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What do double dissociations prove?

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Abstract

Brain damage may doubly dissociate cognitive modules, but the practice of revealing dissociations is predicated on modularity being true (T. Shallice, 1988). This article questions the utility of assuming modularity, as it examines a paradigmatic double dissociation of reading modules. Reading modules illustrate two general problems. First, modularity fails to converge on a fixed set of exclusionary criteria that define pure cases. As a consequence, competing modular theories force perennial quests for purer cases, which simply perpetuates growth in the list of exclusionary criteria. The first problem leads, in part, to the second problem. Modularity fails to converge on a fixed set of pure cases. The second failure perpetuates unending fractionation into more modules.

1. Introduction

Suppose you came across a patient, with brain damage, who has lost the ability to use syntax. The patient still understands the meanings of words but can no longer string words together to produce proper sentences. The patient's speech is disfluent, centered on content words, and missing most words with exclusively syntactic functions (*and*, *the*, etc.). Suppose next that you find a different patient, with brain damage, who has lost conceptual knowledge. This patient strings words together in a proper way, but the sentences don't make sense. The patient fluently produces nouns, verbs and other parts of speech—all in the right order—but they don't add up to a meaningful sentence.

Now consider the two patients together. The first patient exhibits conceptual knowledge (knowledge of words' meanings), in the absence of syntactic knowledge. The second patient

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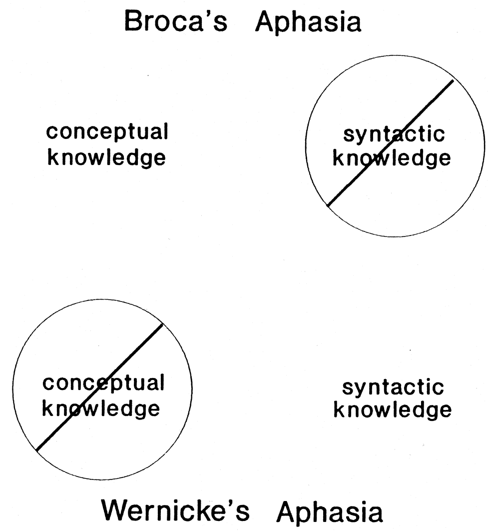

Fig. 1. The double dissociation of syntactic and conceptual knowledge.

exhibits syntactic knowledge, in the absence of conceptual knowledge. The two patients have opposite symptoms. Taken together, these opposite symptoms compose a *double dissociation*. The first patient's symptoms *dissociate* conceptual knowledge from syntactic knowledge. The second patient's symptoms *dissociate* syntactic knowledge from conceptual knowledge (see Fig. 1). Most cognitive scientists believe double dissociations are the best evidence for modularity (but not all, see Appendix A).

Let's take this example a little further. Suppose that the two patients have different loci of brain damage. The first patient has damage in Broca's area, in left frontal cortex. The second patient has damage in Wernicke's area, in the temporal-occipital region. Altogether, these observations suggest that syntax and conceptual knowledge are causally separate in the mind and in the brain. Broca's area appears to contain a causal basis for syntax. Wernicke's area appears to contain a causal basis for conceptual knowledge. Double dissociations relate functional behavior to brain lesions. They are reference points for the causal chains running through mind and brain.

1.1. The plan of this article

This article questions the utility of attributing patients' symptoms, or any performance, to causal modules. The next section, titled *Critical Assumptions*, introduces the double dissociation as a methodological tool, and the assumptions that underlie its use. The three sections that follow concern a paradigmatic double dissociation of lexical and nonlexical modules in reading. We first introduce *Dual Process Theory* of reading, and then use this theory to illustrate the interplay of theory and data in the pursuit of double dissociations (Shallice, 1988). The section *Pure Case Dissociations are Theory Dependent* examines the evidence for a lexical module in reading. A number of pure case dissociations are reviewed. Each, in its time, motivated a lexical module, but none were adequately pure from the perspective of competing explanations. The section *Pure Case Dissociations are Inevitable* examines the evidence for a nonlexical module in reading. This section also reviews a sequence of dissociations that failed to converge on reliable evidence. Subsequent sections clarify the relation between *Modularity and Falsifiability*, and the potential for a modular theory of intact reading performance—*Modularity and Practicability*. Finally, in a section titled *Nonlinear Dynamics of Performance,* we describe an alternative working hypothesis.

2. Critical assumptions

Double dissociations partition human behavior into component effects (e.g., *syntactic performance* vs. *conceptual performance*). Modularity assumes morphological reductionism: Component effects reduce to underlying modules of mind and brain, and modules reduce to elementary causal microcomponents or *single causes* (cf. Coltheart, 1989; Shallice, 1988; Shimamura, 1990, 1993; Van Gulick, 1994). Component effects are the structures of behavior, which are reduced to the structures of mind and brain. The assumption of single causes is the core assumption of modular research programs.

A chain of single causes works like a push on the first domino in a column of standing dominoes. The input to this causal chain becomes a local output, the force of the first domino as it falls. In turn, this local output becomes the input to the second domino, and so on. Chains of single causes form modules, and it is modules that are induced from patterns of performance deficits such as double dissociations. Brain lesions carve cognition at joints between modules (Fodor, 1983)—any missing domino breaks the causal chain for the entire module.

2.1. Double dissociation logic

The term *double dissociation* was introduced by Teuber (1955). Teuber refers to control conditions that are missing in some studies and present in others. Intact performance of a syntactic task is a within-patient control condition, with which the effect of the "conceptual" lesion can be compared, and a between-patient control condition, with which the effect of the "syntactic" lesion can be compared. Conversely, intact performance of the conceptual task is the within-patient control condition, with which the effect of the syntactic lesion can be compared, and the between-patient control condition, with which the effect of the conceptual lesion can be compared. Double dissociation yields all four comparisons from the juxtaposition of two case studies (syndromes).

Early discussions of double dissociations were skeptical about localization of function—Teuber did not advocate the use of double dissociations to discover components of mind (see also Weiskrantz, 1968).[1] In the 1970s, however, a more optimistic view emerged. Dissociations, and especially double dissociations, came to be seen as powerful tools for discovering functional modules of the cognitive architecture: "The crucial theoretical point is that the double dissociation does demonstrate that the two tasks make different processing demands on two or more functionally dissociable subsystems." (Shallice, 1979, p. 191). It is especially useful that ". . . the case study approach is inherently progressive. If a patient is observed with less than the defining number of deficits for a syndrome, then the syndrome as a functional entity fractionates into more specific syndromes." (Shallice, 1979, p. 200, see also Coltheart, 1989).

In 1988, Shallice published a reflective analysis of what can be inferred from double dissociations. He carefully considered numerous threats to double dissociation logic, including the complications posed by individual differences, lesion-induced reorganization of functions, and resource artifacts. Most important, Shallice clarified two circular assumptions at the core of double dissociation logic. One is the circularity involved in the notion of a pure case dissociation. The other is the implicit assumption that double dissociations can only arise within modular architectures. We closely consider how Shallice dealt with these circularities. Both will figure in later arguments.

2.1.1. Pure case dissociations

Shallice (1988) traced the notion of a pure case to Lichtheim's (1885) classic paper on subtypes of aphasia. He acknowledged what Lichtheim's critics, such as Head (1926), had implied: There is no theory independent way to determine whether a given case is pure. We require a reliable theory of cognitive modules, before the fact, to guarantee that we observe a pure dissociation, after the fact. For example, our belief that Broca's aphasia is a dissociation of conceptual knowledge, from syntactic knowledge, requires first that our theory of language makes this distinction. Language must include separate causes of conceptual knowledge and syntactic knowledge. Thus, the present (or absent) "conceptual performance" is only *conceptual performance* with respect to a theory of language.

Accepting a particular theory of language, we next require a theory of tasks, to tell us which language modules are required by which laboratory tasks (Sartori, 1988; Shallice, 1988; Van Orden & Paap, 1997). An indefinite set of choices exists for operational definitions of cognitive components in laboratory tasks (i.e., innumerable tasks, stimulus contrasts, and experimental manipulations). Additionally, brain damage produces innumerable variations of change in patients' behavior. Consequently, one may count on finding some task on which a patient performs poorly, and one may count on finding some patient who performs poorly on a given task. This insures the discovery of dissociation patterns in patient performance. Outside of theoretical guidelines, these patterns (dissociations) have no meaning. Whether dissociations are truly pure cases, and whether combinations of dissociations are truly opposite pure cases, cannot be determined outside one's theory of mind and task.

2.1.2. a priori modularity

The second circularity is more subtle. Shallice (1988) pointed out this circularity using a fallacy involving affirming the consequent:

> If modules exist, then. . . double dissociations are a relatively reliable way of uncovering them. Double dissociations do exist. Therefore modules exist. (p. 248).

After pointing out the circular reasoning, Shallice (1988) revised his 1979 claim that double dissociations imply functionally independent modules (e.g., conceptual knowledge vs. syntactic knowledge). Instead, double dissociations imply causally independent microcomponents—*single causes*.

Shallice (1988) correctly described the circular relation between modules and double dissociations. This circularity extends to single-cause microcomponents as well. Single causes must be assumed before the fact, to provide a logical basis for the modular analysis (cf. van Gelder, 1994). Pure case dissociations entail a subtractive logic. Two contrasted observations of performance are assumed to differ by one module. Ideally, a performance deficit *equals* all the modules of intact performance, *minus* the module of interest (*plus* some noise). The minimum underlying causal difference is a single microcomponent—one single cause that the module cannot do without.

For example, if a patient is unable to perform conceptual knowledge tasks, but the patient retains all other capacities, the minimum difference from intact performance is one necessary single cause of conceptual knowledge. For the subtraction pattern to be transparent, however, it must already be true that the conceptual module is composed of microcomponents that can be cleanly subtracted away. It must be true that conceptual knowledge is a modular collection of single causes. Both single causes and modules are a priori assumptions, neither follows necessarily from the appearance of a double dissociation.

To use double dissociation as a tool, we assume the pivot axioms of the two circularities: (a) Such modules exist—the mind and the brain are modular—and (b) Their absence is directly (transparently) reflected in behavior after a lesion—a pure deficit *equals* the intact mind *minus* one module. These assumptions comprise the logical core of the double dissociation method. Next, we introduce dual process theory of reading and the double dissociation that first motivated its *lexical* and *nonlexical* modules.

3. Dual process theory

Traditional dual process theory comprised two modules. Both modules were defined with respect to grapheme-phoneme-correspondence (GPC) rules. GPC rules govern the relation between spelling and phonology (cf. Venezky, 1970; Wijk, 1966), in a *nonlexical* module that transforms spellings into pronunciations (Coltheart, 1977, 1978). After a process parses a letter-string into graphemes (MINT's graphemes are M, I, N and T; CAVE's are C, A^E and V; and SHEEP's are SH, EE, and P), respective GPC rules transform each grapheme into an appropriate phoneme. The module was called *nonlexical* because it could name pseudoword letter-strings, such as BINT. Pseudowords have plausible spellings that do not happen to be words and are not represented in lexical memory.

Not all words obey GPC rules. Only regular words obey GPC rules, and only regular words could be named correctly via the nonlexical module. A separate *lexical* module was needed to name *exception words* such as PINT (cf. the regular word *mint*). It was called *lexical*, because it only worked for words represented in lexical memory. The lexical module's rules were whole-word rules applied on a case-by-case basis. Each word-specific rule mapped a whole-word spelling into whole-word phonology.[2]

Fig. 2 illustrates the two modules. In the figure, *mint* can be named using either nonlexical rules or a word-specific lexical rule. Lexical and nonlexical modules were also motivated by a double dissociation, observed in the performance of acquired dyslexics. Acquired dyslexia is a language deficit, caused by brain lesions, that shows itself in disordered reading. In this

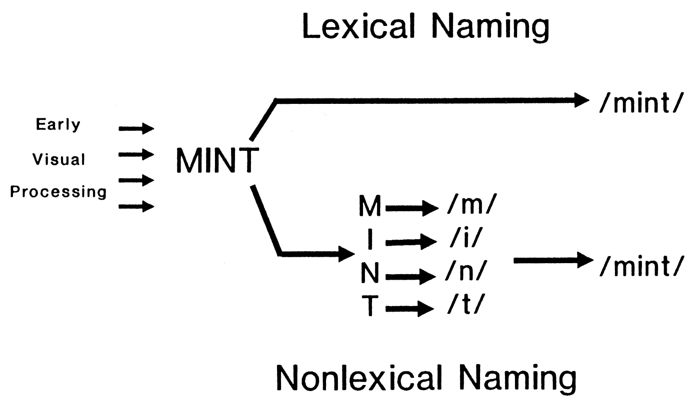

Fig. 2. Traditional dual process theory.

case, *disordered reading* is a performance deficit in a naming task. In this task, patients are presented with words or pronounceable pseudowords (BINT) to read aloud. Types of acquired dyslexia, such as *deep dyslexia* and *surface dyslexia*, are defined by patterns of correct naming and naming errors.

Marshall and Newcombe (1973) first described the double dissociation of lexical versus nonlexical modules. *Deep dyslexics* could name no pseudowords (BINT) but could name correctly some exception words (PINT). Partly intact exception-word naming implied a partly intact lexical module. Absent pseudoword naming implied an absent nonlexical module.

Surface dyslexics could name correctly pseudowords (BINT), but produced regularization errors to exceptions words (PINT pronounced to rhyme with *mint*). Intact pseudoword naming implied an intact nonlexical module. Regularization errors to exception words implied a damaged or absent lexical module. With the lexical module out of commission, the nonlexical module works in its stead, and (mis)pronounces exception words to agree with GPC rules. The opposite patterns of intact and deficit naming performance composed the double dissociation (illustrated in Fig. 3).

4. Pure case dissociations are theory dependent

The previous section described the original double dissociation of lexical and nonlexical modules. This double dissociation is no longer widely trusted. Cognitive neuropsychologists distilled more refined empirical forms for the component dissociations. This and the next section review this refinement process and arguments that have grown up around dissociations. The overarching question is whether a double dissociation supplies reliable evidence for lexical and nonlexical modules. Next we trace the evolution of arguments concerning the lexical leg of this double dissociation, the dissociation of lexical (PINT) naming from nonlexical (BINT) naming.

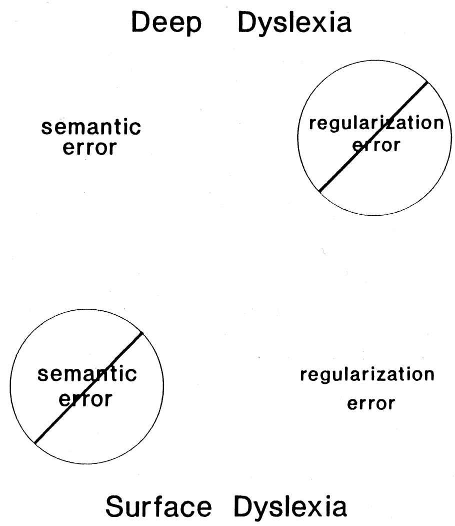

Fig. 3. The double dissociation that motivated traditional dual process theory.

4.1. Deep dyslexia

As noted, Marshall and Newcombe (1973) described the first dissociation of lexical naming. *Deep dyslexics* could name no pseudowords (BINT) but still named correctly some exception words (PINT). Superficially, this profile isolated lexical naming. Exception word naming is the empirical signature of lexical naming. But a closer look at deep dyslexics' naming performance suggested an alternative hypothesis.

The profile of deep dyslexia is a correlation between absent pseudoword naming and grossly deficient word naming. For example, deep dyslexics produce semantic errors (e.g., CARNATION → /narcissus/), visual errors (e.g., CAMPAIGN → /camping/), derivational errors (e.g., ANGLING → /angler/), and visual-then-semantic errors (e.g., COPIOUS → /carbon/). (The examples come from Black and Byng, 1986.) All these errors are bizarre. They are only partly, or not at all, correlated with the surface form of the stimulus word. Bizarre word errors, coupled with absent pseudoword naming, could mean that the basis of pseudoword naming is also the basis of intact word naming (Newcombe & Marshall, 1980). Damage so extreme, that it eliminates pseudoword naming, destabilizes word naming.

Deep dyslexia did not adequately dissociate the lexical module. It was not a pure case dissociation. Nevertheless, advocates claimed that the specific character of deep dyslexics' errors implied a lexical origin (Marshall & Newcombe, 1973; Shallice, 1988). This is a more subtle argument than simply claiming to have a pure case. Advocates proposed that the errors produced by deep dyslexics could be traced exclusively to the visual and semantic properties of words. Consequently, deep dyslexic's errors must have arisen exclusively from damaged visual-semantic components (which have to be part of a lexical module). This hypothesis is widely accepted, but it is not justified by the actual pattern of deep dyslexics' errors.

4.1.1. Visual errors versus the visual-semantic hypothesis

Consider the following visual errors from the corpus of errors produced by the deep dyslexic PW (in the left column that follows) and by the deep dyslexic DE (in the right column). (These are the first five naming errors from the lists on p. 418 and p. 423, respectively, in Coltheart, Patterson, & Marshall, 1980):

TYING	→	/typing/	TYING	→	/tyre/
BUSH	→	/brush/	ARROW	→	/narrow/
PICKING	→	/pickles/	CEREMONY	→	/cemetery/
GOGGLES	→	/gaggle/	FUNNEL	→	/tunnel/
TUMBLE	→	/rumbling/	APPLIANCE	→	/applied/

To be called visual errors, they must have derived exclusively from the visual properties of words. All the examples share several letters between the stimulus and response (a visual resemblance), but they also all exhibit legitimate correspondences with phonology, and typically share common phonology (Goldblum, 1985). How do we determine where phonology effects leave off and visual effects begin? We cannot. The only way to rule out nonlexical phonology, is a priori acceptance of the visual-semantic hypothesis. Visual errors do not implicate lexical naming, unless the visual-semantic hypothesis is true.

The visual-semantic hypothesis was also contradicted by prosody effects (see also Frost, 1998). Prosody is the pattern of stress in the pronunciation of a word. It is an aspect of a word's phonology. The pattern of stress in two-syllable words, predicts the likelihood that a deep dyslexic will make an error, and the syllable in which the error occurs (Black & Byng, 1986). The initial syllable of PARDON is stressed and the visual error /parsnips/ preserves this stressed syllable, for example. Black and Byng claimed that deep dyslexics' errors can usually be traced back to the stimulus word's stressed syllable (e.g., CONFUSE → /fuse, plug/), and deep dyslexics make fewer errors, on average, to words with stress on the initial syllable. Stress on the initial syllable is most common, so this effect correlates with the frequency of subword phonology. Effects of subword phonology implicate the nonlexical module, as Black and Byng propose (cf. Cutler, Howard, & Patterson, 1989, Tabossi & Laghi, 1992, and Black & Byng, 1989). Our argument works with or without a nonlexical theory of prosody. Any reliable phonology effect contradicts the exclusive visual-semantic hypothesis. If visual errors derive from visual properties, then neither prosody, nor any other aspect of phonology, should predict the pattern of visual errors.

Buchanan, Hildebrandt, and MacKinnon (1994) reported a different phonology effect that more pointedly contradicted the visual-semantic hypothesis. The deep dyslexic JC judged whether letter-strings were words or nonwords in a lexical decision task. Sometimes a *pseudohomophone* target, such as TAYBUL, preceded a word target, such as CHAIR. (JC correctly rejected TAYBUL as a nonword.) TAYBUL's phonology indicated the word *table* that is semantically related to CHAIR. Consequently, JC responded *word* more quickly to CHAIR (compared to a control condition). Presentation of TAYBUL primed performance on the subsequent CHAIR trial (cf. Lukatela & Turvey, 1991, 1993, 1994a, 1994b). Keep in mind, however, that JC is a deep dyslexic who cannot produce pronunciations to nonwords. Nonlexical phonology appears absent in the naming task and present in the lexical decision task. JC's performance profile is not an isolated case. Buchanan, Hildebrandt and MacKinnon (1996) replicated her performance profile in two additional case studies with deep dyslexic participants.

Other results also contradict the visual-semantic hypothesis. Hildebrandt and Sokol (1993) found a regularity effect—another phonology effect—in lexical decision performance to low-frequency words, by a patient who fit the phonological/deep dyslexic profile. Katz and Lanzoni (1992) observed a deep dyslexic JA who produced a rhyme advantage in a two-item lexical decision task—better performance to BRIBE/TRIBE than to TOUCH/COUCH (cf. Meyer, Schvaneveldt, & Ruddy, 1974). An effect due to the rhyme of words is obviously a phonology effect. All these patients produced absent nonword naming combined with a phonology effect in lexical decision.

4.1.2. Semantic errors versus the visual-semantic hypothesis

Now consider semantic errors, as we continue our discussion of deep dyslexia. The specific character of semantic errors may also imply a lexical origin. The following errors were chosen from the corpus of errors produced by the deep dyslexic PW (p. 416, in Coltheart et al., 1980):

THERMOS	→	/flask/	CONFINING	→	/hospital/
FENCE	→	/wire/	SOIL	→	/grass/
DIAL	→	/sun/	STOCK	→	/trust/
CAPSULE	→	/tablets/	PAIR	→	/two/

Notice minimal, or no overlap, in spelling or pronunciation, between the stimulus and response pairs. These pairs share only semantic relations. Apparently, words' semantic entailments may constrain performance in a system so crippled as to produce these errors.

Black and Byng (1986) tracked semantic errors back to stressed syllables—a phonology effect—as we noted previously for visual errors. Shallice (1988) claimed that phonology cannot be a source of semantic errors because ". . . even minimal phonological information would allow [deep dyslexics] to eliminate the errors." (Shallice, 1988, p. 99; Marshall & Newcombe, 1973). This claim works as well against the visual-semantic hypothesis, however, as it does against phonology.

Knowledge of a word's spelling is also stored in lexical memory (Davelaar, Coltheart, Besner, & Jonasson, 1978; Forster, 1976; Paap, Newsome, McDonald, & Schvaneveldt, 1982; Rubenstein, Lewis, & Rubenstein, 1971; Schvaneveldt & McDonald, 1981). When THERMOS is presented, visual-semantic lexical-access to the pronunciation /flask/ would also retrieve the spelling of *flask*. Minimal knowledge of *flask*'s spelling should eliminate a semantic error. *Flask*'s spelling would not match the spelling of THERMOS. It is not even necessary to keep in mind the stimulus spelling (as would be the case for phonology). The correct spelling of THERMOS is directly in front of the patient!

Error detection requires that an extensively damaged brain supports intact "frontal" monitoring—a deep dyslexic must check their knowledge of words against the stimulus, and their response, to detect an error. The ability to monitor is most vulnerable to diffuse insults like those associated with deep dyslexia (Prigatano & Schacter, 1991). We do not suggest that a missing "monitoring component" is sufficient for deep dyslexia. Irrespective of how monitoring occurs, an intact capacity for monitoring is necessary to detect one's own errors, even granting minimal phonological information.

4.1.3. Summary

There is no theory-free way to determine whether deep dyslexics are pure cases (Shallice, 1988). Consequently, there is no theory-free way to decide whether the syndrome of deep dyslexia implicates a lexical module. The discovery of modules is strictly guided by a priori assumptions. Pure cases only look pure to those who hold the same a priori beliefs. To others they may appear as impure or mixed cases. Deep dyslexia is viewed as a pure syndrome by some proponents of dual process theory (Newcombe & Marshall, 1980; Saffran, Schwartz, & Marin, 1976, and cf. the *right hemisphere hypothesis* of Coltheart, 1980; Saffran, Bogyo, Schwartz, & Marin, 1980; Zaidel & Peters, 1981). But, others view deep dyslexia as a mixed or impure syndrome that does not adequately dissociate lexical naming (Morton & Patterson, 1980; Nolan & Caramazza, 1982; Shallice, 1978).

4.2. The case of WB

Shallice's important book was published in 1988. By 1988, deep dyslexia was no longer widely accepted as a pure dissociation. More restrictive criteria had been imposed to refine the dissociation of lexical naming. Deep dyslexics' profiles did not satisfy these new criteria. The new case of WB had been reported, with more fully intact lexical (PINT) naming, and absent nonlexical (BINT) naming (Funnell, 1983). WB suffered a cerebrovascular accident to the left cerebral hemisphere. Subsequently, he still named correctly about 85% of the words presented to him. However, he could not pronounce correctly any of 20 four and five-letter pseudowords (e.g., DREED). Absent pseudoword naming implies an absent nonlexical module. Relatively intact word naming implies a relatively intact lexical module. WB's performance profile was subsequently offered as *prima facie* confirmation of the lexical module (Coltheart, 1985a, 1985b; Coltheart, Curtis, Atkins, & Haller, 1993).

Unfortunately, there were several viable sources of WB's deficit, stemming from his severe expressive aphasia (Shallice, 1988). The nonlexical module fed its output to a process that combined individual phonemes prior to pronunciation. WB may have suffered damage to the latter process, such that only familiar phoneme strings were successfully combined. If this were WB's problem, then WB's deficit would not be specific to reading. Consistent with the suggestion, WB performed poorly on Marcel and Patterson's (1986) nonword blending test (cited in Shallice, 1988). In this test, individual phonemes of a nonword are presented, and a patient attempts to combine them.

WB performed poorly on pseudowords in several tasks. When asked to repeat auditorally presented words and pseudowords, he correctly repeated most of a set of one- and two-syllable words (about 87% correct), but not less frequent, three- and four-syllable words (about 7% correct) or four- and five-letter pseudowords (50% correct). The pseudowords were those that he had previously failed to read aloud.

WB could repeat correctly 50% of the pseudowords that he could not read aloud. We do not require quantitatively identical performance in reading and repetition tasks to conclude that these deficits have a common origin in expressive aphasia. Different tasks may produce different profiles for how brain damage is expressed. (We saw this previously for tasks that examined phonology in deep dyslexia.) Hearing the phonology of pseudowords in the repetition task provides explicit environmental support for correct phonology. Explicit environmental support raises pseudoword repetition performance up from floor. This crutch is not present in the reading task; WB must derive phonology from a printed stimulus.

Environmental support plays no role in modular theories, because representations have an arbitrary relation to environmental forms. Other theories assume a direct relation between stimulus forms and psychological functions (e.g., Gibson, 1986/1979; Looren de Jong, 1997; Turvey & Carello, 1981), including words' printed forms (Van Orden & Goldinger, 1994; Van Orden, Jansen op de Haar, & Bosman, 1997). One need not accept the assumption, however, to question WB's status as a pure case. In short, the preferred interpretation of dual process theory is by no means the only one available.

4.2.1. Summary

Once again, the performance of an acquired dyslexic did not adequately dissociate a lexical module from a nonlexical module. WB may be viewed as a mixed case. Marcel and Patterson (1986) questioned other cases of phonological dyslexia on similar grounds. Most case studies did not adequately localize the pseudoword naming deficit within a reading process.

4.3. Contemporary acquired phonological dyslexia

One basic point of our critique should now be clear. Any pure case can be discredited by pointing out its inherent ambiguity (cf. Caplan, 1991). It will then be seen as an impure or mixed case. This section simply iterates this point through one more cycle. We begin by noting the new, more exclusive criteria to confirm a dissociated lexical module. We end by offering contradictory hypotheses that cannot be discriminated by these criteria.

The new criteria required that three dissociations be observed together (Beauvois & Derousné, 1979; Shallice, 1988). The traditional deficit in printed pseudoword (BINT) naming must be dissociated from (a) printed word naming, (b) visual processing, and (c) auditory/articulatory processing (e.g., repetition of spoken pseudowords). Most previous case reports did not corroborate all three dissociations, and they did not satisfy the exclusionary criteria.

Only a few slightly impure cases met all three exclusionary criteria (Shallice, 1988)—RG (Beauvois and Derousné, 1979), GRN (Shallice & Warrington, 1980), AM (Patterson, 1982), and LB (Derousné & Beauvois, 1985). They were slightly impure because, unlike WB, the ability to read aloud pseudowords was deficient but not absent. (In more contemporary reassessments, only RG and LB [cf. Friedman, 1996], or perhaps only LB [cf. Coltheart, 1996] are accepted as pure cases.) The patients' performance on words and pseudowords is summarized in Table 1 (adapted from Shallice, 1988).

4.3.1. Is phonological dyslexia a preexisting condition?

While initially impressive, the data in Table 1 are comparable to data from readers who are developmental dyslexics. This led us to wonder whether acquired phonological dyslexia might be a preexisting condition (Van Orden, Pennington, & Stone, 1990). We got this idea after reading Bryant and Impey (1986). In Bryant and Impey's experiments, readers who were not acquired dyslexics performed like acquired dyslexics. We had also observed

Table 1
Percent of word and pseudoword stimuli named correctly by acquired phonological dyslexics (adapted from Shalllice, 1988)

	Words	Pseudowords
RG	100	10
GRN	98	8
AM	83–95	0–37
LB	87–99	48

performance that looked like acquired phonological dyslexia. In our studies, adult developmental dyslexics, and occasionally even control participants, could name a few or no pseudowords.[3] Pennington, Lefly, Van Orden, Bookman and Smith (1987) described adult developmental dyslexics who, on average, were much worse than nondyslexics at naming pseudowords. Van Orden, Pennington and Green (1997) also observed adult developmental dyslexics who showed substantial deficits in pseudoword naming.

Poor pseudoword naming characterizes the vast majority of developmental dyslexics (see Rack, Snowling, & Olson, 1992, for a review). Perhaps "acquired" phonological dyslexics are developmental dyslexics who had suffered a brain lesion. Table 2 presents data from two adult developmental dyslexics: AZ and BX. The data come from Van Orden et al. (1997b) and Pennington, Van Orden, Smith, Green, and Haith (1990). Table 2 summarizes attempts to read aloud words, from Andrews (1982), and pseudowords, from Glushko (1979). AZ and BX each produced a difference, between word and pseudoword naming, as large as AM and LB, in Table 1. AZ and BX have large relative deficits in pseudoword naming, and their deficits are not confounded with articulatory or visual processing (see Appendix B). Clearly, AZ and BX could pass for acquired phonological dyslexics.

We have come across other readers who could also pass. One case was an Alzheimer's patient in the early stages of dementia. The patient could not read aloud any pseudowords from Glushko (1979) or Rosson (1985), but correctly read aloud all but a few of the words from Andrews (1982), Coltheart, Besner, Jonasson, and Davelaar (1979), and Rosson (1985). Apparently, this Alzheimer's patient is a phonological dyslexic. But more often, in patient studies, there is an association among senile and presenile dementia (one cause of which is Alzheimer's disease), deficient lexical (PINT) naming, and spared nonlexical (BINT) naming—the surface dyslexia profile (Patterson & Hodges, 1992; Patterson, Marshall, & Coltheart, 1985; Warrington, 1975). Virtually all of the reported pure cases of surface dyslexia—deficient lexical naming—also suffer from dementia (cf. Watt, Jokel, & Behrmann, 1997,

Table 2
Percent of word stimuli from Andrews (1982) and pseudoword stimuli from Glushko (1979) that were named correctly by developmental phonological dyslexics

	Words	Pseudowords
AZ	92	39
BX	92	40

however). It was a surprise for us to find senile dementia associated with deficient nonlexical naming. Perhaps the patient's performance was due to a preexisting condition of developmental dyslexia.

We have also seen performance by participants in control conditions, that would pass for acquired phonological dyslexia. One of us occasionally gathers normative data, on the pronunciations of pseudowords, from students and colleagues (e.g., see Van Orden, 1991). One colleague could not provide adequate pronunciations for any pseudowords. This colleague began making naming errors on a list of (mostly) multisyllable pseudowords, and then declined to proceed saying "I've always had trouble with things like this." (A few errors were lexicalizations, the rest were failures to produce a pronunciation.) This neurologically intact adult reads and writes highly technical documents. When we tell this story to others, who study intact naming, they usually match it with one of their own.

The phonological dyslexia profile has also been reported in published studies. The case study of RE is a particularly striking example (Campbell & Butterworth, 1985; see also Campbell, 1991; Funnell & Davison, 1989; Holmes & Standish, 1996; Howard & Best, 1996; Masterson, Hazan & Wijayatilake, 1995; Temple & Marshall, 1983):

> Our subject, RE first came to our attention when she presented a seminar paper on neurotransmitters, a topic containing many new words. Although she clearly understood the meanings of the neurotransmitter names, she told us that she could only read a new word aloud when she heard someone else say it. In pilot studies it turned out that she was sometimes able to offer an approximation to a pronunciation of a nonword, but only after a long delay and with little confidence in its correctness. Her account of these attempts was always in terms of elaborate strategies. When presented with *bant*, for reading aloud, after 15 s she said /bænt/. On being asked how she did this she said "I thought of Bantu and knocked off the 'u'. (p. 439).
>
> RE is impaired at reading and at writing nonwords, while her word reading and writing are at normal undergraduate level. (p. 467). The subject. . . can read aloud, accurately and without hesitation, rare and irregularly spelled words such as *placebo* and *idyll*, but. . . has great difficulty in reading the simplest nonwords, like *bant*, sometimes failing to offer any pronunciation for them. The pattern of reading resembles the acquired reading problem called phonological dyslexia. (pp. 435–436).

RE demonstrates that the most extreme cases of acquired phonological dyslexia could be preexisting conditions. Moreover, a published reassessment of case studies that report acquired phonological dyslexia found associated phonological deficits—including deficits characteristic of developmental dyslexia (see Coltheart, 1996, for an overview). In a review of 17 cases, every one produced impaired performance on some phonological task that did not involve reading.

Readers who are acquired phonological dyslexics produce the symptoms associated with developmental dyslexia. Readers who are not acquired phonological dyslexics produce the symptoms of acquired phonological dyslexia (see also Bryant & Impey, 1986). Lesions acquired after learning to read are not necessary to produce the symptoms. If not *necessary*, we may wonder whether acquired lesions are *sufficient* to produce these symptoms. We do not suggest that acquired phonological dyslexics are unaffected by lesions. Even with this qualification, however, the basic point still holds: Nobody provides pre- and postlesion data, so the available data are indeterminate.

Please note an objection to our preexisting condition hypothesis. We can be faulted for sorting through individual participants' data—checking each participant's performance until we spotted pure cases, given our assumptions. But that objection strengthens our critique (Ellis, 1987; Robertson, Knight, Rafal, & Shimamura, 1993). We employed the contemporary practice of discarding impure cases and reporting pure cases. Table 2 presents the two purest cases of thirty potential cases from Pennington et al. (1990) and Van Orden et al. (1997b).

4.3.2. Does developmental dyslexia dissociate a lexical module?

A persistent advocate of dual process theory might concede our preexisting condition hypothesis, but substitute developmental phonological dyslexia into the double dissociation of lexical and nonlexical naming (Funnell & Davison, 1989). Developmental phonological dyslexia could take the place of acquired phonological dyslexia. A result reported by Hendriks and Kolk (1997) contradicts this possibility. They observed fluid shifts, by the same developmental dyslexics, between opposite patterns of performance.

Hendriks and Kolk (1997) varied the instructions for reading aloud (essentially a naming task). Dyslexic participants were encouraged to read aloud very fast, or very accurately (with an intermediate "neutral" condition). In the fast condition, their performance dissociated lexical naming—they made many naming errors, including visual errors and semantic errors—as though they had failed to develop proper *nonlexical* naming. In the accurate condition, the same dyslexics' performance dissociated nonlexical naming—they showed letter-by-letter or syllable-by-syllable reading—as though they had failed to develop proper *lexical* naming. The respective patterns paralleled the early double dissociation of Marshall and Newcombe (1973, 1977). Here, however, the same participants produced both patterns, as they traded off accuracy for speed, or speed for accuracy.

Our study, in which AZ and BX were participants, found that developmental dyslexics are not missing a nonlexical module. In one experiment, dyslexics performed a categorization task that included word homophones and nonword pseudohomophones (BEATS or SLEAT, respectively, for categories *vegetable* or *weather*). Participants saw first a category name (*vegetable*), and then a target letter-string. They responded *yes* if the target was a category exemplar, and *no* otherwise. Participants falsely identified homophones like BEATS, and pseudohomophones like SLEAT, as category exemplars on 43% (SE = 4.0) of homophone trials, compared to 16% of control trials (SE = 3.3). Virtually every participant that we have tested has produced this effect (of 29 adult, 33 teen, and 23 child dyslexics, Van Orden et al., 1997b). Categorization errors to pseudohomophones (SLEAT) would seem to implicate the nonlexical module. Pseudohomophone spellings are not represented in lexical memory.

A null effect of lexical status was observed in the same studies. The null result came from a contrast in *yes*-error rates between word homophones (BEATS) and yoked pseudohomophones (SLEAT). Dyslexics' error rates to word homophones (46%, SE = 5.6) were statistically indistinguishable from their error rates to pseudohomophones (40%, SE = 5.9). This was also true for chronological-age (BEATS = 10%, SLEAT = 12%) and reading-age control participants (BEATS = 45%, SLEAT = 45%), and these null effects replicate Van Orden, Johnston, and Hale (1988). A lexical module must always distinguish familiar spellings from unfamiliar spellings (pseudohomophones). But categorization performance did not include this distinction (see also Lukatela & Turvey, 1991, 1993). The pattern of categorization errors to word and nonword homophones does not dissociate a lexical module.

4.3.3. Summary

We cannot know whether case studies reporting phonological dyslexia are truly reports of *acquired* dyslexia. It is possible that these cases described developmental dyslexics, who eventually suffered a stroke, or some other trauma. If so, then there are no pure cases of lexical naming. We know that some developmental phonological dyslexics generate the performance profile of acquired phonological dyslexia. We may expect that the widespread pursuit of dissociations would inevitably discover such developmental dyslexics and provide them with the opportunity to produce this profile.

5. Pure case dissociations are inevitable

The previous section illustrated how dissociative methods are guided by theoretical assumptions in the discovery of pure cases. By adopting different theoretical assumptions, one may always redescribe a pure case as impure or mixed. Next we review evidence that dissociated the nonlexical (BINT) module from the lexical (PINT) module. We begin as in the previous section, except this time we track successive instances of surface dyslexia—the nonlexical leg of the double dissociation.

5.1. Early case reports of surface dyslexia

As noted, Marshall and Newcombe (1973, 1977) described the first dissociation of nonlexical naming, in surface dyslexics' regularization errors. In a regularization error, an exception word is incorrectly pronounced to agree with GPC rules (PINT pronounced to rhyme with *mint*). The absent correct pronunciation implies an absent lexical rule and an absent or damaged lexical module. The presence of the regularized pronunciation implies the presence of nonlexical rules and the presence of the nonlexical module.

Surface dyslexics also made visual errors on both exception and regular words (e.g., BROAD → /broke/, GREET → /green/, and REIGN → /region/), consistent with a damaged lexical module, and errors on regular words that seemed to indicate faulty application of GPC rules (e.g., BIKE pronounced to rhyme with *tick*, Marshall & Newcombe, 1973, 1977). The mixed bag of errors eroded the pure case status. Either both modules were damaged, or one module produced all the types of errors. Just as for deep dyslexia, the overall pattern of errors allowed that the basis for exception-word naming was also the basis for regular-word and pseudoword naming. Worse yet, the surface dyslexics of early case studies exhibited compensatory strategies that may not pertain to intact word naming:

> For example, the patient ST, described as a surface dyslexic by Marshall and Newcombe, 1973, used the serial letter-naming strategy . . . It is worth pointing out, in this context, that if a patient is attempting to synthesize a pronunciation from letter-names then some errors will resemble faulty application of GPC rules. Even in cases where there is no report of

> letter-naming strategies, word naming is extraordinarily slow and shows an exaggerated dependence on word length.
>
> [T]he extremely labored reading characteristic of [early case reports of] surface dyslexia, being in some cases an order of magnitude slower than normal reading, in others characterized by attempts mediated by letter-naming, and generally being unusually dependent on word length, does not suggest at all that a mechanism serving normal reading has been revealed as a consequence of selective damage to alternative pathways. Whatever strategy the surface dyslexic is attempting to use, there is no compelling reason to suppose that it serves normal reading. To suggest that this surviving strategy is revealed in an impaired form because annihilation of the lexical path is invariably accompanied by partial damage to the GPC path is possible but tortuous and *ad hoc*. (Henderson, 1982, p. 121; see also Shallice, 1988).

In essence, Henderson updated an earlier critique of Head (1926) who pointed out that one must always project the status of pure case into a complex matrix of deficits:

> As each case arose, it was lopped and trimmed to correspond with a lesion of some cortical center or hypothetical path. (p. 56; cf. Badecker & Caramazza, 1986).

Letter-by-letter readers, who were previously called surface dyslexics, are now called pure alexics (Howard, 1991; Patterson & Kay, 1982; Price & Humphreys, 1995; Warrington & Shallice, 1980). Skilled readers do not exhibit this form of reading, and it is puzzling to consider what component of skilled reading is dissociated. Patterson and Kay (1982) and Warrington and Shallice (1980) proposed competing accounts. Shallice (1988) suggested that the letter-by-letter readers who support Patterson and Kay's account were less pure cases than those who supported Warrington and Shallice's. He then suggested "[t]he most plausible explanation for the purer patients remains damage to an orthographic processing stage. . . " (p. 81).

5.1.1. Summary

Early reports of surface dyslexia may be viewed as mixed cases, insofar as nonlexical naming is concerned, or as cases of pure alexia, a performance phenomenon that does not resemble intact reading. New exclusionary criteria were added to refine the dissociation. The new criteria circumvented the problems raised by Henderson (1982). They included: (a) A strong *regularity effect* on naming with the best performance to regular (MINT) words; (b) pseudowords (BINT) must be read as well as regular monosyllabic words (when matched in their nonsemantic characteristics); (c) errors must typically be nonlexical regularizations; and (d) reading speed must be relatively normal (Shallice, Warrington, & McCarthy, 1983, p. 125). These new criteria defined cases in which lexical (PINT) naming was more purely damaged, and in which intact nonlexical (BINT) naming was more purely spared.

5.2. The case of MP

MP satisfied the new criteria (Bub, Cancelliere, & Kertesz, 1985), and MP's case was offered as *prima facie* confirmation of the nonlexical module (Coltheart, 1985b). MP suffered from dementia, after being struck by a motor vehicle. She showed little evidence of semantic processing, but read aloud fluently. Key findings were MP's success at naming pseudowords (BINT) and her regularization errors to low-frequency exception words (PINT), which dissociate the nonlexical module.

MP's performance also dissociated semantic knowledge from lexical naming (compare Goldblum, 1985). MP lacked access to semantics (see also Shallice & Warrington, 1980). In the traditional version of dual process theory, exception pronunciations were retrieved by the same module as lexical semantics (Coltheart, 1978). MP showed little to no evidence of semantic processing, so she should have shown little to no evidence of exception word naming, and she should never have produced exception pronunciations to pseudowords (Henderson, 1982). Nevertheless, MP correctly read aloud 85% of high-frequency exception words and 40% of low-frequency exception words, and she occasionally produced exception pronunciations to pseudowords (BINT pronounced to rhyme with *pint*).

5.2.1. MP versus dual process theory

MP's profile dissociated a lexical-semantic module (direct access to meanings) from a lexical-naming module (direct access to lexical phonology, Bub et al., 1985). Coltheart (1978) had previously rejected the "radical possibility" (p. 167) of lexical phonology, as an alternative to GPC rules. It was not motivated by extant data, and it did not account for pseudoword naming or regularization errors.

The case of MP split the traditional lexical module into two new lexical modules, that had not been anticipated (see also V. Coltheart, Laxon, Rickard, & Elton, 1988; Friedman & Perlman, 1982; Patterson, 1982; Patterson & Coltheart, 1987; Patterson & Morton, 1985; Schwartz, Saffran, & Marin, 1980). The new, refined, dual process theory (now, strictly speaking, triple process theory) accounted for pseudoword naming, regularization errors, and the case of MP. MP's overall profile created additional problems, however, even allowing *ad hoc* lexical-semantics and lexical-phonology.

The most important prediction of traditional dual process theory was a categorical distinction between performance to pseudowords versus performance to exception words. GPC rules governed the nonlexical module, and word-specific rules governed the lexical module. Separate categories of rules imply separate categories of performance. At one time, the prediction was indirectly supported by intact word naming. Regular words were read faster and more accurately than exception words (Baron & Strawson, 1976; Gough & Cosky, 1977; Marshall & Newcombe, 1973; Stanovich & Bauer, 1978). By the time that Bub et al. (1985) tested MP, this evidence had been challenged, and an alternative distinction had been proposed. Bub et al.'s stimuli reflected both sides of this contest. They used word stimuli chosen according to the GPC hypothesis, but they used pseudoword stimuli derived from a competing *consistency hypothesis* (Glushko, 1979, 1981).

5.2.2. Consistency effects

Consistency concerns the relation between spelling bodies and pronunciation rimes. *Mint* and *pint* share the spelling body *__int*, but *mint* and *pint* are *inconsistent words*, because they have different pronunciation rimes. *Duck* and *luck* are *consistent words*. All words that share the spelling body *__uck* share the same pronunciation rime. Glushko (1979, 1981) used the consistency variable to distinguish two classes of regular words. Naming times for inconsistent but GPC regular (MINT) words were slower than naming times for consistent and

GPC regular (DUCK) words (see also Seidenberg, Waters, Barnes, & Tanenhaus, 1984). Glushko also observed consistency effects in naming times to pseudowords (BINT vs. JUCK), and MP's exception pronunciations to inconsistent pseudowords (BINT pronounced to rhyme with pint) also corroborate the consistency distinction.

Neither regular words nor pseudowords should have fractionated into smaller performance subclasses. The more subtle distinctions were not anticipated.

5.2.3. Strange words

The exception word category also split into ordinary exception words versus strange exception words. *Strange words* such as *gauge* and *yacht* have highly unusual spellings, given their phonology. In studies of intact reading, low-frequency strange words produce many naming errors, and very slow naming times (Seidenberg et al., 1984), and they produce slow, error prone performance in lexical decision (Gibbs & Van Orden, 1998; Seidenberg et al., 1984). Performance to strange words is reliably worse than performance to ordinary exception words.

To our knowledge, no case study in neuropsychology has looked specifically for a strange word effect. Case reports do not often list the full set of stimuli that were presented; they only list the words and pseudowords that produced naming errors. Strange words are very common in these error lists. Six of ten low-frequency strange words, used by Seidenberg et al. (1984), appeared in the error list of Bub et al. (1985). But these strange words served as ordinary exception words in Bub et al.'s analysis. From a modular perspective, the apparent strange word effect splits the exception word category, yielding an "ordinary exception module" and a "strange module," another *ad hoc* fracture.

5.3. Statistical regularity

Other patient data suggest that regularity is a graded distinction (McCarthy & Warrington, 1986; Shallice et al., 1983). MP showed substantial within-class variability in performance to regular and exception words, and variability in both word categories appeared to be correlated with relative consistency (see Bub et al., 1985, Table 1.4). Notably, the range of performance across exception words was as large as the difference between regular and exception words. Regularity begins to appear as a continuous rather than categorical variable.

More refined analysis of consistency, in skilled naming, also found graded distinctions in the body-rime relation (Jared, 1997; Jared, McRae & Seidenberg, 1990; see also Content, 1991). Naming performance is correlated with the relative summed frequency of "friends" and "enemies" in the neighborhoods of particular words. (*Tint* is a friend to *mint*; *pint* is *mint*'s enemy.) Inconsistent words, with high-summed-frequency enemies, and low-summed-frequency friends, produce slower naming times and more naming errors.

As the description of consistency effects was refined, other contradictions to dual process theory were also piling up. Kawamoto and Zemblidge (1992) observed fast regularization errors to inconsistent words by skilled readers. In a speeded naming task, PINT is named to rhyme with *mint* on about 25% of trials. Most interesting, the naming times for regularization errors are faster than correct responses (602 ms vs. 711 ms). Proponents of various dual process theories had long assumed that lexical naming is faster than nonlexical naming. Fast regularization errors contradicted this assumption.

Treiman, Mullennix, Bijeljac-Babic, and Richmond-Welty (1995) conducted a linguistic analysis of how spelling relates to phonology. They included all common English words with consonant-vowel-consonant (CVC) pronunciations (a population of 1,329 words). Grapheme-phoneme correspondence rules cannot possibly map vowel spellings to vowel pronunciations. Relations between vowel spellings and vowel pronunciations are always ambiguous; they are never *single-valued relations*. (In a single-valued relation, each x of a set of xs can be mapped onto a y of a set of ys, and no x can be mapped onto two ys—see Van Orden et al., 1990.). The relations among individual graphemes and phonemes constrain naming, but they cannot do the job alone, even for regular words. Body-rime relations, that define consistency, are more often single-valued relations.

Treiman et al. (1995) also conducted a mega-study of word naming and reanalyzed data from a previous mega-study by Seidenberg and Waters (1989). Both studies corroborated the linguistic analysis. The relative consistency of body-rime relations contributed reliably unique variance to naming times and error rates, and factorial experiments established that children and adults make more naming errors to inconsistent words.

5.3.1. Feedback consistency

Stone, Vanhoy, and Van Orden (1997) generalized the idea of consistency to include feedback consistency. Previously, consistency was only considered in the *feed-forward* direction: from spelling to phonology. From modular and other feed-forward perspectives, this was the only sensible direction to consider. The letter string itself is unambiguous to participants (it is right in front of their eyes). The only potential ambiguity arises with respect to derived phonology. However, recurrent network models generalized ambiguity to the *feedback* direction, and we were led to ask the feedback question: Does it matter in *visual* word recognition that a pronunciation may have more than one *spelling*?

Feedback consistency effects were first observed in lexical decision performance (Stone et al., 1997). The key contrast was between bi-directionally consistent words (DUCK) and feedback inconsistent words. In bi-directionally consistent neighborhoods, the spelling body (_*uck*) is only pronounced one way, and the pronunciation rime (/_*uk*/) is only spelled one way. In feedback inconsistent words (HURL), the spelling body is pronounced in only one way, but the pronunciation rime can be spelled in more than one way (e.g., *girl*). Response times and accuracy were reliably poorer for feedback inconsistent words. Frost, Fowler and Rueckl (1998) directly replicated the finding in English; Ziegler, Montant and Jacobs (1997a) conducted a systematic replication in French.

Previous manipulations of feed-forward consistency in lexical decision did not take into account feedback consistency. Consequently, and in contrast to naming studies, feed-forward consistency effects were sometimes reliable in participant analyses but not item analyses. Once feedback consistency was taken into account, a reliable feed-forward consistency effect emerged (Stone et al., 1997). The previously fickle item effects had been the basis for assuming that nonlexical phonology did not contribute to word recognition. Modular analyses assume that isolated effects imply cognitive modules, they also trust that the absence of an effect indicates the absence of some module. "Accepting the null hypothesis" is worrisome, but inescapable, in dissociation logic (Van Orden et al., 1997a). It is an obvious problem in the present case, because the failure to establish reliable feed-forward consistency effects was shown to stem from the failure to take into account feedback consistency.

Frost et al. (1998) also observed feedback consistency effects in auditory lexical decision, visual and auditory identification accuracy, and visual word familiarity judgments. They used the same words for auditory and visual modes of presentation. What is feed-forward for visual word presentation is feedback for auditory word presentation. Thus the fundamental characterization of "perception as a two-way street" was reliably extended both empirically—to several additional performance phenomena—and theoretically—to feedback consistency effects with auditory presentation. Ziegler and Ferrand (1998) independently corroborated, in French, the feedback effect in auditory lexical decision.

Feedback consistency effects are compelling for several reasons: First, they underscore the importance of bi-directional relations. They demonstrate that stimulus function (e.g., a word's "name function") lends perceptual structure to visual form via feedback. This contradicts the assumption of feed-forward modularity. Note the nonintuitive nature of such phenomena. In visual lexical decision, the letter string is clearly visible to the participant, and it remains visible until a response is recorded. But if feedback from phonology suggests that some *other* letter-string *could have* been presented, recognition is slower (see also Dijkstra, Frauenfelder, & Schreuder, 1993; Ziegler & Jacobs, 1995; Ziegler & Van Orden, 1999; Ziegler, Van Orden, & Jacobs, 1997b).

Second, feedback consistency effects were predicted from a nonlinear dynamical model emphasizing feedback as a basis for reading performance (Stone & Van Orden, 1994; Van Orden & Goldinger, 1994). Nonlinear dynamical models are not mechanical; they do not reduce to modules composed of single causes. Their behavior emerges from reciprocal nonlinear interactions among all components (Van Orden et al., 1997a).

Third, consistency effects refer directly to relations (constraints) in the linguistic environment—estimates of consistency among spelling and pronunciation in samples of literary materials. They do not require the assertion of modularity to be theoretically informative (in contrast to double dissociations, for example).

If Stone et al. (1997) had failed to take a perspective outside of modularity, then they would not likely have tested for feedback effects. If they had granted double dissociation logic its core assertion of single causes, then reciprocal causality should have been dismissed out of hand. The feedback consistency effect does not falsify the modular framework. Feedback effects are simply so nonintuitive from that perspective that they would not have been proposed.

5.3.2. New patient studies

Patterson and Behrman (1997) re-examined MP, to test for statistical regularity effects—effects reflecting the cumulative statistical covariance among words' printed forms and their phonology. Theirs was the first case study to corroborate a graded manipulation of body-rime consistency (as well as a manipulation of *W-word* subregularity—"irregular" vowel pronunciations that form a subpocket of statistical relations specific to words that begin with a *W* such as WORK, WORM, WORTH). MP is not a pure case of nonlexical naming. Either that or nonlexical naming reflects statistical relations, in contradiction to the traditional view.

Table 3
Percent of words named correctly by acquired dyslexic participants of the 39 regular and 39 exception words from Coltheart et al., (1979)

	AK	BJ	CR	DC	EG
Regular	74	85	87	92	100
Exception	64	69	69	72	90

We also conducted patient studies (see Appendix C). Tables 3–7 present the percentage of words named correctly by five patients, corresponding to main effects of regularity manipulations from five respective stimulus sets. The number of correctly named words for each patient, in each stimulus cell, of these five stimulus sets, may be found in Appendix D.

The first and second word sets are of special interest (see Tables 3 and 4, respectively). The first word set is a widely used list of regular and exception words first developed for the experiments of Coltheart et al. (1979). All patients named correctly more regular words than exception words (see Table 3); but this list confounded the regular/exception dichotomy with other forms of regularity (Bauer & Stanovich, 1980). The second word set from Andrews (1982) disconfounded consistency from traditional GPC regularity in a regular/exception $\times$ consistency/inconsistency $\times$ high/low frequency design. Now only AK and EG named more regular words than exception words, and AK showed a much larger effect of consistency (see Table 4). All patients, except EG, named correctly more consistent words than inconsistent words, and EG's performance was very close to ceiling (see Table 4).

The data of Table 5 came from Glushko's (1979) list of consistent and inconsistent pseudowords. The real-word spelling neighborhoods of consistent (JUCK) pseudowords included only consistent words such as *duck* and *luck*. The real-word spelling neighborhoods of inconsistent (BINT) pseudowords included inconsistent words such as *mint* and *pint*. Participants were considered to have made an error if they failed to produce a response, or they produced a response that was not a "possible" pronunciation—a response made up of orthographic-phonologic correspondences that do not appear in any comparable words (Fowler, Shankweiler, & Liberman, 1979). Our transcribers consulted Venezky (1970) in this regard.

EG (along with DC) named correctly more consistent pseudowords than inconsistent

Table 4
Percent of words from Andrews (1982) named correctly by acquired dyslexic participants. Each percentage is of 36 words total. C = consistent, I = inconsistent, H = hi-frequency, L = low-frequency, R = GPC regular, E = GPC exception

	AK	BJ	CR	DC	EG
C	89	89	89	92	89
I	67	78	81	86	97
R	81	81	81	89	94
E	75	86	89	89	92
H	86	86	83	89	97
L	69	81	86	89	89

Table 5
Percent of pseudowords from Glushko (1979) named correctly by acquired dyslexic participants. Each participant was presented with 26 consistent (C) pseudowords and 26 inconsistent (I) pseudowords

	AK	CR	DC	EG
C	4	54	81	81
I	8	62	50	62

pseudowords, but AK's performance was at floor, and CR named correctly more inconsistent than consistent pseudowords (see Table 5). However, every patient showed a consistency effect for either words (Table 4) or pseudowords (Table 5). (BJ declined to proceed through Glushko's pseudowords after failing to produce any response in the practice trials, but produced a consistency effect for words.)

Table 6 summarizes performance to stimulus words from Rosson (1985). These stimuli were constructed to manipulate strong/weak rules × high/low frequency. Rule strength is a statistical (distributional) estimate of grapheme-phoneme correspondence; it derives from a count of the words in which a particular grapheme-phoneme correspondence occurs. Rule strength effects and consistency effects are both consonant with statistical regularity. All patients named correctly more strong-rule than weak-rule words. (And all patients except CR named correctly more high-frequency words than low-frequency words; AK, BJ and EG exhibited a similar frequency effect in Table 4 on the Andrews, 1982, words.)

Table 7 presents totals of correctly named pseudowords from Rosson (1985) that manipulated strong/weak rules × neighbor/no-neighbor. Rule strength was estimated as before; the *neighbor* manipulation tested for a benefit to pseudoword naming from the existence of a real word neighbor (*force* is a neighbor for the pseudoword MORCE). CR and DC named correctly more strong-rule pseudowords, and DC and EG named correctly more pseudowords that had real word neighbors. The neighbor effect is essentially a consistency effect; performance to MORCE benefited from having a consistent neighbor *force*. Thus, DC and EG again produced consistency effects to pseudowords, as they did on the Glushko (1979) pseudowords. (Both AK and BJ declined to name any pseudowords from Rosson, 1985.)

Table 8 presents a summary of overall performance. Statistical regularity effects were apparent in all patients' performance. In contrast, the GPC effect virtually disappeared in performance to Andrews' (1982) word set (only two of five participants produced small

Table 6
Percent of words from Rosson (1985) named correctly by acquired dyslexic participants. Each percentage is of 28 words total. S = strong rule, W = weak rule, H = hi-frequency, L = low-frequency

	AK	BJ	CR	DC	EG
S	46	79	86	93	100
W	39	61	75	75	89
H	57	89	79	96	100
L	29	50	82	71	89

Table 7
Percent of pseudowords from Rosson (1985) named correctly by acquired dyslexic participants. Each percentage is of 30 pseudowords total. S = strong rule, W = weak rule, N = neighbor exists, X = neighbor does not exist

	CR	DC	EG
S	47	30	77
W	27	17	77
N	23	30	83
X	50	17	70

effects, see Table 4). We may compare the reliability of the statistical regularity effects to the reliability of frequency effects (Tables 4 and 6). Frequency effects are a relatively neutral standard from which to estimate reliability, because all accounts expect better performance to high frequency words. (MP produced a large frequency effect despite her damaged lexical module, the source of frequency effects in dual process theory.) All patients except CR produced a frequency effect on at least one word set, and three patients produced frequency effects on both relevant word sets. Statistical regularity compared well with this standard. All patients produced both a consistency effect and a rule-strength effect on at least one stimulus set. Additionally, CR produced rule-strength effects on two stimulus sets (Tables 6 and 7), EG produced consistency effects on two stimulus sets (Tables 5 and 7), and DC produced either a consistency or a rule-strength effect on four stimulus sets (Tables 4, 5, 6, and 7).

5.3.3. Summary

The previous review of surface dyslexia, the case of MP, and our patient studies all favor the statistical regularity hypothesis (but *our critique does not require that it is true*). Nevertheless, the categories *lexical* (whole-word rules) versus *nonlexical* (GPC rules) were corroborated in a dissociation. Dissociation merely requires that performance on exception words is relatively more vulnerable to trauma, and that the dimensions of vulnerability are correlated with the exception/pseudoword distinction. The basis of vulnerability need not

Table 8
Qualitative summary of performance, for each participant, on each of the stimulus lists. ‘‘Y’’ indicates data in the direction that corroborates the hypothesized distinction, ‘‘n’’ indicates a failure to corroborate, and ‘‘–’’ indicates no data available. Data that support a statistical regularity hypothesis are in bold.

	AK	BJ	CR	DC	EG
Confounded GPC effect (Table 3)	Y	Y	Y	Y	Y
Unconfounded GPC effect (Table 4)	Y	n	n	n	Y
Word consistency effect (Table 4)	**Y**	**Y**	**Y**	**Y**	n
Pseudoword consistency effect (Table 5)	–	–	n	**Y**	**Y**
Pseudoword consistency effect (Table 7)	–	–	n	**Y**	**Y**
Word rule-strength effect (Table 6)	**Y**	**Y**	**Y**	**Y**	**Y**
Pseudoword rule-strength effect (Table 7)	–	–	**Y**	**Y**	n
Frequency effect (Table 4)	Y	Y	n	n	Y
Frequency effect (Table 6)	Y	Y	n	Y	Y

honor the precise form of GPC regularity. In fact, it need not even divide stimuli into discrete categories. Dissociation is assured even though stimuli might fall on continua of vulnerability. Any multivariate relationship can be reduced to component correlations (Cohen & Cohen, 1975). However, the exception/pseudoword dichotomy did not anticipate reliable patterns in skilled word naming, and its root GPC hypothesis did not anticipate reliable variance in pseudoword naming (Seidenberg, Plaut, Petersen, McClelland, & McRae, 1994).

6. Modularity and utility

We failed to establish a reliable basis in evidence for lexical and nonlexical modules, but we have not falsified dual process theory as a research program. More contemporary dual process theories accommodate feed-forward consistency effects (Coltheart et al., 1993; Paap, Noel, & Johansen, 1992), and strange-word effects are attributed to "strange" single causes within an orthographic module. Orthographic and phonologic modules could also be reconstituted to accommodate feedback consistency effects (cf. Taft, 1982). In this section we discuss why modularity, itself, is not falsifiable, and why it must be evaluated on a pragmatic basis.

6.1. Are modular theories falsifiable?

Reading theorists do not always agree whether dual process theory is falsifiable (see related discussion in Ellis, 1987; Humphreys & Evett, 1985). A reviewer's comments[4] illustrate the affirmative position:

> . . . could any double dissociation data ever disconfirm dual process theory?. . . Suppose one observed a patient. . . who after a stroke could read regular words much better than exception words, and [another] patient. . . who after a stroke could read exception words much better than regular words. This double dissociation between regular word reading and exception word reading cannot occur, according to dual process theory, because that theory claims that all the processes used [in] exception word reading also support regular word reading.
>
> Another example: [one] patient. . . can read regular words aloud but not nonwords, while [a different] patient. . . can read nonwords aloud but not regular words. This double dissociation between regular word reading and nonword reading cannot happen if dual process theory is true, because that theory claims that all the processes used to read nonwords also support regular word reading.

The reviewer claims that dual process theory is falsified if we find the particular patterns of dissociations. But would these unexpected patterns falsify the theory?

First, can we be sure that such falsifying patients have not been found? Because we must accept dual process theory as the criterion for selecting pure cases, it may happen that falsifying dissociations are disqualified either inside or outside of the review process. The circular relation between theory and pure cases limits a research program emphasizing dissociations and double dissociations. If a popular theory too freely arbitrates the purity of evidence, it becomes somewhat of a stigma for data to be contradictory—troublesome dissociations may be judged impure via new exclusionary criteria, for example.[5] Had the troublesome dissociation been taken at face value, however, it could have been taken as a falsifying dissociation. Consequently, the suggestion that a falsifying double dissociation is possible, in principle, carries no weight in practice.

Second, we should carefully consider what is meant by falsification. As the term *naive* implies, no philosopher of science (or practicing scientist) would endorse a program of *naive falsification* (cf. Duhem, 1954/1906; Einstein & Infeld, 1966/1938; Lakatos, 1970; Quine, 1961/1953). In this case, naive falsification would mean that a dual process theory—that makes precise predictions—would be abandoned wholesale once a critical empirical result provided self-evident disconfirmation. Although local tests of particular modules may fail (as the reviewer pointed out), these tests cannot contradict the assertion of modularity per se. We illustrated this fact repeatedly in the two previous sections. Any defense of a research program, based simply on the potential for falsification of its current instantiation, assumes naive falsificationism. It is unlikely that dual process theory would be abandoned, even if the reviewer's counterfactual dissociations were to become reality. Instead, refinements of the theory would accommodate the new data, as we have seen.[6]

We introduced the term *double dissociation* using the examples of Broca's Aphasia versus Wernicke's Aphasia. At one time, their entailed double dissociation corroborated the linguistic distinction between syntactic and conceptual knowledge. More detailed observations undermined the corroboration, however (Maratsos & Matheny, 1994). Patients presumed to lack syntactic knowledge, on the basis of cursory observation, exhibited syntactic knowledge in more careful studies (Bates, Wulfeck, & MacWhinney, 1991; Heeschen, 1985; Linebarger, Schwartz, & Saffran, 1983). Patients presumed to lack conceptual knowledge, exclusively, exhibited deficits in syntactic knowledge (Berndt, Haendiges, Mitchum, & Sandson, 1997a; Berndt, Mitchum, Haendiges, & Sandson, 1997b; Kolk, van Grunsven, & Keyser, 1985) and reliable effects of the "absent" conceptual knowledge (Heeschen, 1985; Swinney, Zurif, & Nicol, 1989). Nevertheless, the discourse continues to follow the path of refinement and adjustment. Outright dismissal of modularity is almost never considered no matter how contrary the evidence.

Kolk and his colleagues presented the most compelling evidence against static, pure case, linguistic deficits. They observed fluid deficits—deficits that change with changes in task demands (Hofstede & Kolk, 1994; Kolk & Heeschen, 1992; Kolk & Hofstede, 1994; Kolk et al., 1985). A patient may appear agrammatic under some task conditions (i.e., exhibit telegraphic speech) and paragrammatic under other task conditions (i.e., exhibit morphological substitutions). The same patient can exhibit different forms of aphasia under different task demands, and in different tasks (as we saw previously for developmental dyslexia). Patients who shift between opposite forms of aphasia challenge the basic structural assumptions of modularity. Brain damage does not carve cognition at joints between modules. Apparent "modules" simply reflect patients' performance options, as determined by task demands. Interactions with task demands subvert the logic of dissociation (Pachella, 1974; Sternberg, 1969; Van Orden & Paap, 1997; Van Orden, Holden, Podgornik, & Aitchison, 1999).

Fluid deficits were not interpreted as falsification of static modules. Subsequent case studies subdivided linguistic knowledge into more and smaller pieces—verbs/nouns, concepts/word-forms, reversible/nonreversible passive syntax, proper-nouns/common-nouns (Damasio & Damasio, 1992), linguistic/affective prosody (Blonder, Bowers, & Heilman, 1991; Pell & Baum, 1997), and so forth. The more narrowly defined components are all still in dispute, and tend only to grow in number. The original double dissociation of verbs/nouns was apparently grounded in mixed cases. It fractionated into verb/noun modules of comprehension (e.g., Brédart, Brennen, & Valentine, 1997), verb/noun modules of production (Berndt et al., 1997b), and modality specific verb/noun modules of production (to accommodate a double dissociation of speaking verbs vs. writing verbs, Caramazza & Hillis, 1991), plus modality specific function-word modules (to accommodate a double dissociation of speaking function words and writing nouns, Rapp & Caramazza, 1997b).

All the previous modules have been refined even further. The dissociation of reversible sentence comprehension was restricted to verbs of particular types (Jones, 1984; Saffran, Schwartz, Marin, 1980). Agreement inflection was dissociated from tense inflection (Friedman & Grodzinsky, 1997). Affective prosody fractionated along multiple dimensions (see Ross, Thompson, & Jenkosky, 1997, for an overview). The double dissociation of proper/common nouns was grounded in mixed cases. It fractionated into tool names/names of animals, fruits and vegetables (Damasio & Damasio, 1992), fruit and vegetable names/names of vehicles, toys, tools, animals, body parts, food products, school, bathroom, kitchen and personal items, clothing, colors, shapes and trees (Hart, Berndt, & Caramazza, 1985), names of famous people/names of towns (McKenna & Warrington, 1980), names of faces/names of animals/names of tools (Damasio, Grabowski, Tranel, Hichwa, & Damasio, 1996). The defining dimensions of these dissociations remain in dispute (contrast Damasio et al., 1996; Farah & McClelland, 1991; Forde, Francis, Riddoch, Rumiati, & Humphreys, 1997; Gonnerman, Andersen, Devlin, Kempler, & Seidenberg, 1997; Sacchett & Humphreys, 1992; Sartori & Job, 1988; Tyler & Moss, 1997; Warrington & McCarthy, 1987; Warrington & Shallice, 1984), and the basic dissociations fractionated further into input and output types (Franklin, Turner, & Morris, 1994; Martin & Saffran, 1992). Modules inevitably progress toward smaller and more parochial functions (Lashley, 1929).

In accord with all the previous examples, dissociations contrary to the current form of dual process theory would be absorbed by fracturing existing components or simply adding new components (see also Ellis, 1987). However, *ad hoc* components are ". . . a mere restatement of a fact in a special jargon [and] cannot claim to be an *explanation* of that fact." (p. 475, Putnam, 1994, emphasis in original). In MP's case, Bub et al. (1985) posited a theoretical distinction between access to words' names versus access to words' meanings, to explain a dissociation between *naming performance* and *meaning performance*. This restates the empirical distinction, but does not enrich the theory (compare the *effect* = *structure* fallacy described in Lakoff, 1987).

Dissociation methods have no empirical failure point. Any new dissociations contrary to an extant modular theory can always be accommodated by additional exclusionary criteria, by adding modules, or by replacing existing modules with more refined modules. Concerning the latter refinement, Shallice (1979) had proposed that:

> [T]he case study approach is inherently progressive. If a patient is observed with *less* than the defining number of deficits for a syndrome [dissociation], then the syndrome as a functional

Table 9
Opposite interpretations given to the same syndromes or case studies (see text)

Mixed or Impure Cases	Syndrome or Case Study	Pure Cases
Shallice, 1988 Barry & Richardson, 1988 Friedman, 1991	Deep dyslexia	Coltheart, 1980 Marshall & Newcombe, 1973
Shallice, 1988 Coltheart, 1996	WB	Funnel, 1983 Coltheart et al., 1993
Coltheart, 1996 Friedman, 1991 Van Orden et al., 1990	Contemporary Phonological Dyslexia	Shallice, 1998
Henderson, 1982	Early reports of surface dyslexia (letter-by-letter naming)	Shallice, 1988 Marshall & Newcombe, 1973
Shallice, 1988 Coltheart et al., 1993	Early studies of MP	Bub et al., 1985
Coltheart et al., 1993	More recent studies of MP	Patterson & Behrman, 1997

> entity [module] fractionates into *more* specific syndromes [modules]. (p. 200, emphasis added).

We noted for the case of MP: If a patient is observed with *more* than the defining number of deficits for a syndrome/dissociation then extant modules fractionate into *more* specific modules or new modules are discovered. Fewer symptoms imply more modules, and more symptoms imply more modules. Any difference between patients' deficit performances is potentially a dissociation. Because ". . . no two aphasias are absolutely alike" (p. 83, Critchley, 1979), there is a potentially infinite basis for dissociable modules.

6.2. The utility of modular analysis

Modularity is not a falsifiable hypothesis; it is an axiomatic belief. Our critique does not concern whether modularity is false. We ask whether modular analyses may ever provide coherent explanations of reading phenomena? Our review documents the *absence of empirical convergence* on reliable pure cases. This is the heart of our critique, summarized in Table 9. Notice the impasse—the theoretical stalemates when the same patient data are interpreted one way to indicate pure cases, and another way as mixed or impure cases.

Marshall and Newcombe (1973) originally proposed that pure cases of deep dyslexia and surface dyslexia implied two modules: lexical versus nonlexical. Shallice (1988) argued that the patients called deep dyslexics were a heterogeneous collection of impure or mixed cases. Barry and Richardson (1988) view deep dyslexia as a mixed syndrome that fractionates into *input types* and *output types*. Coltheart classifies deep dyslexia as a pure case (right hemisphere reading), but not as a pure case of lexical naming (Coltheart, 1980). By Coltheart's account, WB is a pure case of lexical naming in contrast to (less pure) contemporary phonological dyslexics who are mixed cases (Coltheart et al., 1993)—precisely opposite to Shallice's (1988) account. More recently, Coltheart allows ". . . that selective impairment of nonword reading comes in various forms, since there are various loci of the nonword reading system at which impairments can be caused by brain damage." (Coltheart, 1996, p. 760). Thus, phonological dyslexia becomes a mixed syndrome that divides into more particular syndromes.

Concerning surface dyslexia, Marshall and Newcombe's (1973) early pure cases of surface dyslexia were reinterpreted as mixed cases (Henderson, 1982), or pure cases of letter-by-letter reading (Shallice, 1988). The surface dyslexic MP (Bub et al., 1985) is a pure case according to Coltheart et al. (1993), but a mixed case according to Shallice. Shallice allows that MP may serve as a pure case for other components, but not for nonlexical naming. Patterson and Behrman's (1997) more recent study of MP demonstrates consistency effects. MP's mix of regularization errors and consistency effects classifies MP as a pure case with respect to feed-forward connectionist theories, but as a mixed case with respect to a contemporary dual process model. Coltheart's current model localizes consistency effects in a lexical process (Coltheart et al., 1993). We do not yet know how other accounts may accommodate the most recent description of MP. At worst, they may claim that MP does not adequately dissociate nonlexical from lexical naming.

Our review has cited many more conflicting accounts than those listed in Table 9. Also, there are types of acquired dyslexia that we did not mention, and there are many more theoretical interpretations that we did not review (Shallice, 1988). For example, Friedman (1991) proposes an elegant account in which deep and phonological dyslexia lie on a continuum (Glosser & Friedman, 1990; cf. Newcombe & Marshall, 1980). This hypothesis agrees with several cases of phonological dyslexia who have partly recovered from deep dyslexia. Deep dyslexia includes extensively impaired lexical semantic naming and impaired lexical phonological naming. Phonological dyslexia also includes impaired lexical phonological naming, but partly recovered lexical semantic naming. Friedman's version of lexical phonological naming is not the traditional dual process version. It draws on the consistency distinction (Friedman & Albert, 1985). Friedman proposes a different partition of naming performance and a different cognitive architecture. Her account also diverges from traditional dual process theory in its unique classification of cases. With respect to Table 9, deep and phonological dyslexics are both mixed cases, but the basis for this classification is not the same as those previously discussed.

6.2.1. Modular contests end in stalemate

Head (1926) and Shallice (1988) clarified the theory dependency of pure cases. Shallice claimed that this circularity would not be a problem for testing neuropsychological theories. Competing theories could each produce their own set of pure cases, and the best theory would account for all the cases. With all due respect, Shallice was wrong on this point. Competing theories did not discover the same pure cases, and they did not bother to account for each others' pure cases.

One theory's pure case may appear to a competing theory as a mixed or impure case, which reduces its priority for explanation. It does not meet the circular criteria that the competing theory must impose to decide which cases are pure. The circular corroboration of a theory, by its pure evidence, is not challenged by a competitors' mixed or impure evidence.

No best theory can be selected. No logic or method guarantees that a true theory would account for any more pure cases than a manifestly false theory.

Table 9's impasse need not have emerged. Various laboratories might have converged on common criteria for pure cases, a shared corpus of pure cases, and generally agreeable corroboration for the implied set of modules. They did not. Consequently, double dissociations did not uncover reliable modules of reading. The pursuit of double dissociations yielded equally supported theories that differed in a priori assumptions, in the conclusions they drew from data, and, most objectionably, in their criteria for what counted as evidence.

6.2.2. Summary

Each new dissociation, or challenge to an extant dissociation, may be seen as a predictive failure for a modular theory. The consequent addition of new modules, or new exclusionary criteria, reconstitutes the theory. At every turn, the complexity of the theoretical narrative increases. Either the data no longer pertain to the theory (via exclusionary criteria) or a new causal entity is added to the theory. Modularity's core assertion is that we may discover such mediating causes. Repeated *ad hoc* additions have served primarily to keep this core assertion aligned with a changing empirical landscape, that modular theories repeatedly failed to anticipate or explain. *Ad hoc* modules and exclusionary criteria have thus formed a protective belt; the core assertion is protected despite its failure to do explanatory work. Research programs, that come to rely heavily, or exclusively, on this protective belt, become questionable on that basis (Lakatos, 1970).

7. Modularity and practicability

A defender of modularity could accept the outcome of our critical review, and claim that modularity will demonstrate its usefulness in the future. A modular analysis in cognitive neuropsychology will be possible when we have finally a reliable modular theory of intact reading. As we have noted, dissociations can be no more reliable than the theory of reading from which they derive. Assuming modularity, a credible process of theory refinement should eventually converge on reading modules anchored in reliable phenomena of intact performance. Convergence of theory and evidence would be the critical first step to establish the utility of hypothetical modules (cf. Garner, 1974; Garner, Hake, & Eriksen, 1956; Jacobs, 1994; Jacobs & Grainger, 1994). A successful reduction of intact performance to cognitive modules—reliable modular theories of mind and task performance—must precede a successful morphological reduction to brain.[7] In this section, we consider whether a reliable modular theory of intact reading may be forthcoming.

Our review has focused on causal components of word and pseudoword naming, modules that derive phonology from word and pseudoword letter-strings. However, the literature on intact reading has, so far, failed to resolve debates on phonology's role in skilled reading, or the causal components that are entailed. Those debates show the same symptoms as debates in cognitive neuropsychology, as we have noted elsewhere (Gibbs & Van Orden, 1998; Stone & Van Orden, 1993; Van Orden et al., 1990; 1999; Van Orden & Paap, 1997), and we explain next.

7.1. The task debate

All written languages include systematic relations between phonology and spelling (Mattingly, 1992), which suggests a universal role for phonology in reading (Perfetti & Zhang, 1995; Perfetti, Zhang, & Berent, 1992). Despite the plausibility of this hypothesis, and a century of empirical investigation, no scientific consensus has been reached concerning phonology's causal role in reading. Theorists who view reading primarily as an act of visual perception discover visual modules; whereas theorists who view reading primarily as a linguistic process discover phonology modules, in the same families of performance phenomena (Frost 1998; Van Orden, Aitchison, & Podgornik, 1996). These stalemates occur because the reading tasks that produce large, reliable phonology effects, also produce null effects after subtle changes in task demands. As a consequence, the phonology debate becomes a debate about task conditions in which phonology effects occur, or do not occur. To determine whether, or when, phonology plays a role in reading, we must first determine which laboratory conditions are transparent to the cognitive architecture of reading.

The development of laboratory reading tasks was guided by a desire to induce context-independent modules of intact reading (effectively, cognition in a vacuum). It was crucial for this rationale to distinguish effects due to reading modules from effects due to their contexts of use. With respect to this goal, empirical phenomena become suspect if they depend too much upon particular contexts. With respect to these concerns, a task context is viewed more as a source of experimental contamination, than as a legitimate source of cognitive phenomena.

7.2. Additive factors logic

The most well known tool to individuate cognitive components is Sternberg's (1969) additive factors method. Factorial designs allow simultaneous manipulation of several variables, which provides the opportunity for interaction. If the effects of two or more factors are strictly additive, the manipulated variables may have influenced causally distinct components (cf. Lewontin, 1974). Alternatively, when interactions are observed, the factors do not satisfy the assumption of selective influence. Factors that interact influence (at least) one common cognitive component. Thus, to Sternberg's lasting credit, his method includes an empirical failure point: ubiquitous interaction effects. Interactions preclude the assignment of effects to separate cognitive components.

Interaction effects are the rule in reading experiments. It is not possible to manipulate all reading factors simultaneously, but it is possible to trace chains of interactions across published reading experiments that preclude the assignment of any factors to distinct components (cf. Goldinger, Azuma, Abramson, & Jain, 1997; Van Orden et al., 1996; Van Orden & Paap, 1997). Moreover, recent studies using phonology manipulations have produced more and higher-order interactions among phonology factors, other cognitive variables, and task demands (Azuma & Van Orden, 1997; Berent, 1997; Besner, Stolz, & Boutilier, 1997; Bosman & de Groot, 1996; Cortese, Simpson, & Woolsey, 1997; Farrar, 1998; Ferrand & Grainger, 1996, in press; Frost, Katz, & Bentin, 1987; Gibbs, 1996; Gibbs

& Van Orden, 1998; Goldinger et al., 1997; Gottlob, Goldinger, Stone, & Van Orden, 1999; Jared, 1997; Jared & Seidenberg, 1991; Lupker, Brown, & Colombo, 1997; Rayner, Sereno, Lesch, & Pollatsek, 1995; Stone & Van Orden, 1993; Strain, Patterson, & Seidenberg, 1995; Taft & van Graan, 1998; Tan & Perfetti, 1997; Van Orden et al., 1992; 1999; Xu & Perfetti, 1998; Ziegler et al., 1997a, etc.).

Reliable interactions between phonology factors and task demands make it impossible to decide phonology's role in reading (with respect to modular theories). Interaction could imply that the "common cognitive component" is artifactual, an *ad hoc* product of participation in the laboratory task. The place of artifactual components in intact theory is much like that of mixed or impure cases in cognitive neuropsychology. Potentially artifactual components (interactions with task demands) necessitate exclusionary criteria to discriminate pure reading-task performance from artifactual or "strategic" reading-task performance.

7.3. Exclusionary criteria

One might wish that the task debate could be resolved by new empirical findings, but resolution can only come from exclusionary criteria that unambiguously discriminate task effects from phonology effects. However, recent studies that demonstrate more, and higher-order, interactions, allow more, not fewer, positions within this debate. More positions within the debate yield more contradictory exclusionary criteria, as one laboratory's reading effect becomes another laboratory's task artifact. Exclusionary criteria are sometimes vaguely stated, but several well articulated debates can be tracked in the following articles: for task interactions with word frequency effects compare Balota and Chumbley (1984) with Forster (1989, 1992) and Monsell (1991) and then with Balota (1990); for task demands and homophone errors compare Van Orden (1987) with Jared and Seidenberg (1991) and then with Bosman & de Groot, 1996, and Lesch and Pollatsek (1993); for strategy effects in naming performance compare Baluch and Besner (1991), Buchanan and Besner (1993), and Tabossi and Laghi (1992) with Lupker et al. (1997); for task demands and the phonemic masking effect compare Perfetti, Bell, and Delaney (1988) with Brysbaert and Praet (1992) and Verstaen, Humphreys, Olson, and D'Ydewalle (1995) and then with Xu and Perfetti (1998). As the number of interactions with task demands grows, it becomes incredible to insist that any particular task environment provides a transparent view of reading modules.

No credible modular theory is forthcoming. A complex field of interactions comprises the literature of intact reading performance. Patterns of interaction among cognitive variables are richly and reliably structured, but they do not include the converging, additive, *main effects* that would be consistent with modularity. Most telling of all, these patterns typically change with changes in task demands, they change from task to task, and they change from language to language (Besner & Smith, 1992; Frost, 1998; Katz & Frost, 1992; Lukatela & Turvey, 1998; Perfetti & Tan, 1998). All these changes are, in effect, higher order interactions of pattern, task, and language—higher order interactions that render modular analysis impracticable (Lewontin, 1974; Pachella, 1974; Sternberg, 1969).

7.3.1. Summary.

The cognitive psychology of reading shows no promise that it may someday guide a modular analysis in cognitive neuropsychology. And, insofar as it perpetuates a modular analysis, it shows the same questionable symptoms as cognitive neuropsychology (Gibbs & Van Orden, 1998; Stone & Van Orden, 1993; Van Orden et al., 1990, 1999). Intact reading performance includes fluid accommodation of task demands that contradicts the assertion of static modules, as did the patient studies. Deep dyslexic patients exhibited absent "nonlexical" phonology in a naming task, where it is necessary, but nonlexical phonology reappears in the lexical decision task, where it is optional (Buchanan et al., 1994, 1996; Hildebrandt & Sokol, 1993). Other patients exhibited opposite forms of aphasia under different task demands, and in different tasks (Hofstede & Kolk, 1994; Kolk & Heeschen, 1992; Kolk & Hofstede, 1994; Kolk et al., 1985). Developmental dyslexics showed opposite symptoms of dyslexia in a naming task, where instructions emphasize speed or accuracy (Hendriks & Kolk, 1997). And, finally, the effects of phonology variables (and other variables) can be made to appear and disappear in intact reading with relatively subtle changes in task demands. Paradoxically, were we restricted to a modular perspective, these qualitative interaction effects would motivate context-specific "modules"—highly specialized modules dedicated to the particular conditions of artificial laboratory tasks.

8. Nonlinear dynamics of performance

The problems we uncovered for modularity open the door for an alternative approach, that we describe next. To keep this section short, we present a condensed theoretical overview with citations—footnotes include additional detail and additional references. We begin with measurement. There is no characteristic scale with which to measure reading modules, which explains why no modules were ever reliably measured. An adequate theory of reading must accommodate this fact, and this requires the mathematics of nonlinear dynamical systems.

8.1. Measurement

Modular analyses use task performance—accuracy and response time in a reading task—as a measurement tool. The idea, that task performance is transparent to modular components, requires that task performance provides a characteristic measurement scale. Phenomena that can be measured on characteristic scales are not changed when the measurement tool is changed. The length of a table, measured in centimeters, does not change appreciably if we take a new measurement in millimeters. "Measured" phenomena that cannot be measured on characteristic scales change when the tool is changed. The length of a coastline, measured in kilometers, will increase substantially if measured in meters.

Reading effects are like the coastline. Consider the magnitude of regularity effects, as measured by lexical decision performance. The difference in response time and accuracy, to regular- versus exception-words, consistent- versus inconsistent-words, or ordinary-exception- versus strange-words, will change depending on the nonwords that appear in the lexical decision experiment (Gibbs & Van Orden, 1998; see also Stone & Van Orden, 1993, for the same point concerning frequency effects). As the nonwords become easier to discriminate from the words, the measured effects grow smaller. The same words, in the same task, with participants sampled from the same population, produce large, small, or statistically unreliable effects depending on subtle changes in task demands. Interaction with task demands reflects the more general fact that response time is not a characteristic scale.

It makes sense that response time is not a characteristic scale. Constraints on reading performance are not the static constraints of modules, they change on many different time scales. The language in which an experiment is conducted changes on multiple time scales of cultural evolution. The reading level of a participant changes on multiple time scales of learning and development. The familiarity of a particular word changes on multiple time scales of discourse. Etc. Laboratory constraints also change on multiple time scales. Reading tasks change on the time scales of academic semesters, or scientific careers. Participants' skills in laboratory tasks change on multiple scales, as experiments unfold. Relations among task trials change on the experiment-by-experiment, block-by-block, or trial-by-trial scales of task progression. All of these changes (and many others) implicate changing constraints, on multiple time scales, that combine in real time to determine measurements on the millisecond scale of response time. Constraints that change on multiple time scales imply that no one characteristic time scale exists. It is not possible to give an operational (time independent) definition of a reading module. "The process to be measured changes even as we attempt to measure it." (West & Deering, 1995, p. 29).

8.2. Fractal ambiguity and response selection

Fractal geometry is the geometry of phenomena that have no characteristic scale. Ideal fractal structures are strictly mathematical objects (equivalent patterns are repeated in an infinite nesting of parts and wholes, see Peitgen, Jürgens, & Saupe, 1992). In nature, we observe bounded fractal structure that may resemble mathematical fractals.

Word naming performance is predicted by nested, bi-directional patterns of consistency (ambiguity) among the printed forms of words and their language functions, estimated by sampling the printed corpus of a literate culture.[8] The feed-forward relation between English spelling and phonology has been most fully explored in naming studies, and we use those findings to illustrate the fractal geometry of naming performance.

Consistent and inconsistent relations between spelling and phonology are found in several nested scales, including the relation between graphemes and phonemes, the relation between bodies and rimes, and relation between the whole-word spellings and whole-word pronunciations (Van Orden & Goldinger, 1994). Grapheme-phoneme frequency, body-rime frequency, and word frequency condition these relations, but we do not require that level of detail to introduce the fractal structure.

8.2.1. Grapheme-phoneme ambiguity

The relations between graphemes and phonemes are either consistent or inconsistent across the corpus of printed English. Consonant spellings and consonant phonemes share more consistent relations than vowel spellings and phonemes. Most consonant letters denote one or two phonemes (e.g., C-/k/and C-/s/). Vowels, on the other hand, are grossly ambiguous with respect to phonology. The letter O, for example, occurs in *rod*, *road*, *roof*, *royal*, *rowdy*, and so forth The more inconsistent relations between vowels' spellings and vowels' phonology imply that vowel relations are more slowly resolved, on average, than consonant relations (Van Orden & Goldinger, 1996). Berent and Perfetti (1995) corroborated the slower time course of vowel phonology in word identification experiments. At the scale of graphemes and phonemes, ambiguity is either resolved in consistent grapheme-phoneme relations (for some consonants) or not (for some consonants and all vowels).

8.2.2. Body-rime ambiguity

Vowel ambiguity may be resolved in body-rime relations. At the scale of grapheme-phoneme relations, all English words entail inconsistent relations between vowel spellings and vowel phonology. At the scale of body-rimes (and onset-heads), we again find a pattern of consistent and inconsistent relations. The body-rime relation may or may not resolve the ambiguity in the vowel relation, as body-rime consistent words like DUCK and body-rime inconsistent words like PINT illustrate.

We mentioned a naming study by Kawamoto and Zemblidge (1992), in an earlier section on statistical regularity. They used body-rime inconsistent words, together with changes in task demands, to elicit a nonlinear pattern of responses. Task demands were manipulated by changing the allotted time before a response deadline.[9] The faster response deadline induced regularization errors to inconsistent words such as PINT. More than one systematic response to the same body-rime inconsistent word is a signature of nonlinearity.

Farrar and Van Orden (2001) simulated the previous pattern as a *transcritical bifurcation* in a nonlinear dynamical system (Strogatz, 1994). In the simulated naming of an inconsistent word, the more dominant (or regular) body-rime relation (PINT to rhyme with *mint*) is initially favored by dynamics between spelling and phonology. The spelling body does not activate exclusively the dominant rime; the dominant relation is initially the more stable relation. Constraints in the relation between phonology and semantics, that favor the correct pronunciation, grow stronger over time, however, and eventually stabilize the correct relation between spelling and phonology. The regularized pronunciation exchanges stability with the correct pronunciation at a critical point—the point at which the alternative pronunciations are precisely balanced.[10]

The balance among constraints, that favor one versus the other pronunciation, is a *control parameter*. Values of the control parameter on one side of the critical point come down in favor of the dominant pronunciation, and on the other side they favor the correct pronunciation. In the simulations, the value of this control parameter changed within the time course of a naming trial, and moved through the critical point. In effect, the changing balance of constraints took some time to replace the dominant body-rime with the correct body-rime, which yielded a slower naming-time. This also fits the pattern of regularization errors in a speeded naming task. Naming times for regularization errors are faster on average than correct times. Thus naming performance to inconsistent words is *multistable*—more than one reliable pronunciation occurs to an inconsistent word. Multistability is a nonlinear phenomenon, consonant with the hypothesis of Kawamoto and Zemblidge (1992).[11]

8.2.3. Whole-word ambiguity

Ambiguity at the body-rime scale may be resolved by relations at the whole word scale. At the scale of whole-word spellings and whole-word phonology, we again find a pattern of consistent and inconsistent relations. The whole-word relation may or may not resolve the ambiguity in the body-rime relation (and vowel relation), as in inconsistent words such as PINT versus homograph words such as WIND.

Homographs like WIND have more than one legitimate pronunciation, and thus are multistable. In a naming task, Kawamoto and Zemblidge (1992) presented homographs in which the more familiar pronunciation is the irregular pronunciation, and the less familiar pronunciation is the dominant (regular) pronunciation of the body-rime. Skilled readers produced the dominant pronunciations of homographs with faster naming times than competing, but more familiar (irregular) pronunciations. Kawamoto and Zemblidge also simulated this pattern as a transcritical bifurcation in which the more dominant homograph pronunciation exchanged stability with the more familiar pronunciation at a critical point.

8.2.4. Ambiguity and naming time

Ambiguity at a grapheme-phoneme scale is amplified by ambiguity at the body-rime scale, and is amplified further by ambiguity at the whole word scale—this is the fractal basis of word naming times. Inconsistent (ambiguous) words, as defined by a particular scale of correspondence, appear to be named more slowly than consistent words (defined at the same scale). However, ambiguity does not simply shift the mean of inconsistent words toward slower naming times; ambiguity, at any scale, broadens the naming time distribution. John Holden, a graduate student in psychology at Arizona State University, tested this hypothesis in several ways, for body-rime inconsistency, using data from a replication of Spieler and Balota's (1997) mega-study of word naming (personal communication, April 25, 1999). One conservative test compared variance in naming time to body-rime (and rime-body) consistent words versus inconsistent words, all of which were high-frequency words (≥100 per million). The variance for inconsistent words was reliably greater than that for consistent words (based on a test for differences in variance recommended by Hays, 1974). Holden also found that inconsistent words contribute more data than consistent words to the slow tail (slower than 2.5 SDs from the mean) of a participant's distribution of naming times.

Ambiguity affects the shape of naming time distributions. A naming trial of a particular word, for a particular participant, is determined by the constraints noted earlier (and many others that we have not identified). For example, *language* determines the potential for ambiguity, idiosyncratic *learning* and *development* determine whether a word's body-rime relation is inconsistent for a particular participant on a particular day, *task demands* determine whether particular form-function relations pertain to response selection, and the word on a *previous trial* (and context changing on other time scales) may supply constraints that pertain to a response option, and so forth. Naming time on any particular trial is determined by these and other factors (e.g., the random perturbations that affect all measurements). The values of constraints are distributed through populations of words, participants, and task trials, and combine probabilistically in each sampled naming trial. Consequently, ambiguity changes the probability distribution of naming times. Ambiguity affects naming time by increasing the probability of extreme slow naming times, which broadens the distribution of naming times and exaggerates the slow tail.

Linear statistical analyses assume that data distributions are Gaussian, but response time distributions are never Gaussian (cf. Balota & Spieler, 1999). Raw response time distributions include too many response times slower than three standard deviations from the mean (Ratcliff, 1979; Luce, 1986). Two conventional solutions resolve this dilemma. The most common solution trims off the outliers and assumes that the tails of response time distributions are of little theoretical interest (Ratcliff, 1979; Ulrich & Miller, 1994). But the reviewed examples of body-rime effects and homograph effects have to ban this solution. Our explanation of these phenomena actually emphasizes the fact of outlier data.

The other conventional solution assumes separate, modular, contributions to response time distributions. One module (or set of modules) determines the shape of one or more Gaussian distributions (distributions of automatic "pure" modules), the other module (or set of modules) determines the shape of one or more exponential distributions (distributions of "strategic" processes, compare Balota & Spieler, 1999). All these distributions are convolved into an ex-Gaussian distribution. But response time distributions are not ex-Gaussian. Rather they closely resemble lognormal distributions.[12] (Lognormal distributions appear Gaussian after a logarithmic transformation of response time.) Raw naming time distributions have a lognormal shape which reflects the multiplicative effect of ambiguity (at the nested grain-sizes). Homograph and inconsistent words amplify the effect of vowel ambiguity, causing increased variance and disproportionate growth in the slow tail of the distribution of naming times.

8.3. 1/f Noise

The previous section illustrated how fractal patterns of ambiguity predict the distribution of naming times to words. A fractal geometry is ascribed to the overall pattern of printed languages' nested form-function relations, and a particular word will entail a subset of those relations. This section describes a response phenomenon that resembles *1/f noise*, another fractal object from mathematics.

David Gilden and his colleagues found *1/f noise* in response time data from several cognitive tasks, including a lexical decision task (Gilden, 1997; Gilden, Thornton, & Mallon, 1995). 1/f noise was observed in the residual "error" variance of individual participants' trial-by-trial response times (the variability that remained after the treatment effects were partitioned out). If we graph each residual time, in the trial order of the experiment, the data points oscillate between fast and slow times. The connected data-points form a complex waveform, that may be viewed as a composite of waves that span a wide range of frequencies. 1/f noise is an inverse correlation between the frequency of the composite waves and their power (on a log scale).

The phenomenon of 1/f noise can be difficult to grasp, because it goes against the grain of a typical psychological analysis. Typically, error variance is discarded, rather than analyzed for structure (however, see Kelso, 1995; Mitra, Riley, & Turvey, 1997; Riley, Balasubramaniam, Mitra, & Turvey, 1998; Slifkin & Newell, 1998). In Gilden's data the error variance is analyzed and resembles the mathematically generic pattern of 1/f noise (a fractal structure). 1/f noise is a signature of processes that have no characteristic measurement scale (West & Deering, 1995). It contradicts the conventional logic of partitioning response time into independent sources of variance (modules), as in ANOVA. This practice strictly requires that the response time in each trial is independent of the response time in another trial. The assumption of independence is at the heart of linear statistical models used to discover modules. The presence of 1/f noise contradicts this assumption, because it is defined by long range correlations across response trials. Response time data do not have "joints" that may be separated into modular effects (Gilden, 1997).

8.4. Fractal ambiguity and 1/f behavior

The fractal pattern that predicts nonlinear changes in naming time distributions is a small part of a much larger picture. In the more complete picture, careful attention to the relations among spelling, phonology, and semantics (i.e., contexts of word use, cf. Lakoff, 1987; Landauer & Dumais, 1997; Plaut & Shallice, 1993) may generally explain laboratory performances in reading tasks (for overviews see Bosman & Van Orden, 1997; Kawamoto, 1993; Lukatela & Turvey, 1998; Plaut, 1997; Plaut, McClelland, Seidenberg, & Patterson, 1996; Van Orden & Goldinger, 1994; Van Orden et al., 1990, 1999), including the bizarre naming errors of brain-damaged individuals (Farrar & Van Orden, 2001; Plaut et al., 1996; Plaut & Shallice, 1993; Van Orden et al., 1997a). It may also explain why performance patterns change across languages; because different languages have different patterns of ambiguity among spelling, phonology, and semantics (cf. Frost, 1998; Lukatela & Turvey, 1998; Mattingly, 1992; Perfetti & Tan, 1998; Perfetti & Zhang, 1995; Perfetti et al., 1992).

But what is the relation to 1/f behavior? Response time distributions in reading tasks are lognormal and West and Deering (1995) describe a relation between lognormal distributions and the 1/f distribution, as follows: "As lognormal systems become ever more complex, their distributions become broader, and they take on more of the qualities associated with 1/f behavior." (West & Deering, p. 156). In lognormal systems, the accrual of ". . . subtasks that must be realized for the grand task to be achieved. . . " (p. 158) coincides with an increase in the overlap between the respective data distributions and an inverse power law (1/f) distribution. Task conditions that amplify ambiguity perpetuate disproportionate growth in the slow tails of response time distributions, and increase the overlap between response-time distributions and an inverse power law (1/f) distribution.[13]

We described how ambiguity accrues in the nested relations between spelling and phonology, and the effects are multiplicative. We also proposed that reading performance, in general, reflects the resolution of ambiguity that pertains to response selection (Gibbs & Van Orden, 1998; Kawamoto, 1993; Van Orden & Goldinger, 1994; Van Orden et al., 1990, 1999).[14] In line with this hypothesis, we propose that the accrual of functional ambiguity is one of source of l/f behavior affecting the shape of response time distributions. A different picture of l/f behavior comes from trial-by-trial fluctuations in response times. The relation between these two different pictures is the current focus of our research.

8.4.1. Summary

Reading performances—measurements of behavior attendant on reading—motivate a cognitive systems approach, based on the mathematics of nonlinear dynamical systems. This approach requires neither a characteristic scale of measurement, nor a reduction to modular components. Analyses of nonlinear systems accept that performance is contextually situated, and morphological reduction is impracticable (Abraham & Shaw, 1992; Cohen & Stewart, 1994; Freeman, 1995; Goodwin, 1994; Kauffman, 1995; Stewart & Cohen, 1997). Naturally, we are reminded that working hypotheses are promissory notes for loans on credibility; their proof is in the payoff (Carello, Turvey, & Lukatela, 1992).

9. General conclusions

Brain lesions are obviously located inside the head, and clearly there is some real sense in which the body and its nervous system are in between a stimulus and a response. The body is an excitable medium upon which proximal stimulation and muscle contractions attend, for example (compare Freeman, 1995; Goodwin, 1994; Kelso, 1995; Turvey & Fitzpatrick, 1993). The issue is not whether this is true, but whether modularity's interpretation of "in between" provided a useful perspective from which to develop a theory of reading performance. If we cannot reliably individuate intermediate, causal, modular contributions to reading performance, then it may pay to consider alternative metaphors concerning cause and behavior (compare Riley & Turvey, 1999). In previous sections, we discussed why no credible modular theory of intact reading may be forthcoming, and we introduced an alternative metaphor for naming performance. The primary value of our critique, however, is what it reveals about the modular approach to reading, and what it may imply for modularity in general.

It was inevitable that brain damage would doubly dissociate reading modules. However, the theoretical implications of double dissociations rely on modularity being true. We question the utility and practicability of assuming modularity, as it concerns the double dissociation of reading modules. The pursuit of reading modules in cognitive neuropsychology reveals two general problems. First, modularity fails to converge on a fixed set of exclusionary criteria that define pure case dissociations. Thus competing theories can force endless pursuits of purer cases, which merely perpetuate growth in the list of exclusionary criteria. Second, and partly as a consequence, modularity fails to limit the potential set of pure case dissociations, which perpetuates fractionation into ever more modules.

Modularity fails to demonstrate the utility we expect from a scientific research program. Modularity fails to reduce reading performance to any causal component (module, representation, rule, etc.) upon which we can rely. Our colleague, Bill Uttal, has made a persuasive and general case against modular reduction of behavior (Uttal, 1998, 2000). If his argument holds, then our pragmatic concerns, that modularity fails to converge on a common understanding of modules, should extend to other topic areas in psychology. So far, such failures have been noted for functional neuroimaging (Poeppel, 1997; Van Orden & Paap, 1997; Weldon, 1999), perception (Uttal, 1990, 1997), memory (Weldon, 1999), and development (Thelen & Smith, 1994).

Notes

1. Teuber (1955) mentioned the danger of equating symptoms with functions, and Weiskrantz (1968) mentioned the problem of ". . . reifying a dissociation between tests into a dissociation between functions" (p. 419). These warnings parallel a concern of Hughlings Jackson stated in 1864: "To locate the damage which destroys speech and to localize speech are two different things." (cited in Head, 1926, p. 50). Also, Weiskrantz argued that a double dissociation does not sufficiently demonstrate that different lesions have qualitatively different effects. Lesions may differ in their effects on resources, for example. If the performance/resource function for each task has an inverted U-shape (like the Yerkes-Dodson law), and they are not identical, then a quantitative difference in the effects of two lesions could yield the pattern of a double dissociation (cf. Dunn & Kirsner, 1988). Double dissociations due to quantitative differences do not justify the inference of causally separate components. Shallice (1979) claimed that double dissociations avoid the possible confound of a resource artifact, and presented performance/resource functions to make this case. However, unlike Weiskrantz, he assumed that these functions would be monotonic (e.g., not inverted U-shaped). Consequently, his argument depends critically on the shape of performance/resource functions. Shallice later acknowledged this point in his 1988 book (see footnote on p. 233).
2. Writing requires its own dual process theory (see Rapp & Caramazza, 1997a, for an overview). Patient studies dissociate a spelling module particular to familiar words (compare to lexical naming), and a spelling module particular to unfamiliar words (compare to nonlexical naming). These modules include amodal spelling representations (that may be common to reading), modality specific spelling representations (to accommodate the dissociation of oral and written spelling), effector-independent motoric representations of the component strokes from which letters are constructed (to accommodate the dissociation of letter naming from letter writing), and, perhaps, effector-specific representations of the component strokes (to accommodate a dissociation of right-hand writing from left-hand writing, cf. Zesiger, Pegna, & Rilliet, 1994).
3. One reviewer agreed that control participants often perform poorly at pseudoword naming and wondered whether pervasive "sight reading" instruction contributes to this problem. We do not know of a definitive study, but children who receive phonics instruction can name more novel words than children who receive sight reading instruction (see Jorm & Share, 1983, for a review). Additionally, Johnston and Thompson (1989) found a difference in pseudohomophone (e.g., BLUD) naming between 8-year-old sight readers and phonics readers who were matched for word reading. Sight readers produce a smaller proportion of word-pronunciations to pseudohomophone items that they had previously identified as "sounding like words."
4. Max Coltheart agreed to be identified as the reviewer. We are very grateful for his thoughtful critical review.
5. Consider a hypothetical patient GOS and the first of the reviewer's counterfactual double dissociations. This example already includes an existing dissociation (intact

regular word naming with impaired exception word naming is the pattern of surface dyslexia). But what about the opposite counterfactual dissociation? Assume that a researcher has found a patient GOS. GOS exhibits relatively intact exception word (PINT) naming, but relatively impaired naming of regular words (MINT) and pseudowords (BINT). It would be easy to overlook that GOS is a pure case. There is a strong asymmetry in the distribution of exception and regular words that contributes to this dissociation. Exception words are over-represented at the high end of the frequency spectrum. GOS's relative advantage in naming exception words over regular words could be attributed to this linguistic asymmetry. High frequency words are less vulnerable to trauma (Ellis, Miller, & Sin, 1983; Patterson & Shewell, 1987). Accepting dual process theory as the criterion for selecting pure cases, we may classify GOS as an impure case. As a result, it is unlikely that a case study of GOS would appear in the published literature.

6. Consider another of the reviewer's counterfactual cases. A fictitious patient GVO correctly names exception words (PINT), but cannot name regular words (MINT). Assume that we have adequately dismissed the frequency confound mentioned in the previous footnote. Can we now produce a more refined version of dual process theory consistent with GVO? Suppose that the development of lexical naming is different for regular than for exception words. Assembled nonlexical phonology, based on general GPC rules, governs novice readers' performance (Doctor & Coltheart, 1980). For regular (MINT) words, development of lexical naming rewrites the general GPC rules as automated lexical rules. Subword rules still govern skilled naming of regular words, but they are specific word-applicable copies of these rules. Each regular word's rules are rewritten at its lexical entry where they function like automatic associations. Parsimony actually recommends this account because skilled regular-word naming is built directly out of unskilled regular-word naming (Frost, 1998). However, it cannot work for exception words. Exception words require a separate, case by case, mechanism. This mechanism must store each idiosyncratic exception pronunciation at its lexical entry (Coltheart, 1978; Doctor & Coltheart, 1980). Given two different developmental processes, we may hypothesize separate brain mechanisms in the two cases. Separate brain mechanisms may be doubly dissociated. Thus, the fictitious case of GVO may reasonably participate in the counterfactual double dissociation of exception word naming versus regular word naming.

A refinement on the previous account accommodates the reviewer's, second, counterfactual, double dissociation: A double dissociation of regular word naming versus pseudoword naming. A fictitious patient BFP correctly names pseudowords but not regular words. Pseudowords require nonlexical assembly. Regular words are named via automatic rules written in the lexicon (as noted for GVO). A prelexical spelling check, or familiarity check, directs traffic through these processes. The prelexical familiarity check develops to distinguish familiar word-spellings from relatively unfamiliar word- or pseudoword-spellings. It makes possible direct access to lexical sources of naming (cf. Bosman & de Groot, 1996), which streamlines pronunciation of well learned regular words. Just such a familiarity check was proposed to explain a dissociation between performance to word homophones

(BEATS) versus pseudohomophones (SLEAT) (V. Coltheart, Avons, Masterson, & Laxon, 1991; and compare Carr, Posner, Pollatsek, & Snyder, 1979; Reichle, Pollatsek, Fisher, & Rayner, 1998). Given the previous mechanisms, lesions may selectively damage the lexical representations of regular words. Subsequently, the prelexical check would send processing of familiar regular words down a dead end, but naming of pseudowords would be preserved. However, if the lesions had selectively damaged nonlexical naming, then the prelexical check sends processing of pseudowords to a dead end, although lexical naming of familiar regular words would be relatively preserved. We do not propose that any of these fantasy components actually exist. Our point is that these refinements are no different in principle than that inspired by the case of MP.

7. Dissociation method is a subtractive method. Compare our discussion of modular analysis with Pachella's (1974) discussion of the subtractive method applied in reaction time studies of intact cognition:

   > . . . the Subtraction Method begs one of the most fundamental questions underlying information-processing research, namely, the description of the mental events involved in an experimental task. The starting point for the application of the method is a relatively sophisticated one: In order to construct a comparison task, one must already know the sequence of events that transpire between stimulus and response. Such sophisticated knowledge is rarely available. Rather, it is more often the case that the structure of mental events is presented with only logical or intuitive (as opposed to empirical) justification. Obviously, the conclusions reached on the basis of the application of the method can then be no stronger than the substantiation of the initial conceptualization of the experimental task. (p. 47).

8. To acquire reading skill is to become attuned to constraints that are inherent in a literary environment (cf. E. Gibson, 1969, 1991). Skilled reading performance (Van Orden & Goldinger, 1994), like other performances, may directly refer to goal-relevant constraints in the environment (compare Bernstein, 1967; Brunswik, 1955; Flach & Holden, 1998; J. Gibson, 1979/1986; Kelso, 1995; Looren de Jong, 1997; Mandler, 1997; Merleau-Ponty, 1962, 1942/1963; Putnam, 1994; Rasmussen, 1986; Ray & Delprato, 1989; Saltzman & Kelso, 1987; Shanon, 1993; Shaw & Turvey, 1981; Thelen, 1995a, 1995b; Thelen & Smith, 1994; Turvey & Carello, 1981, 1995; Varela, Thompson, & Rosch, 1991; Vincente & Wang, 1998).
9. Task demands delimit the boundary conditions of task performance (Shaw, Kadar, Sim & Repperger, 1992). A naming task limits participants to spoken responses. The target word, on a particular trial, further limits spoken responses to those consonant with the target's spelling. All constraints work to limit response options (cf. Sternberg, 1969). Demand characteristics of the task environment causally intertwine with cognitive constraints to limit the degrees of freedom in the behavior of a task participant. In this way, a college sophomore, or a brain damaged individual, becomes a *model system*—a "naming device," a "lexical decision device," or a "categorization device" (compare Haken, 1988; Turvey, 1990; Turvey & Carello, 1995). Van Orden

et al. (1999) describe how cognitive constraints and task constraints may combine to set the value of a control parameter in the model system of categorization performance.

10. Farrar and Van Orden (2001) used the same model to simulate patterns of dissociations and double dissociations (see also Van Orden et al., 1997a; Van Orden, Bosman, Goldinger, & Farrar, 1997). Five simulations mimicked benchmark phenomena of intact and dyslexic word naming. Initially, a "neural" network (simulated as an iterative map) was tuned to generate attractor pronunciations similar to intact naming. Subsequently, two model parameters were changed to produce the regularization error of surface dyslexia (e.g., PINT is pronounced to rhyme with MINT), "absent" pseudoword naming of phonological dyslexia (e.g., words can be correctly named, but not pseudowords like BINT), the semantic error of deep dyslexia (e.g., BUSH is named as /tree/), and a dissociation in picture naming between spoken responses versus written responses (e.g., the model's spoken response is /tree/ to a picture of a *bush*, but its written response is BUSH—cf. Hanley, & McDonnell, 1997; Miceli, Benvegnù, Capasso, & Caramazza, 1997; Rapp, Benzing, & Caramazza, 1997; Shelton & Weinrich, 1997).

    Any trajectory through a model system's state space may be simulated using an iterative function or map (cf. Newell, 1990). Iterative maps take their output at time *t* as input at time $t + 1$; they map the present state of a system into its next future state. (See Peitgen et al., [1992], for a general introduction to iterative models, and note that both Turing machines and recurrent "neural" networks are classes of iterative functions.) At the appropriate level of abstraction, iterative functions may yield summary control parameters (Farmer, 1990; Saltzman & Munhall, 1992). In recurrent network models, for example, it is typical for interactive activation to include a mix of constraints that favor competing performance options (McClelland & Rumelhart, 1981; Kawamoto & Zemblidge, 1992). Ratios of competing constraints are the hypothetical control parameters of the model system, which determine the stability of performance options.

    The simulated naming errors derived from multistable patterns of interdependent, node-activation values (Farrar & Van Orden, 2001). For example, to simulate regularization errors, connection weights between phonology and semantic nodes were gradually reduced en masse. This changed the balance among all constraints in the model and, at a critical point, induced a transcritical bifurcation. At the bifurcation point, PINT's correct pronunciation exchanged stability with its regularized pronunciation. The model subsequently produced regularization errors.

11. Even more detail is known about the time course of these effects. Apparently, the body-rime relation is only finally resolved during the pronunciation of onsets, the duration of pronounced onsets is longer for body-rime inconsistent words than for consistent words (Kawamoto, Kello, Jones, & Bame, 1998). Moreover, additional sources of constraint that may favor the correct pronunciation, such has high word-frequency (Kawamoto, Kello, Higareda, & Vu, 1999) or semantic priming (Kawamoto, Goeltz, Abgayani, & Groel, 1998), shorten the duration of onset pronunciations.

12. Ideal ex-Gaussian and lognormal distributions differ in their hazard functions (Luce,

1986). Ex-Gaussian distributions have monotonically increasing hazard functions. Hazard functions of lognormal distributions are nonmonotonic; they first increase and then decrease. Estimated hazard functions of response-time distributions are also nonmonotonic (Luce, 1986; Townsend & Ashby, 1983; Ulrich & Miller, 1993).

13. This hypothesis was fleshed out in conversations with John (Jay) Holden and David Gilden. Also note our debt to West and Deering (1995). Our hypothesis merely substitutes "ambiguity that must be resolved" for "subtasks that must be realized," and "selection of response option" for "grand task to be achieved" in the quoted passage.
14. Lexical decisions are a special case of familiarity judgments. Lewenstein and Nowak (1989a, 1989b) describe general models of recognition performance in which the response options—*familiar* versus *unfamiliar*—are soft-assembled (i.e., an emergent product of self-organization in a dynamical system, see also Skarda & Freeman, 1987; Vallacher & Nowak, 1997). *Familiar* responses in a recognition task correspond to a more-ordered attractor state of the model system; *unfamiliar* responses correspond to a less-ordered state. Gibbs and Van Orden (1998) and Van Orden and Goldinger (1994) discuss soft-assembly of lexical decision performance in similar terms, as the resolution of functional ambiguity ending in more-ordered (*word*) versus less-ordered (*nonword*) attractor states. Please consult these articles for details.

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Appendix A

Not all cognitive neuropsychologists believe double dissociations are the best evidence for cognitive modules. This Appendix briefly reviews the debate. The question at issue is what may count as evidence in a modular analysis?

Traditionally, the facts of neuropsychology pertained to pure syndromes—for example, agrammatism, deep dyslexia, short-term-memory syndrome, and so forth Syndromes are established in patient-group studies. Patients in a syndrome-group share lesions in approximately the same locations and satisfy the exclusionary criteria that define the syndrome. To test functional hypotheses concerning the syndrome, a patient-group's average performance in a cognitive task is subtracted from a control-group's average performance. A statistically reliable difference isolates missing performance associated with the missing module. In turn, the dissociation corroborates the syndrome and its causal locus at the shared lesion cite.

Ultracognitive neuropsychologists demonstrated that patient-group studies are unreliable. The traditional analysis properly emphasized convergence across many patients. Unfortunately, statistical reliability does not insure convergence across a patient group. The outcomes of statistical tests do not reliably establish that the patients in a group share a specific deficit. McCloskey (1993) described this problem inherent to quasi-experimental design. A traditional cognitive neuropsychologist relies on statistical analyses to establish homogeneity across the patient group. However, the group must have been homogeneous to begin with to justify the statistical analysis. A priori homogeneity insures that uncontrolled patient variability is not due to meaningful differences among the patients. Homogeneity of cognitive architectures is also a necessary a priori assumption for group-studies of intact performance, but patients' "architectures" are not intact.

McCloskey (1993) used the following hypothetical patient-group study to illustrate the problem (and Berndt, 1997a, corroborated the essential point in actual patient studies.) Suppose that 40% of a patient-group truly share an underlying deficit, and an additional 30% of the patient-group produce the apparent performance deficit due to sampling variability. The consequent statistically reliable effect is spurious. It is not true for the whole group. It is not even true for the majority of the group. Exclusionary criteria, applied patient by patient, are hypothesized to insure homogeneity across a patient group. However, any additional manipulated variable steps outside what is known about those patients (McCloskey, 1993). The preexisting criteria define an epistemic sphere, but that sphere does not yet include the novel manipulated variable. Each novel manipulation is an untested exclusionary criterion, insofar as homogeneity is concerned. A reliable manipulation should be so reliable that it could serve as a criterion for group membership. If not, then the group is not homogeneous with respect to the effect of the manipulation.

McCloskey (1993) used a parallel thought experiment to discount associations among patients in group studies. Assume again that 40% of the patient-group share a functional deficit that is spuriously generalized to the whole group. A different 40% of the same patient-group share a different functional deficit. Again 70% of the patients produce one, or the other, or both performance deficits, due to sampling variability. Now we are confronted with a spurious association of deficits. No single patient actually has both functional deficits.

Shallice conceded Caramazza's (1986) and McCloskey's (1993) ultracognitivist point that ". . . group studies [are] not likely to lead to rapid theoretical advance and that, in general, information about the localization of lesions is not vital for cognitive neuropsychology." (pp. 214–215). He does not concede this in principle, but as a practical matter. Shallice then takes the argument a step further. He points out that associations among symptoms are never trustworthy, not even in the same patient. Apparent associations of symptoms may always be due to concurrent damage in two separate modules, or damage in an unknown third module that conditions the outputs of the primary modules, and so forth The overarching problem comes from two sources: The problem of induction (no matter how many white swans you have seen, the next one may be black), and the problem of attributing cause within a correlation. There is no guarantee that today's association of functions will not be tomorrow's dissociation or double dissociation. Shallice (1988) correctly recognizes that the reliability of modular analysis rests on the reliability of pure case dissociations.

Shallice (1988) worries that the ultracognitive approach has paid too little attention to the general clinical aspects of a patient's behavior. It is thus too ". . . easy to select a patient with a mixed syndrome—a 'multicomponent' disorder—and to generalize from some particular quirk in the patient's behavior, some consequence of the interaction of multiple deficits, to some invalid abstract conclusion." (p. 215). Every case of brain damage includes idiosyncratic 'quirky' performance. Most idiosyncrasies are so particular that no one bothers to offer an explanation. Consider Broca's famous patient who could only say /tan/. Dissociation logic, by itself, suggests a preserved basis for /tan/ (or selective absence of /tan/). But, to our knowledge, no one has yet assigned the brain a /tan/ module or, more precisely, an output module unique to /tan/ production. The /tan/ module may seem unacceptably singular, but such quirky components can only be ruled out by exclusionary criteria.

Reliable evidence depends upon reliable exclusionary criteria to distinguish it from unreliable evidence. But ultracognitive neuropsychology ". . . is concerned principally with the logic of theory testing—that is, selecting among well-articulated theories by using existing observations on a set of extensively studied patients. However, what is at least as critical for neuropsychology is how to select patients and make observations on patients to produce the best chance of developing valid theories and avoiding invalid ones. [The ultracognitive] approach offers no guidance in this respect" (Shallice, 1988, p. 218). Shallice's (1988) critical assessment of the ultracognitive approach is correct; ultracognitive neuropsychology gives inadequate guidance concerning what may count as reliable evidence.

So what are the facts of contemporary neuropsychology? There is no single answer. As noted, traditional neuropsychologists established syndromes through shared lesion sites and exclusionary criteria. Functional hypotheses were tested in patient-group studies against both associations and dissociations of symptoms. This approach never converged, however. Shallice (1988) described several empirical deadends that came from applying unreliable exclusionary criteria, such as selecting patients according to their etiology. Nevertheless, Shimamura and his colleagues remain committed to lesion site criteria and patient-group studies, but emphasize strong dissociations and double dissociations (Shimamura, 1990, 1993; Robertson et al., 1993). Caramazza (1986), on the other hand, dispenses with lesion site criteria and patient-group studies altogether, gives associations and dissociations equal status, and attributes no special status to a double dissociation. Shallice also dispenses with lesion site criteria, patient-group studies, and adds associations of function to the list of unreliable evidence. He relies instead upon pure case dissociations and double dissociations: "The bedrock of the approach. . . should be the double dissociation." (p. 264).

Appendix B

B.1. Participants

AZ and BX both satisfy traditional criteria for developmental dyslexia. These criteria include a self-reported history of chronic reading and spelling problems and a significant discrepancy between IQ and performance on reading and spelling achievement tests. At time of testing, AZ was 25 years of age. She described her occupation as housewife. AZ is right handed, her IQ measured 107, she had 13.9 years of formal education, and she showed no positive signs of neurological or psychiatric problems. She also showed no signs of sensory problems other than wearing glasses since her first year of school. At time of testing, BX was a salesman, 31 years of age. BX exhibited mixed handedness, his IQ measured 107, he had 16.9 years of formal education, and showed no positive signs of neurological, psychiatric, or sensory problems.

B.2. Procedure for the naming task

Each trial of the naming task presented a participant with a single word or pseudoword in upper-case letters on the monitor of an Apple computer. A trial began with a ready signal (READY) that appeared until the participant pressed the space bar of a standard computer keyboard. READY was replaced in turn by a fixation stimulus (+) centered on the forthcoming target stimulus. The "+" remained visible for 500 ms and was replaced by the target stimulus. The target stimulus remained visible until the participant responded. READY appeared again 50 ms after a participant's response, signaling the next trial.

B.3. Dissociation of visual processing

Participants' performance on a visual task, other than pseudoword naming, may dissociate visual processing from their deficit in pseudoword naming. In this visual task, participants name line drawings from Snodgrass and Vanderwart (1978). Both AZ and BX scored close to ceiling on accuracy (96% and 100%, respectively). AZ's mean response time on this task was 1153 ms. This mean RT is slower than the corresponding RTs of comparable *chronological age* control participants from Pennington et al. (1990). Only three of twelve chronological-age control participants had mean RTs greater than 900 ms and none had mean RTs greater than 1100 ms. However, six of twelve *reading age* control participants from Pennington et al. (1990) had mean RTs greater than 1100 ms. (The reading-age control participants are much younger readers whose scores on a standardized measure of reading ability are comparable to those of AZ and BX, see Pennington et al., 1990, for details.) BX's mean response time on this task was 600 ms, faster than the overall mean (731 ms) of chronological-age control participants. This measure of visual processing is not the same as that used in typical studies of acquired dyslexia, but it shows that AZ and BX, like the vast majority of developmental dyslexics, do not suffer from a visual deficit (cf. Vellutino, 1979).

B.4. Dissociation of auditory/articulatory processing

A different task estimated participants' repetition ability. The repetition task was adapted from Brady, Shankweiler, and Mann (1983). Participants heard a word or pseudoword that was either presented clearly in quiet, or presented less clearly in "white noise" (see Pennington et al., 1990, for details). The task was to repeat the stimulus; accuracy was the dependent variable. AZ and BX correctly repeated 96% and 100%, respectively, of words presented in quiet. The comparable aggregate mean for chronological-age controls was 98%, and for reading-age controls it was 97% (from Pennington et al., 1990). AZ and BX correctly repeated 92% and 79%, respectively, of pseudowords presented in quiet. The comparable aggregate mean for chronological-age controls was 83%, and it was 72% for reading-age controls. AZ and BX correctly repeated 71% and 50%, respectively, of words presented in noise. The aggregate mean for chronological-age controls was 61%, and it was 50% for reading-age controls. AZ and BX correctly repeated 67% and 50%, respectively, of the pseudowords presented in noise. The aggregate mean for chronological-age controls was 41%, and it was 32% for reading-age controls. The performance of AZ and BX on this task is as expected for people of their age or reading experience. They did not show any indication of an auditory/articulatory deficit.

Appendix C

C.1. Participants

Five acquired dyslexic men—AK, BJ, CR, DC, and EG—ranging in age between 50 and 72 participated in these case studies. All of these men were stroke patients who had been diagnosed as having reading deficits by a speech pathologist. Their reading levels were estimated using word-recognition scores from the Peabody Individual Achievement Test (PIAT). Their respective grade-equivalent scores were 5.6 (AK), 10.3 (BJ), 6.6 (CR), 5.0 (DC), and 12.9 (EG). The PIAT grade-equivalent scores for patients BJ and EG might be expected for some adults (grade-equivalent scores of 10.3 and 12.9 would, approximately, span high school level reading), but they are low relative to these patients' pretrauma conditions. These are both college educated men whose work (they reported) required significant amounts of reading. (BJ is a retired lieutenant colonel and EG is a retired mathematics teacher.) Also, both reported that they enjoyed reading as a hobby prior to their stroke.

The men who participated in our studies are not pure cases. Our concern was whether statistical regularity affects performance of patients who make naming errors, not whether the errors come from patients who are pure cases. The criterion for participation was that a patient was known to make naming errors when reading aloud, and their performance upon the word recognition portion of the PIAT fell below that expected for their age, education, and reading history. The patients were recommended to us by Gary Barnes at the San Diego VA hospital.

We hoped that the foregoing exclusionary criteria would be relatively free of the a priori assumptions of any particular account of skilled reading. Some of our manipulations entail hypotheses that contradict GPC regularity. Consequently, the criteria for entry into the study needed to be free of assumptions specific to the GPC account. The above criteria were relatively neutral with respect to the regularity hypotheses in question, but they are also relatively blind to other deficits these participants may exhibit (e.g., we were not concerned at that time with deficits in sentence comprehension, but see Patterson & Hodges, 1992).

C.2. Stimuli and procedure

Our method tested for naming errors to letter-strings chosen to reflect several regularity hypotheses. Control is achieved between stimulus types, and hypotheses are tested within each participant's data. We asked participants to name typed, upper-case, word and pseudoword letter-strings presented individually on three-by-five cards. The order of presentation was either a "forward" or "backward" version of a fixed random order. A constraint on this random order was that stimuli from the respective experimental conditions were approximately evenly distributed throughout the deck of cards. Participants were informed that they could respond "I don't know" on any trial, and they could quit at any time if a task became tiresome.

The nonwords from Glushko (1979) and Rosson (1985) were presented in separate decks. The amalgam of word stimuli from Coltheart et al., (1979), Andrews (1982), and Rosson (1985) were presented in two decks of cards corresponding to two blocks of trials. The word stimuli from the cited publications are slightly redundant. Of 208 words total, six words figured in more than one of the reported contrasts, but these six words were presented only once in our study. The Rosson (1985) and Andrews (1982) word sets shared the word DESK. DESK served as a consistent, high-frequency, regular word in Andrews (1982) and a strong-rule, high-frequency word in Rosson (1985). The Coltheart et al. (1979) and Andrews (1982) word sets shared five words. LOVE, LOSE, and MOVE served as inconsistent, high-frequency, exception words in Andrews (1982) and as exception words in Coltheart et al. (1979). SAVE appeared as an inconsistent, high-frequency, regular word in Andrews (1982), and as a regular word in Coltheart et al. (1979). PINT was an inconsistent, high-frequency, exception word in Andrews (1982), and an exception word in Coltheart et al. (1979).

Appendix D

Number of Andrews' (1982) words named correctly. Each cell of the design contains a total of nine words. C = consistent, I = inconsistent, H = hi-frequency, L = low-frequency, R = GPC regular, E = GPC exception.

	AK	BJ	CR	DC	EG	Cell means
CHR	8	8	7	8	9	8
CHE	9	8	8	9	8	8
CLR	8	8	8	9	7	8
CLE	7	8	9	7	8	8
IHR	7	7	7	7	9	7
IHE	7	8	8	8	9	8
ILR	6	6	7	8	9	7
ILE	4	7	7	8	8	7

Number of Rosson's (1985) words named correctly. Each cell contains 14 words S = strong rule, W = weak rule, H = hi-frequency, L = low-frequency.

	AK	BJ	CR	DC	EG	Cell means
SH	9	13	12	14	14	12
SL	4	9	12	12	14	10
WH	7	12	10	13	14	11
WL	4	5	11	8	11	8

Number of Rosson's (1985) pseudowords named correctly. Each cell contains 15 pseudowords. S = strong rule, W = weak rule. N = neighbor exists, X = neighbor does not exist.

	CR	DC	EG
SN	4	5	13
SX	10	4	10
WN	3	4	12
WX	5	1	11

References

Abraham, R. H., & Shaw, C. D. (1992). *Dynamics: the geometry of behavior*. Redwood City, CA: Addison-Wesley.

Andrews, S. (1982). Phonological recoding: is the regularity effect consistent? *Memory & Cognition, 10,* 565–575.

Azuma, T., & Van Orden, G. C. (1997). Why SAFE is better than FAST: the relatedness of a word's meanings affects lexical decision times. *Journal of Memory and Language, 36,* 484–504.

Badecker, W., & Caramazza, A. (1986). A final brief in the case against agrammatism: the role of theory in the selection of data. *Cognition*, *24,* 277–282.

Balota, D. A. (1990). The role of meaning in word recognition. In D. A. Balota, G. B. Flores d' Arcais, & K. Rayner (Eds.), *Comprehension processes in reading* (pp. 9–32). Hillsdale, NJ: Erlbaum.

Balota, D. A., & Chumbley, J. I. (1984). Are lexical decisions a good measure of lexical access? The role of word frequency in the decision stage. *Journal of Experimental Psychology: Human Perception and Performance, 10,* 340–357.

Baluch, B., & Besner, D. (1991). Visual word recognition: evidence for strategic control of lexical and nonlexical routines in oral reading. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 17,* 644–652.

Baron, J., & Strawson, C. (1976). Use of orthographic and word-specific knowledge in reading words aloud. *Journal of Experimental Psychology: Human Perception and Performance, 2,* 386–393.

Barry, C., & Richardson, J. T. E. (1988). Accounts of oral reading in deep dyslexia. In H. A. Whitaker (Ed.), *Phonological processes and brain mechanisms* (pp. 118–171). New York: Springer-Verlag.

Berent, I. (1997). Phonological effects in the lexical decision task: regularity effects are not necessary evidence for assembly. *Journal of Experimental Psychology: Human Perception and Performance, 23,* 1–16.

Balota, D. A., & Spieler, D. H. (1999). Word frequency, repetition, and lexicality effects in word recognition tasks: beyond measures of central tendency. *Journal of Experimental Psychology: General, 128,* 32–55.

Bates, E., Wulfeck, B., & MacWhinney, B. (1991). Cross-linguistic research in aphasia: an overview. *Brain and Language, 41,* 123–148.

Bauer, D. W., & Stanovich, K. E. (1980). Lexical access and the spelling-to-sound regularity effect. *Memory & Cognition, 8,* 424–432.

Beauvois, M. R., & Derousné, J. (1979). Phonological alexia: three dissociations. *Journal of Neurology, Neurosurgery and Psychiatry, 42,* 1115–1124.

Berndt, R. S., Haendiges, A. N., Mitchum, C. C., & Sandson, J. (1997a). Verb retrieval in aphasia 2. Relationship to sentence processing. *Brain and Language, 56,* 107–137.

Berndt, R. S., Mitchum, C. C., Haendiges, A. N., & Sandson, J. (1997b). Verb retrieval in aphasia 1. Characterizing single word impairments. *Brain and Language, 56,* 68–106.

Bernstein, N. (1967). *The coordination and regulation of movements*. London: Pergamon.

Besner, D., & Smith, M. C. (1992). Basic processes in reading: is the orthographic depth hypothesis sinking? In R. Frost & L. Katz (Eds.), *Orthography, phonology, morphology, and meaning* (pp. 45–66). Amsterdam: Elsevier.

Besner, D., Stolz, J. A., & Boutilier, C. (1997). The Stroop effect and the myth of automaticity. *Psychonomic Bulletin & Review, 4,* 221–225.

Black, M., & Byng, S. (1986). Prosodic constraints on lexical access in reading. *Cognitive Neuropsychology, 3,* 369–409.

Black, M., & Byng, S. (1989). Re-stressing prosody: a reply to Cutler, Howard, and Patterson. *Cognitive Neuropsychology, 6,* 85–92.

Blonder, L. X., Bowers, D., & Heilman, K. M. (1991). The role of the right hemisphere in emotional communication. *Brain, 114,* 1115–1127.

Bosman, A. M. T., & de Groot, A. M. B. (1996). Phonologic mediation is fundamental to reading: evidence from beginning readers. *Quarterly Journal of Experimental Psychology, 49A,* 715–744.

Bosman, A. M. T., & Van Orden, G. C. (1997). Why spelling is more difficult than reading. In C. A. Perfetti, L. Rieben, & M. Fayol (Eds.), *Learning to spell* (pp. 173–194). Mahwah, NJ: Erlbaum.

Brady, S., Shankweiler, D., & Mann, V. (1983). Speech perception and memory coding in relation to reading ability. *Journal of Experimental Child Psychology, 35,* 345–367.

Brédart, S., Brennen, T., & Valentine, T. (1997). Dissociations between the processing of proper and common names. *Cognitive Neuropsychology, 14,* 209–217.

Brunswik, E. (1955). Representative design and probabilistic theory in a functional psychology. *Psychological Review, 62,* 193–217.

Bryant, P., & Impey, L. (1986). The similarities between normal readers and developmental and acquired dyslexics. *Cognition, 24,* 121–137.

Brysbaert, M., & Praet, C. (1992). Reading isolated words: no evidence for automatic incorporation of the phonetic code. *Psychological Research, 54,* 91–102.

Bub, D., Cancelliere, A., & Kertesz, A. (1985). Whole-word and analytic translation of spelling to sound in a non-semantic reader. In K. E. Patterson, J. C. Marshall, & M. Coltheart (Eds.), *Surface dyslexia: neuropsychological and cognitive studies of phonological reading* (pp. 15–34). Hillsdale, NJ: LEA.

Buchanan, L., & Besner, D. (1993). Reading aloud: evidence for the use of a whole word nonsemantic pathway. *Canadian Journal of Experimental Psychology, 47,* 133–152.

Buchanan, L., Hildebrandt, N., & MacKinnon, G. E. (1994). Phonological processing in deep dyslexia: a ROWSE is implicitly a ROSE. *Journal of Neurolinguistics, 8,* 163–181.

Buchanan, L., Hildebrandt, N., & MacKinnon, G. E. (1996). Phonological processing of nonwords in deep dyslexia: typical and independent? *Journal of Neurolinguistics, 9,* 113–133.

Campbell, R. (1991). The importance of special cases: or how the deaf might be, but are not, phonological dyslexics. *Mind and Language, 6,* 107–112.

Campbell, R., & Butterworth, B. (1985). Phonological dyslexia in a highly literate subject. *Quarterly Journal of Experimental Psychology, 37A,* 435–475.

Caplan, D. (1991). Potential pitfalls in neuropsychological studies: the case of short-term memory. *Behavioral and Brain Sciences, 14,* 443–444.

Caramazza, A. (1986). On drawing inferences about the structure of normal cognitive systems from the analysis of patterns of impaired performance: the case for single-patient studies. *Brain and Cognition, 5,* 41–66.

Caramazza, A., & Hillis, A. (1991). Lexical organization of nouns and verbs in brain. *Nature, 349,* 788–790.

Carello, C., Turvey, M. T., & Lukatela, G. (1992). Can theories of word recognition remain stubbornly nonphonological? In R. Frost & L. Katz (Eds.), *Orthography, phonology, morphology, and meaning* (pp. 211–226). Amsterdam: North Holland.

Carr, T. H., Posner, M. I., Pollatsek, A., & Snyder, C. R. R. (1979). Orthography and familiarity effects in word processing. *Journal of Experimental Psychology: General, 108,* 389–414.

Cohen, J., & Cohen, P. (1975). *Applied multiple regression/correlation analysis for the behavioral sciences*. Hillsdale, NJ: Erlbaum.

Cohen, J., & Stewart, I. (1994). *The collapse of chaos*. Viking Penguin.

Coltheart, M. (1977). Critical notice of Gibson, E. J. and Levin, H., "The psychology of reading". *Quarterly Journal of Psychology, 29,* 157–167.

Coltheart, M. (1978). Lexical access in simple reading tasks. In G. Underwood (Ed.), *Strategies in information processing* (pp. 151–216). London: Academic Press.

Coltheart, M. (1980). Deep dyslexia: a right-hemisphere hypothesis. In M. Coltheart, K. E. Patterson, & J. C. Marshall (Eds.), *Deep dyslexia*. London: Routledge.

Coltheart, M. (1985a). Cognitive neuropsychology. In M. I. Posner & O. S. M. Marin (Eds.), *Attention and performance, Vol. 11* (pp. 3–37). Hillsdale, NJ: Erlbaum.

Coltheart, M. (1985b). In defense of dual-route models of reading. *The Behavioral and Brain Sciences, 8,* 709–710.

Coltheart, M. (1989). Implicit memory and the functional architecture of cognition. In S. Lewandowsky, J. C. Dunn, & K. Kirsner. *Implicit memory: theoretical issues* (pp. 285–297). Hillsdale, NJ: Erlbaum.

Coltheart, M. (1996). Phonological dyslexia: past and future issues. *Cognitive Neuropsychology, 13,* 749–762.

Coltheart, M., Besner, D., Jonasson, J. T., & Davelaar, E. (1979). Phonological encoding in the lexical decision task. *Quarterly Journal of Experimental Psychology, 31A,* 489–508.

Coltheart, M., Curtis, B., Atkins, P., & Haller, M. (1993). Models of reading aloud: dual-route and parallel distributed processing approaches. *Psychological Review, 100,* 589–608.

Coltheart, M., Patterson, K., & Marshall, J. C. (Eds.). (1980). *Deep dyslexia.* London: Routledge.

Coltheart, V., Avons, S. E., Masterson, J., & Laxon, V. J. (1991). The role of assembled phonology in reading comprehension. *Memory & Cognition, 19,* 387–400.

Coltheart, V., Laxon, V., Rickard, M., & Elton, C. (1988). Phonological recoding in reading for meaning by adults and children. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 14,* 387–397.

Content, A. (1991). The effect of spelling-to-sound regularity on naming in French. *Psychological Research/ Psychologische Forschung, 53,* 3–12.

Cortese, M. J., Simpson, G. B., & Woolsey, S. (1997). Effects of association and imageability on phonological mapping. *Psychonomic Bulletin & Review, 4,* 226–231.

Critchley, M. (1979). *The divine banquet of the brain*. New York: Raven.

Cutler, A., Howard, D., & Patterson, K. E. (1989). Misplaced stress on prosody: a reply to Black and Byng. *Cognitive Neuropsychology, 6,* 67–83.

Damasio, A. R., & Damasio, H. (1992). Brain and language. *Scientific American, September,* 89–95.

Damasio, H., Grabowski, T. J., Tranel, D., Hichwa, R. D., & Damasio, A. R. (1996). A neural basis for lexical retrieval. *Nature, 380,* 499–505.

Davelaar, E., Coltheart, M., Besner, D., & Jonasson, J. T. (1978). Phonological recoding and lexical access. *Memory & Cognition, 6,* 391–402.

Derousné, J., & Beauvois, M.-F. (1985). The 'phonemic' stage in the non-lexical reading process: evidence from a case of phonological alexia. In K. E. Patterson, M. Coltheart, & J. C. Marshall (Eds.), *Surface dyslexia*. London: Erlbaum.

Dijkstra, T., Frauenfelder, U. H., & Schreuder, R. (1993). Bidirectional grapheme-phoneme activation in a bimodal detection task. *Journal of Experimental Psychology: Human Perception and Performance, 19,* 931–950.

Doctor, E. A., & Coltheart, M. (1980). Children's use of phonological encoding when reading for meaning. *Memory & Cognition, 8,* 195–209.

Duhem, P. (1954). *Aim and structure of physical theory*. York: Antheneum (Originally published in 1906).

Dunn, J. C., & Kirsner, K. (1988). Discovering functionally independent mental processes: the principle of reversed association. *Psychological Review, 95,* 91–101.

Einstein, A., & Infeld, L. (1966). *The evolution of physics*. New York: Simon & Schuster (Originally published in 1938).

Ellis, A. W. (1987). Intimations of modularity, or, the modelarity of mind: doing cognitive neuropsychology without syndromes. In M. Coltheart, G. Sartori, & R. Job (Eds.), *The cognitive neuropsychology of language* (pp. 397–408). Hillsdale, NJ: Erlbaum.

Ellis, A. W., Miller, D., & Sin, G. (1983). Wernicke's aphasia and normal language processing: a case study in cognitive neuropsychology. *Cognition, 15,* 111–144.

Farah, M., & McClelland, J. L. (1991). A computational model of semantic memory impairment: modality-specificity and an emergent category-specificity. *Journal of Experimental Psychology: General, 120,* 339–357.

Farmer, J. D. (1990). A Rosetta Stone for connectionism. *Physica D, 42*, 153–187.

Farrar, W. T. (1998). Investigating single-word syntactic primes in naming tasks: a recurrent network approach. *Journal of Experimental Psychology: Human Perception and Performance.*

Farrar, W. T., & Van Orden, G. C. (November, 1994). *Simulation of surface and deep dyslexia in a unified network*. Poster presented at the Annual Meeting of the Psychonomic Society, St. Louis, MO.

Farrar, W. T., & Van Orden, G. C. (2001). Errors as multistable response options. *Nonlinear Dynamics, Psychology, and Life Sciences, 5,* 223–265.

Ferrand, L., & Grainger, J. (1996). List context effects on masked phonological priming in the lexical decision task. *Psychonomic Bulletin & Review, 3,* 515–519.

Ferrand, L., & Grainger, J. (in press). Homophone interference effects in visual word recognition. *Memory & Cognition*.

Flach, J. M., & Holden, J. G. (1998). The reality of experience: Gibson's way. *Presence, 7* (1), 90–95.

Fodor, J. A. (1983). *Modularity of mind: an essay on faculty psychology*. Cambridge, MA: MIT Press.

Forde, E. M. E., Francis, D., Riddoch, M. J., Rumiati, R. I., & Humphreys, G. W. (1997). On the links between visual knowledge and naming: a single case study of a patient with a category-specific impairment for living things. *Cognitive Neuropsychology, 14,* 403–458.

Forster, K. I. (1976). Accessing the mental lexicon. In R. J. Wales & E. C. T. Walker (Eds.), *New approaches to language mechanisms*. Amsterdam: North-Holland.

Forster, K. (1989). On knowing how many entries. In D. S. Gorfein (Ed.), *Resolving semantic ambiguity* (pp. 126–145). New York: Springer-Verlag.

Forster, K. (1992). Memory-addressing mechanisms and lexical access. In R. Frost & L. Katz (Eds.), *Orthography, phonology, morphology, and meaning* (pp. 413–434). Amsterdam: Elsevier.

Fowler, C. A., Shankweiler, D., & Liberman, I. Y. (1979). Apprehending spelling patterns for vowels: a developmental study. *Language and Speech, 22,* 243–252.

Franklin, S., Turner, J., & Morris, J. (1994). Word meaning deafness: effects of word type. *In Proceedings of the International Conference on Spoken Language Processing*. Yokahama, Japan.

Freeman, W. J. (1995). *Societies of brains: a study in the neuroscience of love and hate*. Hillsdale, NJ: Erlbaum.

Friedmann, N., & Grodzinsky, Y. (1997). Tense and agreement in agrammatic production: pruning the syntactic tree. *Brain and Language, 56,* 397–425.

Friedman, R. B. (1991). *Is there a continuum of phonological/deep dyslexia*? Paper presented at Deep Dyslexia 12 Years Later, Birkbeck College, London, UK.

Friedman, R. B. (1996). Phonological text alexia: poor pseudoword reading plus difficulty reading functors and affixes in text. *Cognitive Neuropsychology, 13,* 869–885.

Friedman, R. B., & Albert, M. L. (1985). Alexia. In K. M. Heilman & E. Valenstein (Eds.), *Clinical neuropsychology* (pp. 49–74). New York: Oxford University Press.

Friedman, R. B., & Perlman, M. B. (1982). On the underlying causes of semantic paralexias in a patient with deep dyslexia. *Neuropsychologia, 20,* 559–568.

Frost, R. (1998). Toward a strong phonological model of reading: true issues and false trails. *Psychological Bulletin, 123,* 71–99.

Frost, R., Katz, L., & Bentin, S. (1987). Strategies for visual word recognition and orthographical depth: a multilingual comparison. *Journal of Experimental Psychology: Human Perception and Performance, 13,* 104–115.

Frost, S. J., Fowler, C. A., & Rueckl, J. G. (1998). *Bidirectional consistency: effects of a phonology common to speech and reading* (submitted for publication).

Funnell, E. (1983). Phonological processes in reading: new evidence from acquired dyslexia. *British Journal of Psychology, 74,* 159–180.

Funnell, E., & Davison, M. (1989). Lexical capture: a developmental disorder of reading and spelling. *Quarterly Journal of Experimental Psychology, 41A,* 471–489.

Garner, W. R. (1974). *The processing of information and structure*. Hillsdale, NJ: Erlbaum.

Garner, W. R., Hake, H. W., & Eriksen, C. W. (1956). Operationism and the concept of perception. *Psychological Review, 63,* 149–159.

Gibbs, P. (1996). *Strategic control of nonlexical effects in word recognition: testing the utility of pathway selection.* Unpublished Doctoral Dissertation, Arizona State University.

Gibbs, P., & Van Orden, G. C. (1998). Pathway selection's utility for control of word recognition. *Journal of Experimental Psychology: Human Perception and Performance, 24,* 1162–1187.

Gibson, E. J. (1969). *Principles of perceptual learning and development*. New York: Appleton-Century-Crofts.

Gibson, E. J. (1991). *An odyssey in learning and perception*. Cambridge, MA: MIT Press.

Gibson, J. J. (1986). *An ecological approach to visual perception*. Hillsdale, NJ: Erlbaum (Original work published 1979).

Gilden, D. L. (1997). Fluctuations in the time required for elementary decisions. *Psychological Science, 8,* 296–301.

Gilden, D. L., Thornton, T., & Mallon, M. W. (1995). 1/f noise in human cognition. *Science, 267,* 1837–1839.

Glosser, G., & Friedman, R. B. (1990). The continuum of deep/phonological alexia. *Cortex, 26,* 343–359.

Glushko, R. (1979). The organization and activation of orthographic knowledge in reading aloud. *Journal of Experimental Psychology: Human Perception and Performance, 5,* 674–691.

Glushko, R. (1981). Principles for pronouncing print: the psychology of phonography. In A. M. Lesgold & C. A. Perfetti (Eds.), *Interactive processes in reading* (pp. 61–84). Hillsdale, NJ: LEA.

Goldblum, M.-C. (1985). Word comprehension in surface dyslexia. In K. E. Patterson, J. C. Marshall, & M. Coltheart (Eds.), *Surface dyslexia: neuropsychological and cognitive studies of phonological reading* (pp. 175–205). Hillsdale, NJ: LEA.

Goldinger, S. D., Azuma, T., Abramson, M., & Jain, P. (1997). Open wide and say "blah!" Attentional dynamics of delayed naming. *Journal of Memory and Language, 37,* 190–216.

Gonnerman, L. M., Andersen, E. S., Devlin, J. T., Kempler, D., & Seidenberg, M. S. (1997). *Brain and Language, 57,* 254–279.

Goodwin, B. (1994). *How the leopard changed its spots: the evolution of complexity*. New York: Scribners.

Gough, P. B., & Cosky, M. J. (1977). One second of reading again. In N. J. Castellan, D. B. Pisoni, & G. R. Potts, *Cognitive theory 2* (pp. 271–288). Hillsdale, NJ: Erlbaum.

Gottlob, L. R., Goldinger, S. D., Stone, G. O., & Van Orden, G. C. (1999). Reading homographs: orthographic, phonologic, and semantic dynamics. *Journal of Experimental Psychology: Human Perception and Performance, 25,* 561–574.

Haken, H. (1988). *Information and self-organization*. Berlin: Springer Verlag.

Hanley, J. R., & McDonnell, V. (1997). Are reading and spelling phonologically mediated? Evidence from a patient with a speech production impairment. *Cognitive Neuropsychology, 14,* 3–33.

Hart, J., Berndt, R. S., & Caramazza, A. (1985). Category-specific naming deficit following cerebral infarction. *Nature, 316,* 439–440.

Hays, W. L. (1994). *Statistics*. New York: Harcourt Brace.

Head, H. (1926). *Aphasia and kindred disorders of speech*. Cambridge: Cambridge University Press.

Heeschen, C. (1985). Agrammatism versus para-grammatism: a fictitious opposition. In M. Kean (Ed.), *Agrammatism* (pp. 207–248). New York: Academic Press.

Henderson, L. (1982). *Orthography and word recognition in reading*. New York, NY: Academic Press.

Hendriks, A. W., & Kolk, H. H. J. (1997). Strategic control in developmental dyslexia. *Cognitive Neuropsychology, 14,* 321–366.

Hildebrandt, N., & Sokol, S. M. (1993). Implicit sublexical phonological processing in an acquired dyslexic patient. *Reading and Writing, 5,* 43–68.

Hofstede, B. T. M., & Kolk, H. J. (1994). The effects of task variation on the production of grammatical morphology in Broca's aphasia: a multiple case study. *Brain and Language, 46,* 278–328.

Holmes, V. M., & Standish, J. M. (1996). Skilled reading with impaired phonology: a case study. *Cognitive Neuropsychology, 13,* 1207–1222.

Howard, D. (1991). Letter-by-letter readers: evidence for parallel processing. In D. Besner & G. W. Humphreys (Eds.), *Basic processes in reading: visual word recognition* (pp. 34–76). Hillsdale, NJ: Erlbaum.

Howard, D., & Best, W. (1996). Developmental phonological dyslexia: real word reading can be completely normal. *Cognitive Neuropsychology, 13,* 887–934.

Humphreys, G. W., & Evett, L. J. (1985). Are there independent lexical and nonlexical routes in word processing? An evaluation of the dual-route theory of reading. *Behavioral and Brain Sciences, 8,* 689–740.

Jacobs, A. M. (1994). On computational theories and multilevel, multitask models of cognition: the case of word recognition. *Behavioral and Brain Sciences, 17,* 670–672.

Jacobs, A. M., & Grainger, J. (1994). Models of visual word recognition: sampling the state of the art. *Journal of Experimental Psychology: Human Perception and Performance, 20,* 1311–1334.

Jared, D. (1997). Spelling-sound consistency affects the naming of high-frequency words. *Journal of Memory and Language, 36,* 505–529.

Jared, D., McRae, K., & Seidenberg, M. S. (1990). The basis of consistency effects in word naming. *Journal of Memory and Language, 29,* 687–715.

Jared, D., & Seidenberg, M. S. (1991). Does word identification proceed from spelling to sound to meaning? *Journal of Experimental Psychology: General, 120,* 358–394.

Johnston, R. S., & Thompson, G. B. (1989). Is dependence on phonological information in children's reading a product of instructional approach? *Journal of Experimental Child Psychology, 48,* 131–145.

Jones, E. V. (1984). Word order processing in aphasia: effect of verb semantics. In F. C. Rose (Ed.), *Advances in neurology: progress in aphasiology* (pp. 159–181). New York: Raven Press.

Jorm, A. F., & Share, D. L. (1983). Phonological recoding and reading acquisition. *Applied Psycholinguistics, 4,* 103–147.

Katz, L., & Frost, R. (1992). The reading process is different for different orthographies: the orthographic depth hypothesis. In R. Frost & L. Katz (Eds.), *Orthography, phonology, morphology, and meaning* (pp. 67–84). Amsterdam: Elsevier.

Katz, R. B., & Lanzoni, S. M. (1992). Automatic activation of word phonology from print in deep dyslexia. *Quarterly Journal of Experimental Psychology, 45,* 575–608.

Kauffman, S. (1995). *At home in the universe: the search for the laws of self-organization and complexity*. New York: Oxford University Press.

Kawamoto, A. H. (1993). Nonlinear dynamics in the resolution of lexical ambiguity: a parallel distributed processing account. *Journal of Memory and Language, 32,* 474–516.

Kawamoto, A. H., Goeltz, K., Agbayani, J. T., & Groel, K. (1998). Locus of semantic priming effects in speeded naming. *Psychonomic Bulletin & Review, 5,* 676–682.

Kawamoto, A. H., Kello, C. T., Higareda, I., & Vu, J. V. Q. (1999). Parallel processing and initial phoneme criterion in naming words: evidence from frequency effects on onset and rime duration. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 25,* 362–381.

Kawamoto, A. H., Kello, C. T., Jones, R., & Bame, K. (1998). Initial phoneme versus whole-word criterion to initiate pronunciation: evidence based on response latency and initial phoneme duration. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 24,* 862–885.

Kawamoto, A. H., & Zemblidge, J. (1992). Pronunciation of homographs. *Journal of Memory and Language, 31,* 349–374.

Kelso, J. A. S. (1995). *Dynamic patterns: the self-organization of brain and behavior*. Cambridge, MA: MIT Press.

Kolk, H. H. J., & Heeschen, C. (1992). Agrammatism, paragrammatism and the management of language. *Language & Cognitive Processes, 7,* 89–129.

Kolk, H. H. J., & Hofstede, B. T. M. (1994). The choice for ellipsis: a case study of stylistic shifts in an agrammatic speaker. *Brain and Language, 47,* 507–509.

Kolk, H. H. J., Van Grunsven, M. H. F., & Keyser, A. (1985). On parallelism between production and comprehension in agrammatism. In Kean, M. (Ed.), *Agrammatism* (pp. 165–206). New York: Academic Press.

Lakatos, I. (1970). Falsification and the methodology of scientific research programmes. In I. Lakatos & A. Musgrave (Eds.), *Criticism and the growth of knowledge* (pp. 91–195). London: Cambridge University Press.

Lakoff, G. (1987). *Women, fire, and dangerous things: what categories reveal about the mind*. Chicago: University of Chicago Press.

Landauer, T. K., & Dumais, S. T. (1997). A solution to Plato's problem: the latent semantic analysis theory of acquisition, induction and representation of knowledge. *Psychological Review, 104,* 211–240.

Lashley, K. S. (1929). *Brain mechanisms and intelligence*. Chicago: University of Chicago Press.

Laudan, L. (1990). *Science and relativism: some key controversies in the philosophy of science*. Chicago: University of Chicago Press.

Lesch, M. F., & Pollatsek, A. (1993). Automatic access of semantic information by phonological codes in visual word recognition. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 19,* 285–294.

Lewenstein, M., & Nowak, A. (1989a). Fully connected neural networks with self-control of noise levels. *Physical Review Letters, 62,* 225–228.

Lewenstein, M., & Nowak, A. (1989b). Recognition with self-control in neural networks. *Physical Review A, 40,* 4652–4664.

Lewontin, R. C. (1974). The analysis of variance and the analysis of causes. *American Journal of Human Genetics, 26,* 400–411.

Lichtheim, L. (1885). Über aphasie. *Deutsches Archiv für klinische Medizin, 36,* 204–268 (English version: On aphasia. *Brain, 7,* 433–484.).

Linebarger, M. C., Schwartz, M. F., & Saffran, E. M. (1983). Sensitivity to grammatical structure in so-called agrammatic aphasics. *Cognition, 13,* 361–392.

Looren de Jong, H. (1997). Some remarks on a relational concept of mind. *Theory & Psychology, 7,* 147–172.

Luce, R. D. (1986). *Response times: their role in inferring elementary mental organization*. New York: Oxford University Press.

Lukatela, G., & Turvey, M. T. (1991). Phonological access of the lexicon: evidence from associative priming with pseudohomophones. *Journal of Experimental Psychology: Human Perception & Performance, 17,* 951–966.

Lukatela, G., & Turvey, M. T. (1993). Similar attentional, frequency, and associative effects for pseudohomophones and words. *Journal of Experimental Psychology: Human Perception & Performance, 19,* 166–178.

Lukatela, G., & Turvey, M. T. (1994a). Visual lexical access is initially phonological: 1. Evidence from associative priming by words, homophones, and pseudohomophones. *Journal of Experimental Psychology: General, 123,* 107–128.

Lukatela, G., & Turvey, M. T. (1994b). Visual lexical access is initially phonological: 2. Evidence from phonological priming by homophones and pseudohomophones. *Journal of Experimental Psychology: General, 123,* 331–353.

Lukatela, G., & Turvey, M. T. (1998). Reading in two alphabets. *American Psychologist, 53,* 1057–1072.

Lupker, S. J., Brown, P., & Colombo, L. (1997). Strategic control in a naming task: changing routes or changing deadlines? *Journal of Experimental Psychology: Learning, Memory and Cognition.*

Mandler, G. (1997). *Human nature explored*. New York: Oxford University Press.

Maratsos, M., & Matheny, L. (1994). Language specificity and elasticity: brain and clinical syndrome studies. *Annual Review of Psychology, 45,* 487–516.

Marcel, A. J., & Patterson, K. E. (1986, April). *Articulating non-lexical reading processes in phonological dyslexia*. Paper presented to the joint conference of the Experimental Psychological Society and Societa Italiana di Psicologia, Padua. (Cited in Shallice, 1988).

Marshall, J. C., & Newcombe, F. (1973). Patterns of paralexia: a psycholinguistic approach. *Journal of Psycholinguistic Research, 2,* 175–199.

Marshall, J. C., & Newcombe, F. (1977). Variability and constraint in acquired dyslexia. In H. Whitaker & H. A. Whitaker, *Studies in neurolinguistics, Volume 3*. New York: Academic Press.

Martin, N., & Saffran, E. (1992). A computational account of deep dysphasia: evidence from a single case study. *Brain and Language, 51,* 240–274.

Masterson, J., Hazan, V., & Wijayatilake, L. (1995). Phonemic processing problems in developmental phonological dyslexia. *Cognitive Neuropsychology, 12,* 233–259.

Mattingly, I. G. (1992). Linguistic awareness and orthographic form. In R. Frost & L. Katz (Eds.), *Orthography, phonology, morphology, and meaning* (pp. 11–26).

McCarthy, R. A., & Warrington, E. K. (1986). Phonological reading: phenomena and paradoxes. *Cortex, 22,* 359–380.

McClelland, J. L., & Rumelhart, D. E. (1981). An interactive activation model of context effects in letter perception: Part 1. An account of basic findings. *Psychological Review, 88,* 375–407.

McCloskey, M. (1993). Theory and evidence in cognitive neuropsychology: a "radical" response to Robertson, Knight, Rafal, and Shimamura (1993). *Journal of Experimental Psychology: Learning, Memory, and Cognition, 19,* 718–734.

McKenna, P., & Warrington, E. K. (1980). Testing for nominal dysphasia. *Journal of Neurology, Neurosurgery, and Psychiatry, 43,* 781–788.

Merleau-Ponty, M. (1962). *Phenomenology of perception*. (C. Smith, Trans.). New York: Routledge.

Merleau-Ponty, M. (1963). *The structure of behavior*. (A. L. Fisher, Trans.). Pittsburgh, PA: Duquesne University Press. (Original work published 1942).

Meyer, D. E., Schvaneveldt, R. W., & Ruddy, M. G. (1974). Functions of graphemic and phonemic codes in visual word recognition. *Memory & Cognition, 2,* 309–321.

Miceli, G., Benvegnù, B., Capasso, R., & Caramazza, A. (1997). The independence of phonological and orthographic lexical forms: evidence from aphasia. *Cognitive Neuropsychology, 14,* 35–69.

Mitra, S., Riley, M. A., & Turvey, M. T. (1997). Chaos in human rhythmic movement. *Journal of Motor Behavior, 29,* 195–198.

Monsell, S. (1991). The nature and locus of word frequency effects in reading. In D. Besner & G. W. Humphreys (Eds.), *Basic processes in reading: visual word recognition* (pp. 148–197). Hillsdale, NJ: Erlbaum.

Morton, J., & Patterson, K. E. (1980). A new attempt at an interpretation, or, an attempt at a new interpretation. In M. Coltheart, K. E. Patterson, & J. C. Marshall (Eds.), *Deep dyslexia*. London: Routledge.

Newcombe, F., & Marshall, J. C. (1980). Transcoding and lexical stabilization in deep dyslexia. In M. Coltheart, K. E. Patterson, & J. C. Marshall (Eds.), *Deep dyslexia* (pp. 176–188). London: Routledge & Kegan Paul.

Newell, A. (1990). *Unified theories of cognition*. Cambridge, MA: Harvard University Press.

Nolan, K. A., & Caramazza, A. (1982). Modality-independent impairments in word processing in a deep dyslexic patient. *Brain and Language, 16,* 237–264.

Paap, K. R., Newsome, S. L., McDonald, J. E., & Schvaneveldt, R. W. (1982). An activation-verification model for letter and word recognition: the word-superiority effect. *Psychological Review, 89,* 573–594.

Paap, K. R., Noel, R. W., & Johansen, L. S. (1992). Dual-route models of print to sound: red herrings and real horses. In R. Frost & L. Katz (Eds.), *Orthography, phonology, morphology, and meaning* (pp. 293–318). Amsterdam: North-Holland.

Pachella, R. G. (1974). The interpretation of reaction time in information processing research. In B. Kantowitz (Ed.), *Human information processing: tutorials in performance and cognition* (pp. 41–82). Hillsdale, NJ: Erlbaum.

Patterson, K. E. (1982). The relation between reading and phonological coding: further neuropsychological observations. In A. W. Ellis (Ed.), *Normality and pathology in cognitive functioning* (pp. 77–111). London: Academic Press.

Patterson, K., & Behrman, M. (1997). Frequency and consistency effects in a pure surface dyslexic patient. *Journal of Experimental Psychology: Human Perception and Performance, 23,* 1217–1231.

Patterson, K. E., & Coltheart, V. (1987). Phonological processes in reading: a tutorial review. In M. Coltheart (Ed.), *Attention and performance XII*: *the psychology of reading* (pp. 421–447). London: LEA.

Patterson, K. E., & Hodges, J. R. (1992). Deterioration of word meaning: implications for reading. *Neuropsychologia, 30,* 1025–1040.

Patterson, K. E., & Kay, J. (1982). Letter-by-letter reading: psychological descriptions of a neurological syndrome. *Quarterly Journal of Experimental Psychology, 34A,* 411–441.

Patterson, K. E., Marshall, J. C., & Coltheart, M. (Eds.). (1985). *Surface dyslexia*. London: Erlbaum.

Patterson, K. E., & Morton, J. (1985). From orthography to phonology: an attempt at an old interpretation. In K. E. Patterson, J. C. Marshall, & M. Coltheart (Eds.), *Surface dyslexia: neuropsychological and cognitive studies of phonological reading* (pp. 335–359). London: LEA.

Patterson, K. E., & Shewell, C. (1987). Speak and spell: dissociations and word-class effects. In M. Coltheart, G. Sartori, & R. Job (Eds.), *The cognitive neuropsychology of language* (pp. 273–294). London: Erlbaum.

Peitgen, H.-O., Jürgens, H., & Saupe, D. (1992). *Chaos and fractals: new frontiers of science*. New York: Springer-Verlag.

Pell, M. D., & Baum, S. R. (1997). The ability to perceive and comprehend intonation in linguistic and affective contexts by brain-damaged adults. *Brain and Language, 57,* 80–99.

Pennington, B. F., Lefly, D. L., Van Orden, G. C., Bookman, M. O., Smith, S. D. (1987). Is phonology bypassed in normal or dyslexic development? *Annals of Dyslexia, 37,* 62–89.

Pennington, B. F., Van Orden, G. C., Smith, S. D., Green, P. A., & Haith, M. M. (1990). Phonological processing skills in adult dyslexics. *Child Development, 61,* 1753–1778.

Perfetti, C. A., Bell, L. C., & Delaney, S. (1988). Automatic (prelexical) phonetic activation in silent word reading: evidence from backward masking. *Journal of Memory and Language, 27,* 59–70.

Perfetti, C. A., & Tan, L. H. (1998). The time course of graphic, phonological, and semantic activation in Chinese character identification. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 24,* 101–118.

Perfetti, C. A., & Zhang, S. (1995). The universal word identification reflex. In D. L. Medin (Ed.), *The psychology of learning and motivation* (Vol. 33, pp. 159–189). San Diego: Academic Press.

Perfetti, C. A., Zhang, S., & Berent, I. (1992). Reading in English and Chinese: evidence for a "universal" phonological principle. In R. Frost & L. Katz (Eds.), *Orthography, phonology, morphology, and meaning* (pp. 227–248). Amsterdam: North-Holland.

Plaut, D. C. (1997). Structure and function in the lexical system: insights from distributed models of word reading and lexical decision. *Language and Cognitive Processes, 12,* 765–805.

Plaut, D. C., McClelland, J. L., Seidenberg, M. S., & Patterson, K. (1996). Understanding normal and impaired word reading: computational principles in quasi-regular domains. *Psychological Review, 103,* 56–115.

Plaut, D. C., & Shallice, T. (1993). Deep dyslexia: a case study of connectionist neuropsychology. *Cognitive Neuropsychology, 10,* 377–500.

Poeppel, D. (1996). A critical review of PET studies of phonological processing. *Brain and Language, 55,* 317–351.

Price, C. J., & Humphreys, G. W. (1995). Contrasting effects of letter-spacing in alexia: further evidence that different strategies generate word length effects in reading. *Quarterly Journal of Experimental Psychology, 48A,* 573–597.

Prigatano, G. P., & Schacter, D. L. (Eds.). (1991). *Awareness of deficit after brain injury: clinical and theoretical issues*. New York: Oxford University Press.

Putnam, H. (1994). The Dewey lectures: sense, nonsense, and the senses: an inquiry into the powers of the human mind. *The Journal of Philosophy, 91,* 445–517.

Quine, W. V. O. (1961). Two dogmas of empiricism. In W. V. O. Quine (Ed.), *From a logical point of view* (pp. 20–46). New York: Harper & Row (Originally published in 1953).

Rack, J. P., Snowling, M. J., & Olson, R. K. (1992). The nonword reading deficit in developmental dyslexia: a review. *Reading Research Quarterly, 27,* 29–53.

Rapp, B., Benzing, L., & Caramazza, A. (1997). The autonomy of lexical orthography. *Cognitive Neuropsychology, 14,* 71–104.

Rapp, B., & Caramazza, A. (1997a). From graphemes to abstract letter shapes: levels of representation in written spelling. *Journal of Experimental Psychology: Human Perception and Performance, 23,* 1130–1152.

Rapp, B., & Caramazza, A. (1997b). The modality-specific organization of grammatical categories: evidence from impaired spoken and written sentence production. *Brain and Language, 56,* 248–286.

Rasmussen, J. (1986). *Information processing and human-machine interaction: an approach to cognitive engineering*. Amsterdam: North Holland.

Ratcliff, R. (1979). Group reaction time distributions and an analysis of distribution statistics. *Psychological Bulletin, 86,* 446–461.

Ray, R. D., & Delprato, D. J. (1989). Behavioral systems analysis: methodological strategies and tactics. *Behavioral Science, 34,* 81–127.

Rayner, K., Sereno, S. C., Lesch, M. F., & Pollatsek, A. (1995). Phonological codes are automatically activated during reading: evidence from an eye movement priming paradigm. *Psychological Science, 6,* 26–32.

Reichle, E. D., Pollatsek, A., Fisher, D. L., & Rayner, K. (1998). Toward a model of eye movement control in reading. *Psychological Review, 105,* 125–157.

Riley, M. A., Balasubramaniam, R., Mitra, S., & Turvey, M. T. (1998). Visual influences on center of pressure dynamics in upright posture. *Ecological Psychology, 10,* 65–91.

Riley, M. A., & Turvey, M. T. (1999). *Variability and determinism in elementary behaviors*. (Submitted for publication.).

Robertson, L. C., Knight, R. T., Rafed, R., & Shimamura, A. P. (1993). Cognitive neuropsychology is more than single case studies. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 19,* 710–717.

Ross, E. D., Thompson, R. D., Yenkosky, J. (1997). Lateralization of affective prosody in brain and the callosal integration of hemispheric language functions. *Brain and Language, 56,* 27–54.

Rosson, M. B. (1985). The interaction of pronunciation rules and lexical representations in reading aloud. *Memory & Cognition, 13,* 90–99.

Rubenstein, H., Lewis, S. S., & Rubenstein, M. A. (1971). Evidence for phonemic recoding in visual word recognition. *Journal of Verbal Learning and Verbal Behavior, 10,* 645–657.

Sacchett, C., & Humphreys, G. W. (1992). Calling a squirrel a squirrel but a canoe a wigwam: a category-specific deficit for artefactual objects and body parts. *Cognitive Neuropsychology, 9,* 73–86.

Saffran, E. M., Bogyo, L. C., Schwartz, M. F., & Marin, O. S. M. (1980). Does deep dyslexia reflect right-hemisphere reading? In M. Coltheart, K. Patterson, & J. C. Marshall (Eds.), *Deep dyslexia* (pp. 381–406). London: Routledge & Kegan Paul.

Saffran, E. M., Schwartz, M. F., & Marin, O. S. M. (1976). Semantic mechanisms in paralexia. *Brain and Language, 3,* 255–265.

Saffran, E. M., Schwartz, M. F., & Marin, O. S. M. (1980). Evidence from aphasia: isolating the components of a production model. In B. Butterworth (Ed.), *Language production* (pp. 221–241). London: Academic Press.

Saltzman, E. L., & Kelso, J. A. S. (1987). Skilled actions: a task dynamic approach. *Psychological Review, 94,* 84–106.

Saltzman, E. L., & Munhall, K. G. (1992). Skill acquisition and development: the roles of state-, parameter-, and graph-dynamics. *Journal of Motor Behavior, 24,* 49–57.

Sartori, G. (1988). From neuropsychological data to theory and vice-versa. In G. Denes, P. Bisiacchi, C. Semenza, E. Andreewsky (Eds.), *Perspectives in cognitive neuropsychology*. London: Erlbaum.

Sartori, G., & Job, R. (1988). The oyster with four legs: a neuropsychological study on the interaction of visual and semantic information. *Cognitive Neuropsychology, 5,* 105–132.

Schvaneveldt, R. W., & McDonald, J. E. (1981). Semantic context and the encoding of words: evidence for two modes of stimulus analysis. *Journal of Experimental Psychology: Human Perception and Performance, 7,* 673–687.

Schwartz, M. F., Saffran, E. M., & Marin, O. S. M. (1980). Fractionating the reading process in dementia: evidence for word-specific print-to-sound associations. In M. Coltheart, K. Patterson, & J. C. Marshall (Eds.), *Deep dyslexia* (pp. 259- 269). London: Routledge & Kegan Paul.

Seidenberg, M. S., Plaut, D. C., Petersen, A. S., McClelland, J. L., & McRae, K. (1994). Nonword pronunciation and models of word recognition. *Journal of Experimental Psychology: Human Perception and Performance, 20,* 1177–1196.

Seidenberg, M. S., & Waters, G. S. (1989, November). *Naming words aloud: a mega-study*. Paper presented at the meeting of the Psychonomic Society, Atlanta, GA.

Seidenberg, M. S., Waters, G. S., Barnes, M. A., & Tanenhaus, M. K. (1984). When does irregular spelling or pronunciation influence word recognition? *Journal of Verbal Learning and Verbal Behavior, 23,* 383–404.

Shallice, T. (1978). The dominant action system: an information-processing approach to consciousness. In K. S. Pope & J. L. Singer (Eds.), *The stream of consciousness: scientific investigations into the flow of human experience* (pp. 117–157). New York: Plenum Press.

Shallice, T. (1979). Case study approach in neuropsychological research. *Journal of Clinical Neuropsychology, 1,* 183–211.

Shallice, T. (1988). *From neuropsychology to mental structure*. New York, NY: Cambridge University Press.

Shallice, T., & Warrington, E. K. (1980). Single and multiple component central dyslexic syndromes. In M. Coltheart, K. Patterson, & J. C. Marshall (Eds.), *Deep dyslexia* (pp. 119–145). London: Routledge & Kegan Paul.

Shallice, T., Warrington, E. K., & McCarthy, R. (1983). Reading without semantics. *Quarterly Journal of Experimental Psychology, 35A,* 111–138.

Shanon, B. (1993). *The representational and the presentational: an essay on cognition and the study of the mind*. New York: Harvester Wheatsheaf.

Shaw, R. E., Kadar, E., Sim, M., & Repperger, D. W. (1992). The intentional spring: a strategy for modeling systems that learn to perform intentional acts. *Journal of Motor Behavior, 24,* 3–28.

Shaw, R. E., & Turvey, M. T. (1981). Coalitions as models for ecosystems: a realist perspective on perceptual organization. In M. Kubovy & J. Pomerantz (Eds.), *Perceptual organization* (pp. 343–415). Hillsdale, NJ: Erlbaum.

Shelton, J. R., & Weinrich, M. (1997). Further evidence of a dissociation between output phonological and orthographic lexicons: a case study. *Cognitive Neuropsychology, 14,* 105–129.

Shimamura, A. P. (1990). Forms of memory: issues and directions. In J. L. McGaugh, N. M. Weinberger, & G. Lynch (Eds.), *Brain organization and memory: cells, systems, and circuits* (pp. 159–173). New York: Oxford University Press.

Shimamura, A. P. (1993). Neuropsychological analyses of implicit memory: history, methodology and theoretical interpretations. In P. Graf & M. E. J. Masson (Eds.), *Implicit memory: new directions in cognition, development, and neuropsychology* (pp. 265–285). Hillsdale, NJ: Erlbaum.

Skarda, C. A., & Freeman, W. J. (1987). How brains make chaos in order to make sense of the world. *Behavioral and Brain Sciences, 10,* 161–195.

Slifkin, A. B., & Newell, K. M. (1998). Is variability in human performance a reflection of system noise? *Psychological Science, 7,* 170–177.

Snodgrass, J. C., & Vanderwart, M. (1978). A standardized set of 260 pictures: norms for name agreement, image agreement, familiarity and visual complexity. *Journal of Experimental Psychology: Human Learning and Memory, 6,* 174–215.

Spieler, D. H., & Balota, D. A. (1997). Bringing computational models of word naming down to the item level. *Psychological Science, 8,* 411–416.

Stanovich, K. E., & Bauer, D. W. (1978). Experiments on the spelling-to-sound regularity effect in word recognition. *Memory & Cognition, 6,* 410–415.

Sternberg, S. (1969). The discovery of processing stages: extensions of Donders' method. *Acta Psychologica, 30,* 276–315.

Stewart, I., & Cohen, J. (1997). *Figments of reality*. Cambridge University Press.

Stone, G. O., Vanhoy, M. D., & Van Orden, G. C. (1997). Perception is a two-street: feedforward and feedback phonology in visual word recognition. *Journal of Memory and Language, 36,* 337–359.

Stone, G. O., & Van Orden, G. C. (1993). Strategic processes in printed word recognition. *Journal of Experimental Psychology: Human Perception and Performance, 19,* 744–774.

Stone, G. O., & Van Orden, G. C. (1994). Building a resonance framework using design and system principles. *Journal of Experimental Psychology: Human Perception and Performance, 20,* 1248–1268.

Strain, E., Patterson, K., & Seidenberg, M. S. (1995). Semantic effects in single-word naming. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 21,* 1140–1154.

Strogatz, S. H. (1994). *Nonlinear dynamics and chaos*. Reading, MA: Addison-Wesley.

Swinney, D., Zurif, E., & Nicol, J. (1989). The effects of focal brain damage on sentence processing: an examination of the neurological organization of a mental module. *Journal of Cognitive Neuroscience, 1,* 274–290.

Tabossi, P., & Laghi, L. (1992). Semantic priming in the pronunciation of words in two writing systems: Italian and English. *Memory & Cognition, 20,* 303–313.

Taft, M. (1982). An alternative to grapheme-phoneme conversion rules? *Memory & Cognition, 10,* 465–474.

Taft, M., & van Graan, F. (1998). Lack of phonological mediation in a semantic categorization task. *Journal of Memory and Language, 38,* 203–224.

Tan, L. H., & Perfetti, C. A. (1997). Visual Chinese character recognition: does phonological information mediate access to meaning? *Journal of Memory and Language, 37,* 41–57.

Temple, C. M., & Marshall, J. C. (1983). A case study of developmental phonological dyslexia. *British Journal of Psychology, 74,* 517–533.

Teuber, H. L. (1955). Physiological psychology. *Annual Review of Psychology, 6,* 267–296.

Thelen, E. (1995a). Motor development. *American Psychologist, 50,* 79–95.

Thelen, E. (1995b). Time-scale dynamics and the development of embodied cognition. In R. F. Port & T. van Gelder (Eds.), *Mind as motion: explorations in the dynamics of cognition* (pp. 69–100). Cambridge, MA: MIT Press.

Thelen, E., & Smith, L. B. (1994). *A dynamic systems approach to the development of cognition and action*. Cambridge, MA: MIT Press.

Townsend, J. T., & Ashby, F. G. (1983). *The stochastic modeling of elementary psychological processes*. Cambridge: Cambridge University Press.

Treiman, R., Mullennix, J. W., Bijeljac-Babic, R., & Richmond-Welty, E. D. (1995). The special role of rimes in the description, use, and acquisition of English orthography. *Journal of Experimental Psychology: General, 124,* 107–136.

Turvey, M. T., & Carello, C. (1981). Cognition: the view from ecological realism. *Cognition, 10,* 313–321.

Turvey, M. T., & Carello, C. (1995). Some dynamical themes in perception and action. In R. F. Port & T. van Gelder (Eds.), *Mind as motion: explorations in the dynamics of cognition* (pp. 373–401). Cambridge, MA: MIT Press.

Turvey, M. T., & Fitzpatrick, P. (1993). Commentary: development of perception-action systems and general principles of pattern formation. *Child Development, 64,* 1175–1190.

Tyler, L. K., & Moss, H. E. (1997). Imageability and category-specificity. *Cognitive Neuropsychology, 14,* 293–318.

Ulrich, R., & Miller, J. (1993). Information processing models generating lognormally distributed reaction times. *Journal of Mathematical Psychology, 37,* 513–525.

Ulrich, R., & Miller, J. (1994). Effects of truncation on reaction time analysis. *Journal of Experimental Psychology: General, 123,* 34–80.

Uttal, W. R. (1990). On some two-way barriers between models and mechanisms. *Perception & Psychophysics, 48,* 188–203.

Uttal, W. R. (1997). Do theoretical bridges exist between perceptual experience and neurophysiology? *Perspectives in Medicine and Biology, 40,* 28–302.

Uttal, W. R. (1998). *Toward a new behaviorism: the case against perceptual reductionism.* Mahwah, NJ: LEA.

Uttal, W. R. (2000). *The war between mentalism and behaviorism: on the accessibility and analyzability of mental processes*. Mahwah, NJ: Erlbaum.

Vallacher, R. R., & Nowak, A. (1997). The emergence of dynamical social psychology. *Psychological Inquiry, 8,* 73–99.

van Gelder, T. (1994). Playing Flourens to Fodor's Gall. *Behavioral and Brain Sciences, 17,* 84.

Van Gulick, R. (1994). Prosopagnosia, conscious awareness and the interactive brain. *Behavioral and Brain Sciences, 17,* 84–85.

Van Orden, G. C. (1987). A ROWS is a ROSE: spelling, sound, and reading. *Memory & Cognition, 15,* 181–198.
Van Orden, G. C. (1991). Phonologic mediation is fundamental to reading. In D. Besner, & G. Humphreys (Eds.), *Basic processes in reading: visual word recognition* (pp. 77–103). Hillsdale, NJ: Erlbaum.
Van Orden, G. C., Aitchison, C. S., & Podgornik, M. N. (1996). *When a ROWS is not a ROSE: null effects and the absence of cognitive structures*. Manuscript submitted for publication.
Van Orden, G. C., Bosman, A. M. T., Goldinger, S. D., & Farrar, W. T. (1997). A recurrent network account of reading, spelling, and dyslexia. J. W. Donahoe & V. P. Dorsel (Eds.), *Neural network models of cognition: biobehavioral foundations* (pp. 522–538). Amsterdam: Elsevier.
Van Orden, G. C., & Goldinger, S. D. (1994). Interdependence of form and function in cognitive systems explains perception of printed words. *Journal of Experimental Psychology: Human Perception and Performance, 20,* 1269–1291.
Van Orden, G. C., & Goldinger, S. D. (1996). Phonologic mediation in skilled and dyslexic reading. In C. H. Chase, G. D. Rosen, & G. F. Sherman (Eds.), *Developmental dyslexia: neural, cognitive, and genetic mechanisms* (pp. 185–223). York Press.
Van Orden, G. C., Holden, J. G., Podgornik, M. N., & Aitchison, C. S. (1999). What swimming says about reading: coordination, context, and homophone errors. *Ecological Psychology, 11,* 45–79.
Van Orden, G. C., Jansen op de Haar, M. A., & Bosman, A. M. T. (1997a). Complex dynamic systems also predict dissociations, but they do not reduce to autonomous components. *Cognitive Neuropsychology, 14,* 131–165.
Van Orden, G. C., Johnston, J. C., & Hale, B. L. (1988). Word identification in reading proceeds from spelling to sound to meaning. *Journal of Experimental Psychology*: *Learning, Memory, and Cognition, 14,* 371–385.
Van Orden, G. C., & Paap, K. R. (1997). Functional neuroimages fail to discover pieces of mind in the parts of the brain. *Philosophy of Science, 64,* S85–S94.
Van Orden, G. C., Pennington, B. F., & Green, P. (1997b, April). Phonological mediation and developmental dyslexia. In J. R. Booth, & B. MacWhinney (Chairs), *How does phonology support reading?* Symposium conducted at the biennial meeting of the Society for Research in Child Development, Washington DC.
Van Orden, G. C., Pennington, B. F., & Stone, G. O. (1990). Word identification in reading and the promise of subsymbolic psycholinguistics. *Psychological Review, 97,* 488–522.
Van Orden, G. C., Stone, G. O., Garlington, K. L., Markson, L. R., Pinnt, G. S., Simonfy, C. M., & Brichetto, T. (1992). "Assembled" phonology and reading: a case study in how theoretical perspective shapes empirical investigation. In R. Frost, & L. Katz (Eds.), *Orthography, phonology, morphology, and meaning* (pp. 249–292). Amsterdam: North-Holland.
Varela, F. J., Thompson, E., & Rosch, E. (1991). *The embodied mind: cognitive science and human experience*. Cambridge, MA: MIT Press.
Vellutino, F. R. (1979). *Dyslexia: theory and research*. Cambridge, MA: MIT Press.
Venezky, R. L. (1970). *The structure of English orthography*. The Hague: Mouton.
Verstaen, A., Humphreys, G. W., Olson, A., & D'Yewalle, G. (1995). Are phonemic effects in backward masking evidence for automatic prelexical phonemic activation in visual word recognition? *Journal of Memory and Language, 34,* 335–356.
Vincente, K. J., & Wang, J. H. (1998). An ecological theory of expertise effects in memory recall. *Psychological Review, 105,* 33–57.
Warrington, E. K. (1975). The selective impairment of semantic memory. *Quarterly Journal of Experimental Psychology, 27,* 635–657.
Warrington, E. K., & McCarthy, R. (1987). Categories of knowledge: further fractionation and an attempted integration. *Brain, 110,* 1273–1296.
Warrington, E. K., & Shallice, T. (1980). Word-form dyslexia. *Brain, 103,* 99–112.
Warrington, E. K., & Shallice, T. (1984). Category specific semantic impairments. *Brain, 107,* 829–854.
Watt, S., Jokel, R., & Behrman, M. (1997). Surface dyslexia in nonfluent progressive aphasia. *Brain and Language, 56,* 211–233.
Weiskrantz, L. (1968). Some traps and pontifications. In L. Weiskrantz (Ed.) *Analysis of behavioral change*. New York: Harper & Row.

Weldon, M. S. (1999). The memory chop shop: issues in the search for memory systems. In J. K. Foster & M. Jelicic (Eds.) *Memory systems, processes, or functions*? New York: Oxford University Press.

West, B. J., & Deering, B. (1995). The lure of modern science. River Edge, NJ: Word Scientific.

Wijk, A. (1966). *Rules of pronunciation for the English language*. London: Oxford University Press.

Xu, B., & Perfetti, C. A. (1999). Nonstrategic subjective threshold effects in phonemic masking. *Memory & Cognition, 27,* 26–36.

Zaidel, E., & Peters, A. M. (1981). Phonological encoding and ideographic reading by the disconnected right hemisphere: two case studies. *Brain and Language, 14,* 205–234.

Zesiger, P., Pegna, A., & Rilliet, B. (1994). Unilateral dysgraphia of the dominant hand in a left-hander: a disruption of graphic motor pattern selection. *Cortex, 30,* 673–683.

Ziegler, J. C., & Ferrand, L. (1998). Orthography shapes the perception of speech: the consistency effect in auditory word recognition. *Psychonomic Bulletin & Review, 5,* 683–689.

Ziegler, J. C., & Jacobs, A. M. (1995). Phonological information provides early sources of constraint in the processing of letter strings. *Journal of Memory and Language, 34,* 567–593.

Ziegler, J. C., Montant, M., & Jacobs, A. M. (1997a). The feedback consistency effect in lexical decision and naming. *Journal of Memory and Language, 37,* 533–554.

Ziegler, J. C., & Van Orden, G. C. (1999). *Feedback consistency and subjective familiarity*. (submitted for publication).

Ziegler, J. C., Van Orden, G. C., & Jacobs, A. M. (1997b). Phonology can help or hurt the perception of print. *Journal of Experimental Psychology: Human Perception and Performance, 23,* 845–860.