Brain and Language **74,** 48–69 (2000)
doi:10.1006/brln.2000.2330, available online at http://www.idealibrary.com on IDEAL®

Oral Reading in Dementia

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Reading has been thought to consist of three main processing components: the orthographic, phonological, and semantic lexicons. In traditional psycholinguistic models, these components have been treated independently such that the selective dysfunction of one does not necessarily imply the breakdown of another. Recently, it has been proposed that a word's semantic representation is essential to oral reading such that a disturbance within the semantic lexicon will disrupt processing within the orthographic and/or phonological lexicons. From this view, semantic deterioration should lead to fragmentation of the other systems contributing to reading, resulting in a specific pattern of errors during oral reading. This would include (1) a larger than normal advantage for reading words with regular spelling-to-sound correspondence over words with exception spelling, as well as the production of ''regularization errors'' when reading exception words; and (2) a smaller than normal difference between reading real words and pronounceable nonwords, or pseudowords (PW's). We found that patients with Semantic Dementia generally conformed to these hypothesized patterns of reading difficulty. Despite the presence of a semantic impairment, however, patients with Alzheimer's Disease, Frontotemporal Dementia, and Progressive Non-Fluent Aphasia did not demonstrate these patterns of reading difficulty. Our findings suggest that not all semantic impairments invariably lead to the disruption of the orthographic and phonological lexicons.

INTRODUCTION

Reading is a complex cognitive task that requires multiple processing components. By investigating the breakdown of reading processes in patients with selective brain dysfunction, we gain clues to the neural bases of acquired reading difficulty, or alexia, as well as to the various cognitive procedures involved in normal reading.

Most models of reading assume three major processing components in the

This article was completed as an Honors Thesis for the Biological Basis of Behavior program at the University of Pennsylvania. Supported in part by grants from the USPHS (AG15116, NS35867, and DC02320), American Health Assistance Foundation, and the Charles A. Dana Foundation.

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0093-934X/00 $35.00

form of orthographic, phonological, and semantic lexicons. The orthographic lexicon refers to representations of previously encountered sets of letters in each written word and the order in which they appear. This is not a visual template, as many different fonts and types of handwriting are easily recognized by the normal reader as depicting the same word. The phonological lexicon refers to representations that specify the pronunciation of previously encountered words or letter strings, and the semantic lexicon contains information about the meaning of these words, independent of the modality of presentation.

Although most cognitive models of reading include these cognitive components, models differ as to how these components interact. In traditional models (e.g., Friedman et al., 1993), after the visual perceptual analysis of a written word and subsequent letter identification, the orthographic lexicon is accessed so that the letter pattern may be identified as a previously encountered word. Then, in two separate, bidirectional paths, the corresponding phonological and semantic codes are activated, allowing access to the pronunciation and meaning associated with a written word, respectively. There is likewise a bidirectional flow of information between the semantic and phonological codes. This path is utilized when the word is accessed from sound or meaning rather than from orthography. Although there are proposed bidirectional links between the three processing components, each of the three lexicons is assumed to function independently, the selective dysfunction of one not necessarily resulting in a breakdown of another.

Recently, however, it has been proposed that a word's semantic representation is essential to oral reading such that a disturbance within the semantic lexicon is postulated to result in disruption of processing within the orthographic and/or phonological lexicons. K. Patterson, J. Hodges, and colleagues (Patterson et al, 1994a, 1994b; Patterson & Hodges, 1992) propose that representations in the orthographic and phonological lexicons operate at the subword level of the word fragment and that meaning is the basis for binding these elements together into whole-word units. This account postulates that the integrity of orthographic and phonological lexical representations depends on a functioning semantic system; that is, semantics is the ''glue'' that binds the phonological and orthographic elements of a word together. According to this view, when the semantic lexicon deteriorates, the other systems contributing to reading also become fragmented, resulting in an increased number of errors during oral reading.

The latter view predicts that semantic breakdown leads to several characteristic changes in oral reading, as both orthographic representations at input and phonological representations at output lose their lexical semantic glue: (1) When semantics is impaired, the deterioration of semantically mediated sublexical binding requires that oral reading is achieved only through the segmental translation from orthography to phonology. For words with regu-

lar spelling-to-sound correspondence such as *get,* this will not pose a problem, as the translation of the individual segments will lead to the same outcome as the translation of the bound word. However, for words with exceptional spelling-to-sound correspondence, like *gone,* the fragmentation of the individual segments could lead the reader to pronounce the letter string to rhyme with *cone,* thereby producing a ''regularization'' error. Thus, Patterson and colleagues predict that a semantic impairment will lead to a surface alexia, in which the patient demonstrates a larger relative advantage for accurately reading regular words over exception words compared to controls. Furthermore, many errors in exception word reading would be expected to be regularizations. (2) It is well known that normal controls demonstrate an advantage in reading real words over pronounceable nonwords, or pseudowords (PW's) (e.g., Baddeley, 1966). This advantage can be attributed both to autoassociative phonological and to semantic factors. Since the phonological elements of a word are activated together every time it is spoken, their mutual association is necessarily stronger than that of the elements of a novel PW. These associations are represented in the phonological lexicon. The word's meaning would also serve to give a previously encountered real word a lexical advantage over a PW. Patterson and Hodges (1992) maintain that the interaction between the word's meaning and its pronunciation serve to bind its phonological representation together. As PW's do not have a semantic representation, they would essentially be phonological productions lacking in ''glue.'' In the case of semantic deterioration, once-known words that have lost their semantically mediated sublexical binding would ostensibly be treated like PW's. Therefore, if this account is correct, we would also predict a decreased pseudoword effect for patients with semantic difficulties as compared to controls. That is, the advantage for real words over pseudowords would diminish.

This newly proposed account will hereafter be referred to as the ''Patterson and Hodges hypothesis.'' If this account is true, we would predict an increased regularity effect, an increased proportion of ''regularizations'' of exception words, and a decreased PW effect in all patients with semantic deficits, regardless of the underlying neurological dysfunction. Patients with neurodegenerative disorders often display semantic difficulties (Johnson et al., 1995; Grossman et al., 1996a, 1996b; Hodges et al., 1992; Kalmanson et al., 1996) and offer an opportunity to test these predictions.

Semantic dementia (SD) patients are said to have a progressive fluent aphasia. A profound and pervasive semantic deterioration is the hallmark of SD (Hodges et al., 1992; Hodges & Patterson, 1996). Features include an overwhelming and progressive loss of expressive and receptive vocabulary in the face of fluent, prosodic speech that is relatively lacking in phonological or syntactic abnormalities. Anomia is often severe. Speech output eventually becomes highly stereotyped, with frequent semantic paraphasias. However, comprehension of the grammatical structure of language appears to be pre-

served in the face of the severe semantic deficit. Progressive surface alexia is often observed in these patients (Snowden et al., 1996). This syndrome appears to be associated with dysfunction of inferior temporal regions (Mummery et al., 1999; Hodges et al., 1992).

Alzheimer's Disease (AD) is the most common neurodegenerative disease and typically includes dysfunction of multiple areas, most frequently in the temporo-parietal brain regions (Brun & Gustafson, 1978; Salmon et al., 1994), which have been related to these patients' language difficulties (Grossman et al., 1997). AD patients are widely recognized to have semantic impairments, as evidenced by difficulties with word–picture-matching, category membership judgments of words and pictures, and confrontation-naming tasks. Oral reading, repetition, and syntax are relatively less affected (Cummings et al., 1986; Glosser et al., 1997; Grossman & Mickanin, 1994; Johnson et al., 1995; Martin & Fedio, 1983; Grossman et al., 1996a; Murdoch et al., 1987).

Fronto-temporal dementia (FTD) refers to a group of pathologically diverse brain disorders that affect prefrontal and anterior temporal regions (Snowden et al., 1996). This family of disorders includes Pick's disease, Dementia Lacking Distinctive Histology, and Corticobasal Degeneration. Unlike AD patients, patients with FTD have been found to have difficulty in sentence comprehension, including impaired grammatical and syntactic processing (Grossman et al., 1996a), that may also be due to their limitations in working memory and executive functioning (Grossman et al., 1998). While FTD patients maintain relatively preserved processing of semantic information in single words early in the disease process, many of these patients make semantic errors on measures of single-word processing as the disease progresses (Kalmanson et al., 1996).

A subgroup of patients with FTD has been shown to exhibit primarily language-based deficits. Progressive Nonfluent Aphasia (PNFA) presents with progressive impairment in speech fluency, phonological errors in speech output, limited short-term memory, and deficits in syntactic production and comprehension, while their single-word comprehension declines later in the course of illness (Hodges & Patterson, 1996; Grossman et al., 1996b). Speech tends to be progressively telegraphic in quality, with the frequent omission of small grammatical words and eventual evolution to complete mutism. These patients have reduced left-hemispheric metabolic activity, as demonstrated in brain imaging, primarily in the frontal and superior temporal regions (Grossman et al., 1996b; Liberman et al., 1998; Turner et al., 1996).

If orthographic and phonological processing are critically dependent on intact semantic abilities, as Patterson and colleagues maintain, we would predict that patients with semantic deficits, such as the four groups of patients described above, would demonstrate the predicted pattern of impaired oral reading. Specifically, a semantic impairment would be predicted to lead to a greater difficulty with words having exceptional spelling-to-sound corre-

spondences, an increased number of regularization errors in reading these words, and a decreased pseudoword effect.

On the other hand, if semantics is not crucial to translation from orthography to phonology, we would not necessarily expect such effects in all patients with semantic difficulty. The orthographic, phonological, and semantic lexicons have been associated with different anatomical regions, both in neuropsychological lesion studies as well as in functional neuroimaging studies of healthy adults. Traditional accounts that assume independence of semantic, phonological, and orthographic processing thus might predict that different patterns of reading impairment will emerge based on different regions of compromised neural function that disrupt functioning of different processing components. For example, lesion studies have linked semantic processing to left temporal lobe structures, including the left temporal pole and basal neocortical regions of the left temporal lobe (Laiacona et al., 1997), as well as to left posterior superior temporal-inferior parietal regions (Hart & Gordon, 1990) and the left prefrontal area (Rapcsak & Rubens, 1990). Both PET and fMRI studies have linked semantic processing to left temporal lobe structures, including the ventral temporal lobe (Martin et al., 1996; Damasio et al., 1996), the middle and superior temporal gyri (Pugh et al., 1996), and left extrasylvian temporal cortices (Price et al., 1997). Deficits in orthographic processing have been reported to result from single lesions located more posterior than those resulting in semantic difficulties. Specifically, orthographic deficits have been linked to lesions of the left inferior temporo-occipital region and left medial occipital cortex (Friedman et al., 1993; McCarthy & Warrington, 1990). Functional neuroimaging studies have associated orthographic processing with the left lateral and medial extrastriate regions (Pugh et al., 1996; Howard et al., 1992). Finally, lesion studies have associated phonological disturbance with the left middle temporal gyrus (McCarthy & Warrington, 1990) and the left frontal cortex (Ziegler et al., 1997). In neuroimaging studies, phonological processing has been linked to frontal regions including the inferior frontal gyrus, the lateral orbital gyrus, and the dorsolateral prefrontal region (Pugh et al., 1996) as well as to the supramarginal and angular gyri and the precentral sulcus and left cuneus (Price et al., 1997; Celsis et al., 1999; Demonet et al., 1994; Price et al., 1994).

It should be remembered that the predictions of the two accounts are not necessarily mutually exclusive. It is conceivable that a semantic impairment disrupts the cohesion of orthographic and phonological representations in a similar manner across all groups, resulting in some common characteristics of oral reading, and that simultaneously some characteristics of oral reading will be distinct among groups due to differences in the anatomic distribution of neurodegeneration in the various dementia groups. We tested these alternative hypotheses in groups of patients suffering from AD, FTD, SD, and PNFA. Real-word reading of regular and exception words and PW reading

TABLE 1
Fronto-Temporal Dementia Patient Profiles

Clinical symptoms	MD	BD	RD	GS	JW
Insidious onset, slow progression	√	√	√	√	√
Loss of personal awareness	√				
Loss of social awareness	√		√		
Disinhibition	√		√	√	
Mental Rigidity		√		√	
Hyperorality			√		
Stereotyped, Perseverative Behavior		√		√	√
Unrestrained Exploration of Environment				√	
Loss of insight into changed state			√	√	
Depression, anxiety, aggression, delusion	√	√	√	√	√
Emotional unconcern	√	√	√		√
Inertia	√	√			√
Progressive economy of speech	√	√		√	√
Stereotypy of speech				√	
Late mutism	√				
Early incontinence	√				
Low and labile b.p.		√	√		
Neuroimaging: structural and functional frontotemporal degeneration	√	√	√	√	√
Impairment on neuropsychological ''frontal lobe tests''	√	√	√	√	√
Onset before age 65	√		√	√	√
Distractible	√	√		√	√
Kluver–Bucy syndrome	√				
Disorganized mental search	√	√		√	

were assessed in dementia patients with various degrees of semantic impairment, as quantified on a test of word-meaning knowledge.

METHODS

Subjects

We recruited 5 FTD patients (4 male and 1 female), 2 PNFA patients (1 male, 1 female), 3 SD patients (all male), 10 AD patients (7 male and 3 female), and 20 healthy elderly control subjects (8 male and 12 female). All diagnoses were made by a board-certified neurologist at the Hospital of the University of Pennsylvania following the diagnostic criteria found in Hodges et al. (1992); Turner et al. (1996); Grossman, Mickanin et al. (1996); and McKhann et al. (1984) for SD, FTD, PNFA, and AD, respectively. Diagnoses were supported by structural neuroimaging studies in all cases and by functional neuroimaging in most. The four patient groups and the group of control subjects were matched in mean age [$F(4, 36) = 1.037$; n.s.] and mean years of education [$F(4, 36) = 0.185$; n.s.]. In addition, the groups of patients were matched for mean dementia severity using Mattis' Dementia Rating Scale [$F(3, 17) = .382$; n.s.]. Due to the fact that these are relatively unusual syndromes, we have summarized the clinical symptoms of the individual FTD, PNFA, and SD patients in Tables 1 through 3 respectively, with features compiled from Snowden et al. (1996) and Turner et al. (1996).

TABLE 2
Progressive Nonfluent Aphasia Patient Profiles

Clinical symptoms	SC	ES	PS
Presenile onset	√		
Late behavioral signs of FTD	√	√	√
Neuroimaging: left hemisphere frontotemporal abnormalities	√	√	√
Impaired verbal expression	√	√	√
Relatively preserved comprehension	√	√	√
Preserved object identification	√	√	√
Preserved event memory	√	√	√
Preserved planning and judgment			
Preserved social skills	√		√
Some frustration and irritability	√		√
Nonfluent, agrammatic, stuttering	√	√	√
Impaired repetition	√	√	√
Impaired word retrieval	√	√	√
Phonemic paraphasias	√	√	√
Reading paralexias		√	√
Telegrammatic writing		√	
Lexical comprehension preserved	√	√	√
Preserved insight			√
Preserved orientation in time and place			√

TABLE 3
Semantic Dementia Patient Profiles

Clinical symptoms	EA	TM	GD
Onset between ages 48 and 71	√	√	√
Impaired object and face recognition	√	√	√
Preserved construction skills		√	
Good autobiographical memory			√
Impaired general knowledge	√		√
Fluent, effortless spontaneous speech	√	√	√
Reduction in substantives	√	√	√
Semantic paraphasias		√	√
Use of stereotyped, generic terms		√	√
No phonological errors	√	√	√
Preserved syntax	√	√	√
Relatively preserved repetition			√
Severe loss of individual word comprehension	√	√	√
Good comprehension of syntax	√	√	√
Profound anomia	√	√	√
Fluent oral reading	√	√	√
Regularization errors	√	√	√

Procedures

Two tasks assessed oral reading. Both tasks involved presenting a string of lowercase letters on a computer CRT for 2 s. The subject had as long as desired to name the written stimulus. One SD subject (TM) was unable to read single words presented at this rapid rate because he was a letter-by-letter reader, so the words were made available to him as long as was necessary to produce a response. For all subjects, responses were tape recorded for later transcription.

The first reading task was designed to test the ''regularity effect'' (Glosser, Grugan, & Friedman, 1998). The list included 72 one- and two-syllable stimuli that are real words, with equal numbers of high-frequency and low-frequency regular, ambiguous, and exceptional words. ''High-frequency'' was defined as an occurrence of greater than 34 per million in Francis and Kucera's corpus (1984) and ''low-frequency'' was defined as an occurrence of less than 26 per million in the corpus. Regular words (e.g., *green*) contained a rhyme that had a single obvious pronunciation according to Venezky's (1970) criteria, and a pronunciation that was produced by >90% of subjects when embedded in a pseudoword (Seidenberg et al., 1994). Ambiguous words (e.g., *snow*) were defined as words which contained letter groups that could be pronounced two or more different ways, (e.g., to rhyme with ''crow'' or ''plow'') and for which each possible pronunciation was produced by between 30 and 70% of subjects (Seidenberg et al., 1994). Exceptional words (e.g., *blood*) were defined as words that contained letter groups whose pronunciation is very irregular in that there is no more than one other word in the English language that uses this same spelling pattern to represent this sound (e.g., *flood*) and for which less than 10% of Seidenberg et al. (1994) subjects pronounced the pseudoword containing that letter pattern in that way. Lists were matched for proportions of words from different word classes and for number of letters and syllables.

The second reading task consisted of a list of pronounceable nonwords, or pseudowords (PW's) (Glosser et al., 1999). There were 48 four to six-letter, single-syllable PW's, 24 of each of two types: (1) regular PW's (e.g., *brist*) had a single or invariant pronunciation and (2) ambiguous PW's (e.g., *grour*) contained letter combinations that had several potentially acceptable pronunciations. For instance, *grour* can be pronounced to rhyme with ''tour,'' ''four,'' or ''flour.'' Correct responses consisted of those conforming to rules of English pronunciation (Venezky, 1970) as well as those corresponding to real English words with analogous but irregular spellings. Thus, ambiguous PW's had more than one acceptable pronunciation.

To evaluate semantic abilities, a 24-item written word–picture-matching task was administered. Each item consisted of a written word at the top of a page, with four vertically arrayed line-drawing pictures of objects below, one of which accurately depicted the written word. All word and picture stimuli were concrete nouns, with foils from the same superordinate category as the target (e.g., the word *pig* had to be correctly matched to a picture of a pig, displayed with pictures of three other animals). Subjects were instructed to choose the picture that means the same thing as the written word and were not required to read the word aloud.

To test phonological ability independent of written input, subjects were asked to repeat 16 one-syllable, 24 two-syllable, and 24 three-syllable real words (Glosser et al., 1997). Mean word frequency (Francis & Kucera, 1982) did not differ between the one-, two-, and three-syllable words. Subjects were then asked to repeat the same number of pseudowords, each matched to real-word stimuli in letter length and consonant–vowel complexity. Pseudowords were constructed by changing approximately one half of the consonants in the real words by one or two distinctive features (e.g., snail/spail; lemon/fepon; transition/flaksition). Responses were considered correct if they matched the presented target exactly, disregarding influences of local dialect.

In addition to measuring accuracy of response, we also analyzed the relative frequency of real-word reading errors of the ''regularization'' type that were made by different subjects. A regularization consisted of a response in which letters are pronounced to conform to their usual (regular) pronunciation, resulting either in a real-word response (e.g., *coup* read as

''coop'') or a nonword response (e.g., *colonel* pronounced ''kohlohnell''). Error scoring using these criteria has previously been verified by the investigators in samples of control and AD subjects. Interrater agreement for error classification was found to be >90% in AD and normal control groups (Glosser et al., 1997, 1998).

RESULTS

For single-word oral reading and repetition tasks, both measures of response accuracy and errors were analyzed. Because of the relatively small numbers of subjects with the rarer forms of dementia, group statistics could not be computed reliably on these data. Rather, based on the scores of 20 age- and education-matched control subjects, *z* scores were calculated for each demented subject's performance on single-word and PW reading, repetition of single words and PW's, and word–picture-matching tasks. Table 4 lists all demented subjects' normalized *z* scores for word–picture-matching accuracy, overall real-word reading accuracy, regular real-word reading accuracy, exceptional real-word reading accuracy, overall PW reading accuracy, overall real-word repetition accuracy, and overall PW repetition accuracy. A *z* score of a magnitude greater than 1.96 indicates that the patient's score differed from the mean of the control group at $p < .05$ (two-tailed).

It can be seen from Table 4 that all but two of the patients were impaired on the word–picture-matching task used to test semantic word knowledge, scoring significantly outside the range for normal controls. One FTD subject (RD) and one AD subject (BR) performed within the normal range on this relatively easy task. These two patients were therefore excluded from further analyses as they did not meet the criterion for a semantic impairment.

Patients in only two groups demonstrated real-word reading difficulty significantly below normal. Two of the three SD patients and two of the three PNFA patients were significantly impaired in overall real-word reading. However, all AD patients and all but one FTD patient read real words within normal limits, despite the presence of a significant semantic impairment.

Some evidence consistent with Patterson and Hodges' hypothesis comes from the overall significant positive correlation across all semantically impaired dementia subjects between performance on the test of semantic performance and overall real-word reading accuracy [$r(16) = .536$; $p < .03$]. In addition, there was a significant correlation across these patients between semantic performance and accuracy in reading words with exceptional spelling-to-sound correspondence [$r(16) = .594$; $p < .01$]. This conforms to the Patterson and Hodges prediction that an impairment in semantics is associated with increased difficulty in reading exceptionally spelled words. However, we also found a significant correlation across semantically impaired dementia patients between semantic performance and accuracy in reading words with regular spelling-to-sound correspondence [$r(16) = 0.533$; $p < .03$]. This does not conform to their hypothesis, since an impairment of semantics would not be expected to interfere in the oral reading of regularly

TABLE 4
Normalized Measures of Semantics, Reading, and Repetition

Patient	Dx	WPM	RWread	Regread	Excread	PWread	RWrep	PWrep	Regeff	PWeff
TM	SD	−86.5	−8.6	−25.3	−14.8	−4.50	−6.13	−1.95	4.40	−.15
EA	SD	−12.3	−1.2	.32	−3.9	−.51	−17.7	−4.22	4.40	0.48
GD	SD	−64.7	−4.8	−9.27	−12.1	−.59	−1.50	.82	8.90	−.94
SC	PNFA	−3.64	−2.4	−1.28	−6.6	−2.95	−27.0	−11.0	6.65	1.74
PS	PNFA	−3.64	.24	.32	.22	−1.26	−10.8	−6.99	−.09	.64
GS	FTD	−69.0	−1.6	−1.28	−5.23	−.67	−1.50	−2.71	5.15	.01
RD	FTD	.72	.57	.32	.90	.42	−6.13	−4.22	N/A (semantics normal)	N/A (semantics normal)
JW	FTD	−12.4	.41	.32	.22	−.34	.81	.06	−.09	.32
BD	FTD	−12.4	.09	−1.28	−.46	−.76	−14.23	−9.50	−.09	1.11
MD	FTD	−103.9	−.22	.32	−1.83	−2.70	−7.29	−4.72	2.15	2.38
BB	AD	−51.6	.24	.32	−4.55	−3.20	−6.13	−2.20	5.15	3.01
LG	AD	−3.6	−.54	−2.88	−1.14	.51	−20.01	−10.76	−.09	−.94
RM	AD	−3.6	.57	.32	.90	.25	−.35	.57	−.84	.16
CH	AD	−8.0	−1.01	.32	−2.51	−4.21	−6.13	−3.97	2.90	4.75
HP	AD	−3.6	−.86	.32	−1.83	−3.87	.81	−.19	2.15	4.12
JP	AD	−8.0	.41	−1.28	.90	−1.10	.81	.06	−1.59	0.96
EM	AD	−3.6	.09	.32	−1.14	.34	−.35	−.19	1.40	−.31
MS	AD	−8.0	−.22	.32	−1.83	−1.10	−.35	−1.45	2.15	.96
BR	AD	.72	.25	.32	−.46	.17	.81	.82	N/A (semantics normal)	N/A (semantics normal)
FC	AD	−47.2	−1.49	−9.27	−1.82	−2.44	−3.82	−3.46	−2.34	1.75

Note. Columns 3 through 9 represent patient *z* scores of the following measures: world–picture matching (WPM), overall real-word reading (RWread), regular real-word reading (Regread), exception real-word reading (Excread), overall pseudoword reading (PWread), real–word repetition (RWrep), and pseudoword repetition (PWrep). The final two columns indicate *z* scores for the regularity effect (Regeff) and the pseudoword reading effect (PWeff).

spelled words. Despite the lack of semantic ''glue,'' Patterson and Hodges would predict that the individual sublexical elements of a regular word should lead to the same phonological production upon reconstruction as would a word that is semantically bound.

More detailed inspection of real-word reading revealed that all SD patients performed at significantly impaired levels on exception real-word reading. However, only one of the PNFA patients, one of the FTD patients, and two AD patients also demonstrated exception word reading difficulty at the $z < -1.96$ level. Thus, a large number of patients who demonstrated a semantic impairment did not demonstrate a corresponding difficulty with exception word oral reading.

Exceptionally spelled words are more difficult for normal subjects to read correctly than words that follow regular spelling-to-sound correspondence rules. The difference of regular real-word reading minus exceptional real-word reading thus would be expected to be positive in normal controls. This is known as the ''regularity effect.'' According to Patterson and Hodges' model, patients with a semantic deficit should display even greater relative difficulty with exception words than controls, as these patients would have lost the sublexical binding normally provided through semantics that is needed to support reading in the absence of regular correspondence between letters and sounds. Therefore, if the Patterson and Hodges hypothesis is correct, we would expect an even larger difference score in patients whose semantics is compromised; that is, we would expect an exaggerated regularity effect. Using data from healthy controls, *z* scores were computed for patients based on the difference between regular real-word reading minus exception real-word reading. A normalized *z* score greater than 1.96 for this difference score would indicate a significantly increased regularity effect. This *z* score for the regularity effect is provided for each subject in Table 4.

It can be seen that all SD patients demonstrated an exaggerated regularity effect, consistent with Patterson and Hodges' previous observations. An exaggerated regularity effect was also seen for one PNFA patient, two FTD patients, and four AD patients. All of these patients also had semantic difficulty on the word–picture-matching task. Although 10 patients with semantic difficulty did exhibit an exaggerated regularity effect, 8 patients with semantic impairment did not demonstrate such an effect, in fact, one of these patients (FC, and AD patient) had a significant *reversed* regularity effect (i.e., significantly greater difficulty with regular words than exception words). There was no significant correlation across semantically impaired dementia patients between the word–picture-matching measure of semantic comprehension and the calculated regularity effect [$r(16) = .392$, n.s.]. In sum, although some patients with semantic dementia demonstrated the predicted difficulty reading exception words and an exaggerated regularity effect, this did not necessarily correlate with their semantic performance. In addition, other patients with a significant semantic deficit did not display a pattern of performance consistent with the Patterson and Hodges hypothesis.

TABLE 5
Percentage Regularity Errors[a]

Patient	DX	% Regularity errors
TM[b]	SD	8.0
EA	SD	25.0
GD	SD	17.0
SC	PNFA	6.0
PS	PNFA	1.0
GS	FTD	11.0
JW	FTD	1.0
BD	FTD	1.0
MD	FTD	6.0
BB	AD	8.4
LG	AD	1.4
RM	AD	2.9
CH	AD	0
HP	AD	0
JP	AD	0
EM	AD	0
MS	AD	2.8
FC	AD	10.0
Total controls	N/A	.62

[a] Percentages of the total number of responses.
[b] TM was a letter-by-letter reader for all stimuli. Error analyses came from his attempts at producing word responses after he had spelled the words to himself.

We also examined the proportion of all responses that were errors of the regularization type made by the patients when reading real words with exceptional spelling. These findings are summarized in Table 5. It can be seen that all three SD patients showed increased percentages of regularization errors, consistent with their pattern of oral reading accuracy and with the Patterson and Hodges hypothesis. In addition, one PNFA patient, two FTD patients and six AD patients Showed increased percentages of regularization errors. All but one of these patients (AD patient FC) also showed an exaggerated regularity effect. Thus, regularization errors tended to co-occur with difficulties in reading exception words, though these deficits are not necessarily related to severity of semantic impairment.

Pseudoword reading was assessed to evaluate orthographic–phonologic processing of linguistic stimuli without semantic value to test the hypothesis that there is no difference between real-word and PW reading in patients with semantic impairment. Among each group of patients were individuals that had difficulty with PW reading at the $z < -1.96$ level. One of the three SD patients (TM) had such difficulty; however, as will be discussed below, TM was a letter-by-letter reader. One of the five FTD patients, one of the

two PNFA patients, and 4 of the 10 AD patients also demonstrated PW reading difficulty.

Consider now the patients' relative difficulty with PW's compared to real words. *Z* scores were computed for the PW effect, consisting of the difference between reading of real words with regular and ambiguous spellings minus reading of PW's with regular and ambiguous spellings. None of the patients demonstrated the significantly decreased PW effect that Patterson and Hodges would predict. In fact, four patients (one FTD and three AD) actually demonstrated a significantly greater PW effect than controls. Moreover, there was no significant correlation across semantically impaired dementia subjects between scores on the semantic measure and the PW effect score [$r(16) = .061$; n.s.].

It is possible that the observed oral-reading difficulties are due to a derangement in phonologic output that has little to do with orthographic processing per se. To assess the phonologic output component of oral reading, patients were asked to repeat words and PW's. Two SD patients, both PNFA patients, three FTD patients, and four AD patients demonstrated difficulty with real-word repetition that differed significantly from control subjects. One SD patient, both PNFA patients, four FTD patients, and five AD patients had difficulty with PW repetition at the $z < -1.96$ level. There was no significant correlation across semantically impaired dementia patients between performance on the semantic task and real-word repetition [$r(16) = -.167$; n.s.] or between performance on the semantic task and PW repetition [$r(16) = -.162$; n.s.].

DISCUSSION

Our results indicate only qualified support for the hypothesis that semantics is critical for binding together the orthographic and phonologic elements of words. Indeed, our observations supporting this hypothesis are far from unambiguous and universal. We argue that this ambiguity may arise out of the fact that the co-occurrence of semantic breakdown and surface alexia may be an anatomical coincidence rather than a necessarily dependent relationship.

To assess single-word reading comprehension, we used a word–picture-matching task. The task requires the subject to access the semantic representation of the word from the orthographic input and then use that semantic representation to correctly match the word to the appropriate pictorial representation. If the semantic representation of the word is degraded, or if orthographical access to this representation is impaired, the subject will perform poorly on the task. Although the task does not distinguish between impaired semantic representation of the item or impaired access to an intact (or degraded) semantic representation, it does provide information as to whether the subject can activate a semantic representation from orthographic informa-

tion. If the subject is unable to use orthography to access a semantic representation, then we presume that the subject will not be able to use semantic information to bind the sublexical elements of the word into a coherent phonological representation, making the task a suitable one for testing hypotheses regarding the role of semantics in oral reading. Word–picture-matching tasks are generally considered good indicators of single-word reading comprehension and have been widely used to measure semantic ability in a variety of patient populations (Parkin, 1993; Price et al., 1998; Glosser et al., 1998; Patterson & Hodges, 1992). However, although the task provides an accurate measure of overall semantic ability, it should be noted that the words used in this task are not the same as those used in the oral reading or repetition tasks; we therefore have no direct measure of the patients' ability to comprehend the words used in these tasks. Nonetheless, we can assume that an impairment in comprehension as measured by the word–picture-matching task would imply a general semantic deficit that would impact upon the patients' ability to read aloud, if the Patterson and Hodges model is correct.

We found that all but two of the dementia subjects demonstrated significantly impaired single-word reading comprehension, as demonstrated on the word–picture-matching task. This impairment of semantics across neurodegenerative disorders allows us to test the generalizability of the Patterson and Hodges hypothesis across many different groups of patients. Consider first the SD patients, the group that showed the most profound semantic impairment and the group around which Patterson and Hodges originally formulated their hypothesis. Each SD patient demonstrated single-word reading comprehension that deviated significantly from normal, which is a defining feature of this condition. Each patient also showed an oral-reading regularity effect that was significantly greater than that which was produced in normal control subjects. In addition, SD patients produced substantially more regularization errors than other patient groups. However, none of the SD patients demonstrated a decrease in the PW effect predicted by the Patterson and Hodges hypothesis.

Other observations of SD patients do not provide strong support for the Patterson and Hodges approach. First, we might have expected that the level of both the regularity effect and the PW effect would reflect the level of semantic impairment in these patients. However, patient TM demonstrated the greatest semantic deficit, yet he did not show the largest regularity effect or PW effect. In addition, both regular real words and PW's should have been accurately read aloud, even in the face of a semantic impairment, as these words have predictable letter–sound correspondences that should lead to accurate phonological production upon reconstruction regardless of semantically mediated sublexical binding. However, two SD patients, TM and GD, did not display this pattern. Both patients showed significantly impaired oral reading of regular real words, and both showed trends toward decreased PW reading accuracy as well. TM's deficits can be explained in part by the

fact that he had become a letter-by-letter reader. Therefore, his difficulty with all types of words was likely to have been multifactorial in nature; that is, due to a semantic deficit as well as a deficit in visual processing that resulted in letter-by-letter reading. At least one other SD patient has been reported who, like TM, evolved into a letter-by-letter reader (Hodges et al., 1994).

While some of the data from SD patients is consistent with the Patterson and Hodges hypothesis, this does not extend to performance of other groups of patients with apparent semantic difficulty. Taken together, these observations detract from the generalizability of Patterson and Hodges' hypothesis.

Consider first the AD patients. A considerable proportion of AD patients are thought to exhibit semantic impairments (Chertkow et al., 1994; Martin & Fedio, 1983; Johnson et al., 1995; Grossman et al., 1996). These patients, like the SD patients, should also have exhibited a performance pattern consistent with the Patterson and Hodges claim, namely an increased regularity effect, an increased proportion of errors of the regularization type, and a decreased pseudoword effect. However, this was not found. All but one of the AD patients demonstrated decreased performance on the semantic task. However, none of the AD patients was significantly impaired in overall reading of real words. Four AD patients showed a significantly increased regularity effect, but one patient (FC) demonstrated a significantly decreased regularity effect. That is, he actually showed a significant advantage for exception words over regular words as compared to controls. FC was in fact the AD patient with the second greatest semantic impairment. Though several AD patients showed a slightly increased tendency to regularize, many demonstrated no regularization errors whatsoever. In addition, not one AD patient showed a significantly decreased PW effect as compared to controls. Three AD patients showed a significantly increased advantage for reading real words over PW's. The Patterson and Hodges model would have difficulty explaining these findings.

Consider next the FTD patients. All but one of these five patients demonstrated a semantic impairment. However, none was significantly impaired in overall real-word reading. In addition, only two of these patients (MD and GS) demonstrated a significantly increased regularity effect. It should be noted that these patients were in fact the two among the FTD patients with the greatest semantic deficit as measured by our word–picture-matching task. In addition, they were the only FTD patients to show a substantial proportion of errors of the regularization type. Not one FTD patient showed a significantly decreased PW effect. In fact, all FTD patients showed a tendency toward an increased PW effect. Furthermore, patient MD, who had the greatest semantic impairment in the group, actually showed a significantly increased PW effect. These findings are difficult to reconcile with the Patterson and Hodges hypothesis. According to their model, if semantics aids in binding together the phonological elements of a word, then compromised seman-

tics should result in the loss of lexical glue and make real-word reading no better than PW reading. Instead, patient MD actually demonstrated greater advantage for real words over PW's as compared to controls. In addition, as mentioned above, the Patterson and Hodges model would not predict that a semantic deficit would lead to a decreased ability in reading PW's, but patient MD was in fact significantly impaired in PW reading. In sum, despite the presence of a semantic deficit, FTD patients do not demonstrate the effects on oral reading that Patterson and Hodges would predict.

Consider now the final group of patients we tested. Like other patient groups, both of the PNFA patients performed significantly below normal on the test of semantic ability. Only one patient, SC, showed a significantly increased regularity effect in oral reading, even though both patient SC and patient PS had equal levels of semantic impairment. Patient PS, however, showed a nonsignificant trend in the opposite direction. In addition, neither subject had a significantly smaller PW effect than that of controls; on the contrary, both had a nonsignificant increase in their PW effect. SC demonstrated significantly impaired PW reading. Once again, this additional impairment would not be predicted under the Patterson and Hodges hypothesis. Finally, patient PS actually displayed normal exception word reading. Although the PNFA patients both showed a significant semantic impairment, they did not show all deficits predicted by the theory, and one showed a deficit not predicted by the theory. These findings do not lend support to the hypothesis of Patterson and Hodges that semantics is necessary for the translation of orthography to phonology.

Our failure to find unambiguous support for the notion that a semantic impairment is invariably associated with impaired lexical phonologic and/or orthographic processing is consistent with several other authors who have provided evidence against the Patterson and Hodges hypothesis. There have been several reports of brain-damaged patients with severe semantic memory deficits whose phonological and/or orthographic processing of exception words is preserved. For example, Cipolotti and Warrington (1995) reported an SD patient whose reading of exception words was remarkably well preserved. It has been demonstrated that AD patients with semantic impairment do not necessarily demonstrate a greater than normal regularity effect (Raymer & Berndt, 1995). In addition, Weekes and Robinson (1997) found that the oral reading of exception words was not impaired in a semantic anomic patient. Finally, in the case of a mentally retarded child with developmental hyperlexia, knowledge of a word's meaning was not found to affect orthographic or phonological processing (Glosser, Grugan, & Friedman, 1997).

Several alternate explanations to the Patterson and Hodges hypothesis have been proposed to explain the association between semantic impairment and surface alexia in SD patients. In one account, Watt, Jokel, and Behrmann (1997) proposed that the development of surface alexia may actually arise

out of the inability to access phonological information from semantics rather than out of a semantic deficit per se. They provided support for this possibility in an SD patient with surface alexia who demonstrated preserved semantic knowledge when assessed on tasks that do not require oral output. The patient could translate orthography directly into phonology, as evidenced by his high degree of accuracy in reading regular words and PW's, and could also access semantics from orthography, as illustrated by good performance on written semantic comprehension tasks. However, performance was poor when an oral output was required in response to a semantic stimulus. Furthermore, the patient's oral reading accuracy was not correlated with semantic knowledge. The investigators concluded that it is actually the link between phonology and semantics that is disrupted in surface alexia and not, as Patterson and Hodges maintain, the decomposition of the orthographic and phonological representations themselves due to deterioration of the semantic system. Since we found difficulties in both real-word and PW reading in SD patients, this particular explanation cannot account for our data.

An alternative account based on anatomical considerations can be entertained to explain why the SD patients have combined deficits in semantic and orthographic processing. Specifically, Semantic Dementia is recognized to result from progressive degeneration that principally affects the inferior temporal regions in the left cerebral hemisphere (Hodges et al., 1992; Mummery et al., 1999). These regions have also been linked to lexical semantic processing in various functional and structural imaging studies (Price et al., 1997; Pugh et al., 1996; Martin et al., 1996; Damasio et al., 1996). Although it has proven difficult to determine through lesion studies the precise locus that causes surface alexia, the syndrome appears to be linked to lesions of the posterior middle temporal region of the left hemisphere (McCarthy & Warrington, 1990). The orthographic lexicon itself has been associated with an area in the infero-lateral extrastriate region of the occipital lobe (Pugh et al., 1996; Petersen et al., 1990). Thus, it is plausible that, as the degeneration centered in the inferior temporal lobe causing the SD patients' profound semantic impairment enlarges posteriorly and superiorly over time as the disease progresses, it may begin to affect the mapping of orthography onto phonology, leading to a surface alexia that may (incorrectly) appear to be caused by the semantic deficit. As the deterioration increases with further disease progression, the reading of words with regular spelling may become affected. Finally, as the degeneration progresses posteriorly over time, we may expect it to affect occipital association regions adjacent to the inferior temporal lobe, including the left inferior temporo-occipital region and left mesial occipital cortex, lesions which have been associated with pure alexia, or letter-by-letter reading (Friedman et al., 1993; McCarthy & Warrington, 1990). Lending support to this explanation, one of our SD patients, TM, has gradually evolved into a letter-by-letter reader, reflecting precisely this type of neurodegenerative progression. Furthermore, TM was the patient who ex-

hibited the greatest degree of semantic impairment. Hodges, Patterson, and Tyler (1994) have also reported an SD patient with a severe semantic impairment who likewise developed a tendency to read in a letter-by-letter fashion.

Although this article has primarily addressed the issue of reading, it is of note that Patterson, Graham, and Hodges (1994) have made claims about the impact of semantics on repetition as well. Specifically, they have reported that SD patients make more errors in repeating short lists of unknown words compared to known words. They conclude that the semantic system also serves to bind together sublexical phonological units. In the present study, several patients showed significant difficulty on both of the repetition tasks. Specifically, both PNFA patients, two SD patients, three FTD patients, and four AD patients demonstrated difficulty with real-word repetition. However, there was no significant correlation across semantically impaired patients between semantic ability and repetition of either real words or PW's. It is therefore possible that an independent phonological deficit accounts for the reading problems in some of the dementia patients, rather than impaired semantics interfering with repetition and oral reading. A number of patients also demonstrated difficulty with repetition without a corresponding reading impairment. This may reflect a milder deficit in phonological processing that results in compromised decoding and encoding of phonological information in repetition, but leaves relatively intact oral reading in which the patient is provided with support of orthographic input to access degraded phonological information.

In sum, we have shown that not all semantic impairments lead equally to the dissolution of semantically mediated sublexical binding that Patterson and colleagues have claimed is essential for maintaining the intact phonological production of exception words during oral reading. We have suggested that additional factors might contribute to reading difficulty among patients with impaired semantics due to a neurodegenerative disorder. For example, an anatomical model was presented in which the co-occurrence of semantic impairment and surface alexia is an artifact of the proximity of regions of progressive neurodegeneration that is found in SD and not in the other forms of dementia. A primary deficit of phonological processing may also contribute to the oral reading difficulties found in some patients. We conclude that the Patterson and Hodges model is difficult to generalize across patient populations.

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