first attempts were simply the initial letter H, which for him was a complete written representation of his name. Later he learned to write it correctly as HANNO. At the beginning of the alphabetic phase of writing, during which he produced the examples quoted in the preceding paragraph, he wrote his name as HNO. This kind of regression indicates that the lographemic representations previously set up have lost their connection with semantics. This is indicated in figure 3.3 by weakening the connections. Note that logographic writing and alphabetic writing can coexist, but so far as we know, not for the same item.

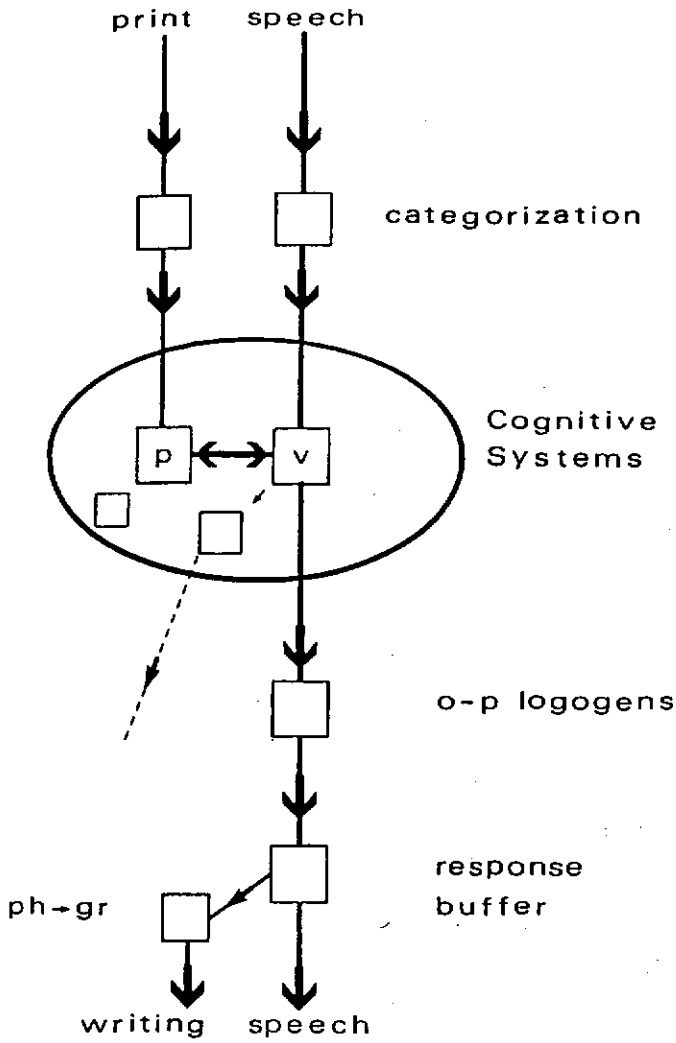

Figure 3.3
Stage 2*a*. An information-processing model of a child during the alphabetic-writing stage. (The processes involved with objects have been omitted for the sake of simplicity.) Logographic writing is dropping out and the child is concerned with learning about the relationship between the phonemic structure of her speech and the writing system. This leads to setting up phoneme-grapheme rules, which are labeled *ph-gr* in the figure.

Stage 2b-i—Alphabetic Reading

The alphabetic-reading stage is divided into two sections that are distinguished by the connections made with the semantic system. At the beginning of the alphabetic phase the child is beginning to segment words into component letters rather than recognizing them as wholes. Individual letters consolidate their representations, and a set of mapping rules are set up between them and the phonemes. Presumably, the setting up of grapheme-phoneme rules is influenced by the already existing phoneme-grapheme rules. Yet there is no simple reverse procedure to arrive at the correct rules. Such an influence is indicated in figure 3.4. Again, however, there does not appear to be sufficient information on the development of individual children to enable such hypotheses to be tested.

Alphabetic writing cannot develop without a minimum of explicit instruction. Similarly, alphabetic reading appears to require some kind of systematic approach. Such instruction consists of detailing the rules themselves, as "G is 'guh'." Certainly, explicit instruction in the knowledge that letters map onto sounds is a part of any contemporary reading instruction. This proves to be a difficulty for some theories in recent or current vogue. Analogy theories of adult reading hold that there are no grapheme-phoneme rules at all, merely mapping between input lexical representations and output lexical representations. Abilities such as being able to read nonwords are accounted for in terms of the use of principles of analogy on the lexicon (Glushko 1979; Henderson 1982; Marcel 1980). Apart from problems related to the viability and adequacy of such theories as have been specified (see Patterson and Morton 1985), it is not clear how these theories would account for children's abilities in the alphabetic-reading stage. Most notably, only regular words can be read, and nonwords can be read as accurately as words. In addition, if the child has learned an irregular word once this phase has begun, he will not attempt to use that ability in trying to read a word that differs by the initial letter (Marsh et al. 1980).

The problems for current connectionist models are different. McClelland and Seidenberg (this volume) do away with lexicons of all kinds, acknowledging only letters, phonemes, and semantic features. Such a model can not cope with the logographic phase at all and can only begin to operate at the alphabetic phase. However, their model is not currently built to allow *direct* mapping between elements such as the letter *d* and the phoneme /d/. Rather, the mapping between end elements is determined via a large number of intervening "hidden units" with connection weights. The owner of such a network (i.e.,

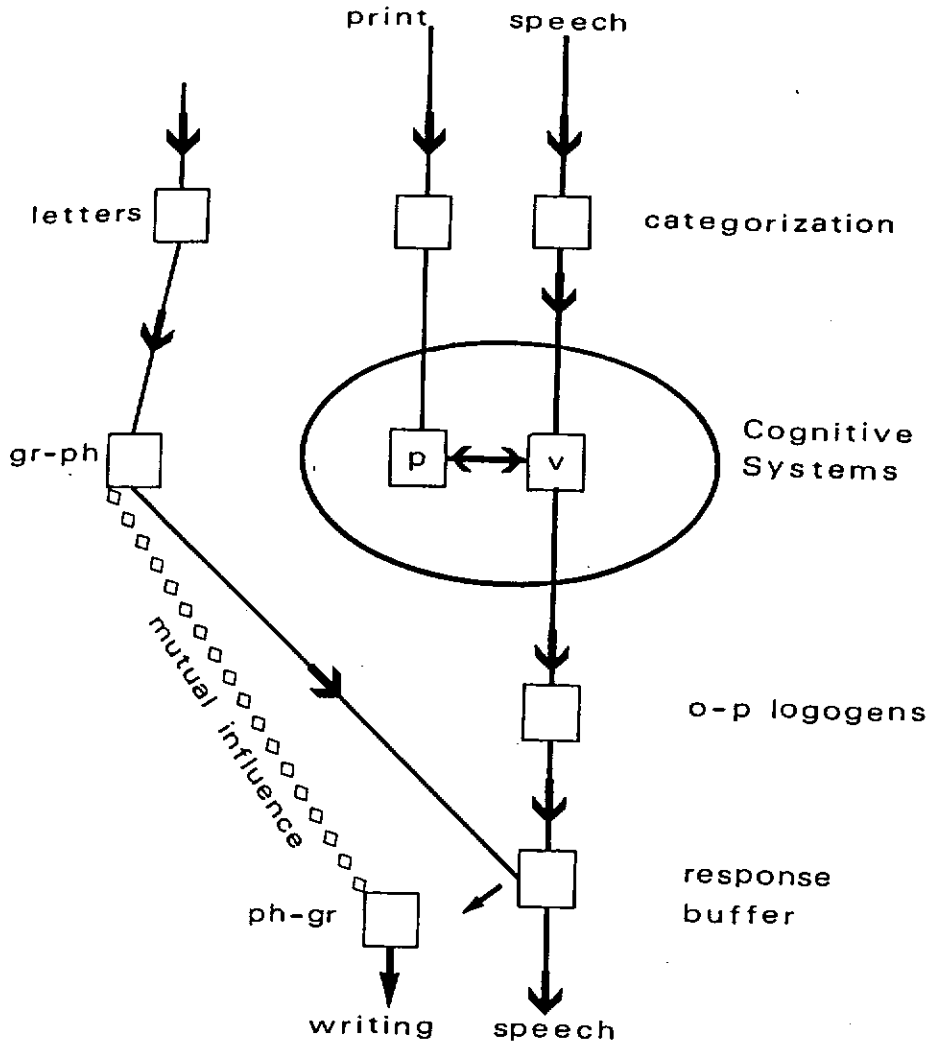

Figure 3.4
Stage 2*b-i*. An information-processing model of a child during the early part of the alphabetic-reading stage. This stage is characterized by the child's increasing her understanding of the phonological equivalents of individual letters and setting up grapheme-phoneme rules (labeled *gr-ph*). These rules are context-sensitive as well as context-free and include rules relating to letter combinations, not just single letters. The nature of the emerging grapheme-phoneme rules is influenced by the nature of the already existing phoneme-grapheme rules.

the child in the alphabetic stage) would not be able to offer any insights into its mode of operation in a way that would help with establishing the networks. Such insights, like "*B* means 'buh,'" would be only incidental.

One interesting feature of the child's performance in stage 2*b-i* is that they cannot understand the words they read alphabetically. Marx (1987) reports that after his son successfully read a list of words, he said "Now you read them so that I know what they mean." Examination of figure 3.4 reveals the reason for this. When the child reads alphabetically, the letter sequence is converted into a phonemic sequence. This is sent to the response buffer, the only process capable of handling it. However, there is no feedback from the response buffer to the semantic systems. So the child can correctly read regular words, though he has no means of understanding what he has read (acoustic feedback not being a possible means for this; see Morton, 1968). This situation slowly changes. Scheerer-Neumann writes, "Gradually reading comes under lexical control." By this means the child moves to the next stage.

Stage 2b-ii—Alphabetical Reading with Understanding

The main feature of this stage are that the child now has feedback from phonology to meaning and that logographic reading drops out completely. The connection with meaning is established directly from the response buffer to verbal semantics. These features are depicted in figure 3.5.

Stage 3a—Orthographic Reading

The final stages of development are of less interest to those whose primary concern is with dyslexia. By the time a child has mastered most of the alphabetic stages, progress on to the orthographic stage is a simple consequence of the interaction of reading, linguistic knowledge, and the general processes of cognitive abstraction. Very few children fail to make the transition painlessly.

What happens is that input representations become established in which letter order is respected and morphological structure is central. The resulting recognition units map onto the verbal semantic system directly. This is shown in figure 3.6.

Stage 3b—Orthographic Writing

In the final stage, shown in figure 3.7, we approach the literate adult. All that needs to be established is a proper graphemic-lexicon system, in which each word is noted with proper acknowledgment of the morphological structure. Seventeen percent of the population fail to

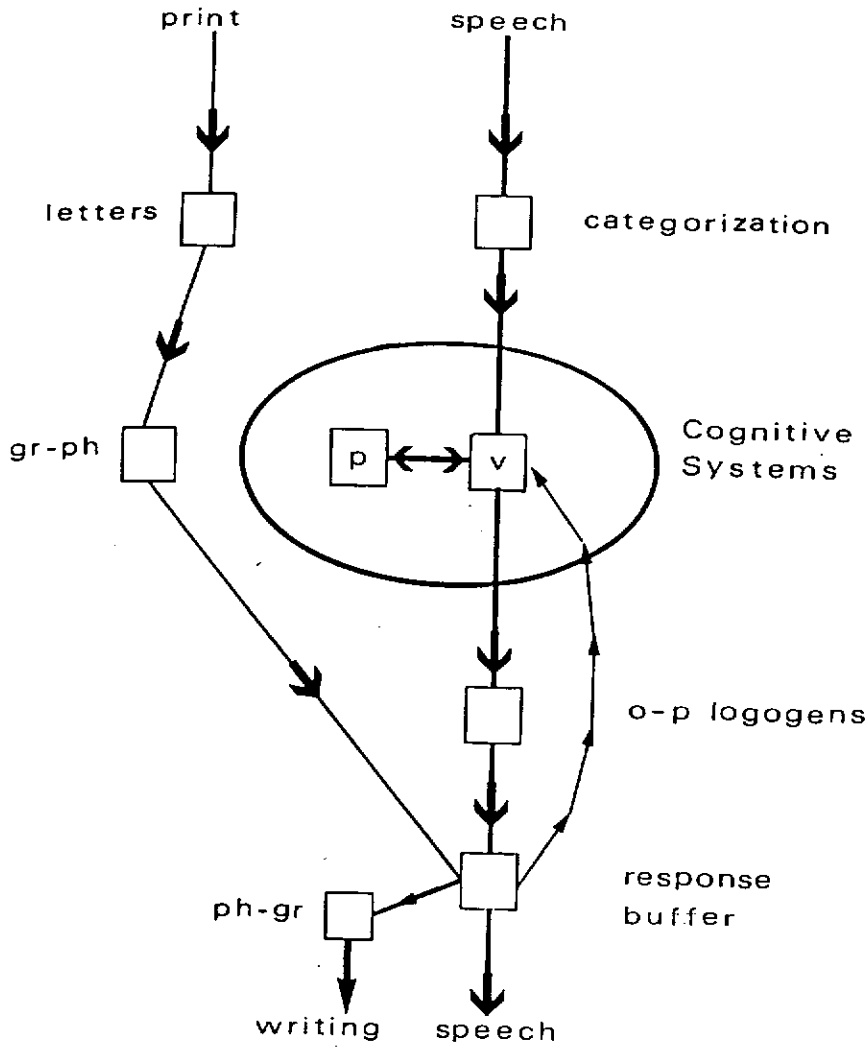

Figure 3.5
Stage 2*b-ii*. An information-processing model of a child during the later part of the alphabetic-reading stage. Logographic reading has become completely suppressed. Feedback is being established from the response buffer to the cognitive systems so that the words can now be understood.

achieve this stage. They fall in the category of "type B spellers" (Frith 1985).

Frozen Cases

The very nature of the developmental process means that we get only a passing glimpse of children with only logographic reading or of children in the alphabetic stage. Most children are in the logographic phase for only a brief time before they begin to get instruction in reading. Thus, we may not be able to find many examples of logographically represented words in any child. In Frith's framework, classical developmental dyslexia results from a failure to attain the alphabetic strategy. Dyslexic children, therefore, give us a chance to

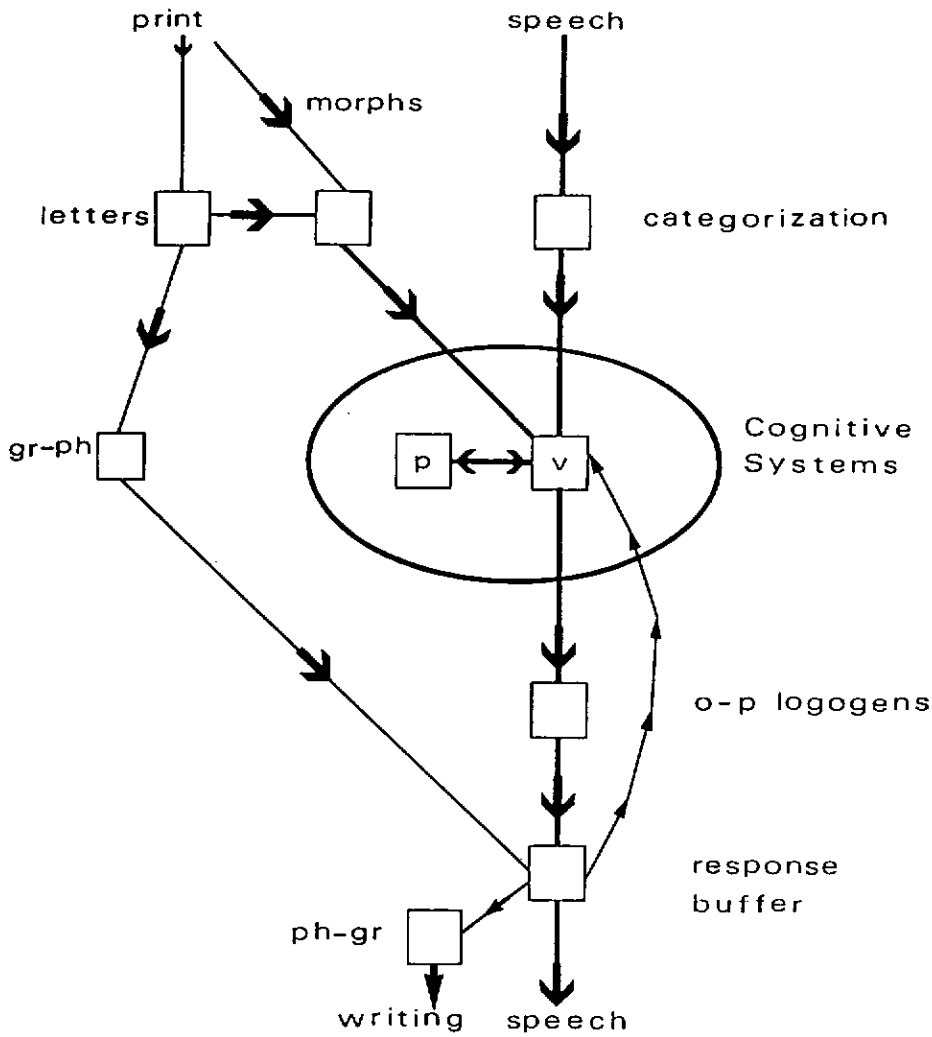

Figure 3.6
Stage 3*a*. An information-processing model of a child during the orthographic reading stage. A new input lexicon is being established that takes account of the morphology of words. This lexicon has access to the verbal semantic system.

examine in more detail the consequences of sticking at the logographic stage.

I regard logographic reading as equivalent to picture recognition. The exact visual form of lexical items is not required by the recognition system. Furthermore, there is a very strong bias towards acquiring lexical items for which there is a representation in the child's pictorial semantics.

What are the consequences of these two constraints? First, the reader should produce responses of words in his vocabulary to stimuli that physically resemble these words. The relationships between stimuli and responses will resemble those already described as typical of the logographic phase. Furthermore, the child should make similar responses to nonwords that resemble words in his vocabulary.

The second question concerns the nature of the pictorial-semantic system. Clearly, we would expect to find accurate representations of

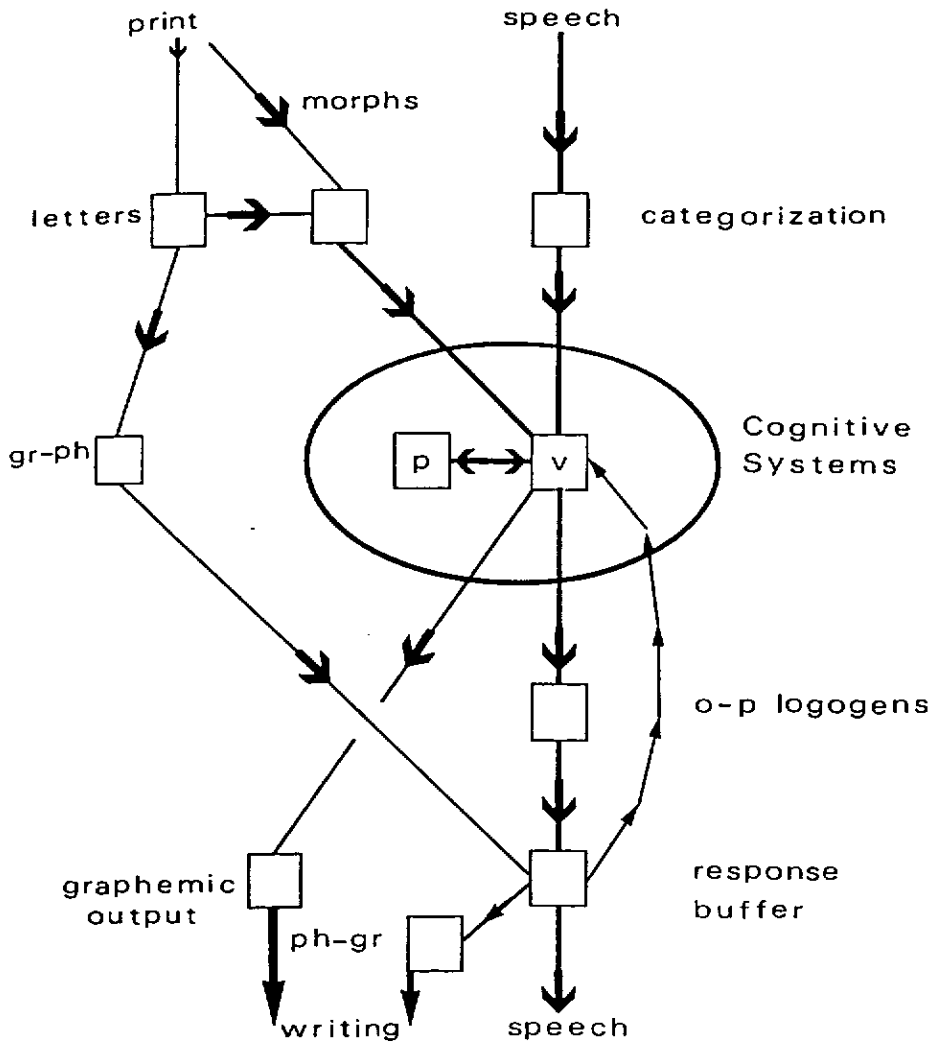

Figure 3.7
Stage 3*b*. An information-processing model of a child during the orthographic writing stage. During this final stage of development a graphemic-output system is being established within which lexical items are represented. This figure corresponds to the adult model (see Morton 1980).

the world of objects. More generally, we can expect that the more a word can be linked up to an image, the more likely that it can be read.

A good example of a logographic dyslexic is described by Johnston (1983). The case is that of C. R., a girl of between 16 and 18 years during the time of testing. She is reported to have a full WISC score of 75 and a reading age on the BAS Word Reading Test of 6.2. What of her reading? First let us look at the semantic effects. C. R. was given 60 words of high imageability and 60 of low imageability. She managed to read 9 of the high-imageability words but only 1 of the low-imageability ones. In addition, there was a part-of-speech effect with the high-imageability words: 5 out of 20 nouns were correctly read but only 3 out of 20 adjectives and 1 out of 20 verbs. As Johnston remarks, this difference could reflect an imageability effect. C. R. was

also given a test in which she had to judge whether pairs of words were synonymous. With pairs of high-imageability words she was correct 58 percent of the time; with low-imageability words she was correct only 32 percent of the time.

Overall, C. R. was asked to read 382 words. Of these, 78 were correct and 219 were not attempted. The most common errors were what Johnston called "visual" errors, following Coltheart, Patterson, and Marshall (1980). In these errors the stimulus and response words had 50 percent of their letters in common. These errors are typical of the logographic phase. I should point out that Johnston presents the case as an example of a developmental deep dyslexic. She argues by analogy. Acquired deep dyslexic patients favor highly imageable words; so does C. R. They produce visual errors, like C. R. again. C. R. is also reported to produce a few semantic errors, such as saying "table" when presented with *chair,* but there are only 5 of these reported out of a total of 163 responses, and this is not a sufficient number to give us confidence that they are genuinely semantic (Ellis and Marshall 1978). More crucial in rejecting the analogy with deep dyslexia is the fact that C. R. often made word responses to nonword stimuli. Deep dyslexics hardly ever do this.

Conclusion

Frith's (1985) framework has been used as the basis of a preliminary information-processing account of reading acquisition. The stages of Frith's framework should be understood as designating the location of maximum change in the nature of the processing. A crucial aspect of the model is that in the first, logographic stage of reading, words access pictorial semantics rather than verbal semantics. This theoretical step has the advantage of providing an account of what have hitherto been called developmental deep dyslexics. I propose that we henceforth call them logographic dyslexics.

Note

Uta Frith not only has provided the starting framework for this article but has advised me throughout its writing, preventing me from making gross errors. I am also grateful to Guinevere Tufnell for comments on an earlier draft.

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