INTRODUCTION

In comparison with other research areas, such as reading, there have been relatively few studies of spelling. Furthermore, spelling is an area where most of the available evidence comes from studies of brain damaged individuals. The majority of these studies have been conducted within the theoretical framework that is schematized in Figure 11.1. According to this framework (see, e.g., Caramazza, 1988; Ellis, 1989), spelling involves a variety of functionally distinct processing components that can be selectively impaired by brain damage. Some of these components are specific to spelling while others are not.

Skilled spellers can produce correct spellings in a variety of contexts and in a variety of formats. In other words, the input can vary (e.g., spoken input in spelling to dictation tasks, visual input in written picture naming tasks), as can the output (e.g., writing, typing, spelling aloud). However, it is assumed that all of these tasks involve abstract orthographic representations that are not tied to a specific modality of input or output. Therefore, we use the term “spelling” to refer in a general sense to the expression of orthographic knowledge regardless of the modality of output.

Another central assumption of the theory depicted in Figure 11.1 is that spelling can be achieved by means of two sets of processes sometimes referred to as lexical and sublexical (or semantic and asemantic). This “dual route” system has been proposed to explain how we can both spell words with which we are familiar and generate plausible spellings for novel words. Consider the situation where you are taking a telephone message from a caller identified as “Colonel Rapp”: If you are unfamiliar with this particular individual you will recognize the spoken form “colonel” and retrieve its spelling. Since, however, you are unfamiliar with the caller you will not have a stored spelling for “Rapp.” Nevertheless, you will still be able to produce a spelling and although it is likely to be “wrong,” it will be phonologically plausible (e.g., “you have a message from Colonel Rap/Rapp/Wrap”). This ability to produce a plausible spelling for a word that has never been seen or heard before relies on the phonology to orthography conversion system (POC), also known as the sublexical or nonlexical route to spelling. This process is assumed to involve the following steps:

1. the acoustic/phonological analysis of the spoken input, and its segmentation into smaller units (i.e., phonemes, syllables, or other functional units);
2. the conversion of each phonological unit into a corresponding orthographic unit;
3. the assembling of these orthographic units into a correctly sequenced abstract letter string.

The POC process calls upon stored knowledge about the possible phoneme–grapheme (PG) correspondences in a given language (e.g., /s/ -> SS, /s/ -> C, etc.), their relative frequency of use (e.g., /s/ is spelled more often with SS than with C) and the context in which they can be applied (e.g., a word initial /s/ cannot be spelled SS). It is often assumed that the POC process applies PG correspondences according to their frequency; high-frequency (high-probability) correspondences are selected more often than low-frequency (low-probability) ones. The functioning of the sublexical route is usually evaluated with the task of spelling to dictation of made-up words ("nonwords") such as "flope" to ensure that all stimuli will be unfamiliar.

Many familiar words such as cat, dog or cup are composed of very common or high-probability PG correspondences. These words are likely to be spelled correctly using the sublexical procedure. However, other familiar words like "phone," "two," or "coat" have less frequent or predictable spellings, and using the sublexical route in such cases might lead to the production of incorrect, yet phonologically plausible responses (e.g., fone, too, cote). We will refer to phonologically plausible errors produced in response to word stimuli as PPEs. Actually, the proportion of words containing ambiguous, or low-probability, spellings is quite large in languages such as English or French. For this reason, it has been proposed that the spelling of familiar words is learned and stored in an orthographic lexicon (at least in such languages). The integrity of the lexical procedure can be assessed by using words with low-probability spellings in a variety of tasks, such a spelling to dictation, written picture naming, or spelling from
definitions. In real life situations, the orthographic lexicon would be involved in spontaneous writing. Depending on the task, other components that are not specific to spelling may also be involved. For example, the phonological lexicon, in which the spoken form of familiar words are stored, would be involved in spelling to dictation, as well as in speech comprehension. Similarly the semantic system (the repository of word meanings) would also be involved in all modalities of word comprehension and production. According to Figure 11.1, the orthographic lexicon is activated by the semantic system. It has also been proposed that direct connections between the phonological and orthographic lexicons are involved in spelling to dictation (for a discussion of the lexical nonsemantic “route” in reading, see Rapp, Folk, & Tainturier, this volume).

In summary, spelling can be achieved by retrieving stored spellings in the orthographic lexicon, or by converting phonological representations into orthographic representations sublexically. It is assumed that up to that point the spelling representations consist of abstract letters that do not yet have a specific format. These will then need to be expressed in a specific modality and format of output: cursive writing, typing, oral spelling, etc. This will involve translating the abstract letter representations into specific letter shapes or letter names via letter-name conversion or letter-shape conversion processes. The role of the graphemic buffer (e.g., Caramazza & Miceli, 1990; Houghton, Glasspool, & Shallice, 1994) is to maintain the activation levels of the abstract letter sequences made available by the lexical or the sublexical spelling processes during the time it takes for the sequential assignment of format-specific information.

The theory of spelling that we have summarized has guided most of the empirical investigations of spelling. Alternative theories have recently been proposed (e.g., Brown & Loosemore, 1994; Campbell, 1983; Van Orden, Jansen op de Haar, & Bosman, 1997). The main differences among theories concern the format of orthographic representations, and the specific nature of the processing components and of their interconnections. However, all models postulate at least two different “routes” to spelling, and seem to agree on the existence of relatively abstract orthographic representations that are independent of input or output format.

In this chapter, we will discuss the following fundamental questions regarding the spelling process: (a) Is spelling contingent upon the prior retrieval of a word’s phonology or can word spellings be retrieved directly from semantics, as suggested in Figure 11.1? (b) Are lexical and sublexical spelling processes strictly independent from one another or do they interact in some way? (c) To what extent do reading and spelling rely on distinct versus shared processing components? (d) What do we know about the internal structure of orthographic representations? (e) Are the different representations employed in the course of spelling format-independent or format-specific?

For each question, we will highlight the specific contribution of cognitive neuropsychological studies. We will also present related evidence from unimpaired adults when available. Due to space limitations, studies of normal or delayed written language acquisition will not be reviewed, although they often include data which are relevant to the theoretical questions that we will address (for recent reviews, see Harris & Hatano, 1999; Hulme & Joshi, 1998; Perfetti & Rieben, 1997; Treiman, 1997).

**THE AUTONOMY OF ORTHOGRAPHY AND PHONOLOGY**

Although spelling is often studied in dictation tasks that necessarily involve phonology, but need not involve semantics, a theory of spelling must also specify how orthographic information is accessed from meaning in order to account for our capacity to spell words in written naming as well as in spontaneous writing.

According to the orthographic autonomy hypothesis, the spellings of words can be retrieved from the orthographic lexicon through direct links with semantics, without any necessary involvement of phonology.
An alternative classical view is that spelling from meaning necessarily involves phonological mediation (e.g., Geshwind, 1969; Luria, 1970; and more recently Perfetti, 1997; Van Orden et al., 1997) (see Figure 11.2). There are two main forms of the obligatory phonological mediation hypothesis. According to one of them phonological words are translated into spellings by a sublexical phonology-to-orthography conversion procedure. Because this process in notoriously unreliable in languages with “deep” orthographies (such as English and French) for words with low probability spellings (e.g., YACHT or CHEF), it has been proposed that sublexical conversion should be followed by a checking procedure involving the orthographic lexicon (Perfetti, 1997). According to the second form of the obligatory phonological mediation hypothesis, word spellings are retrieved from the orthographic lexicon via direct links with the corresponding representations in the phonological lexicon. Under this particular form of the hypothesis, there is no need for an orthographic check, except perhaps in the case of homophones like NUN-NONE (but only if one assumes that homophones only have one stored phonological representation).

The obligatory phonological mediation and orthographic autonomy hypotheses make very different predictions as to the possible effects of brain damage on written naming. According to the phonological mediation hypothesis, a deficit at the level of the phonological lexicon should necessarily affect both spoken and written naming. On the other hand, if the orthographic lexicon can be accessed directly from semantics it should be possible to observe cases with impaired spoken naming due to damage to the phonological lexicon with no corresponding written naming deficit.

Although patients with spoken-naming deficits usually show comparable deficits in written naming, a number of dissociations have been reported (for reviews see Basso, Taborelli, & Vignolo, 1978; Rapp, Benzing, & Caramazza, 1997). However, some of these cases do not speak directly to the issue of orthographic autonomy because the locus of the deficit responsible for the spoken naming impairment is unclear. To test the orthographic autonomy hypothesis, the deficit must be at the level of the phonological lexicon, since this is the component that would be involved in phonologically-mediated written naming. The mere presence of a spoken naming disorder is not sufficient to establish a lexical deficit, because damage at the level of postlexical phonological or articulatory processes would also affect spoken naming. Under either hypothesis, damage to these more peripheral components should not interfere with spelling performance. Although distinguishing between lexical and postlexical damage is not always straightforward, superior written naming has been documented in several cases where spoken naming disorders were likely due to a lexical impairment. Such cases are problematic for the hypothesis of obligatory phonological mediation and provide strong support for the orthographic autonomy hypothesis.

For example, MH (Bub & Kertesz, 1982b) could write the names of 15 out of 20 pictures, although she could only name one orally, producing no response at all in the remaining cases. Crucially, her spoken deficit could be traced to an impairment at the level of the phonological

![Diagram](https://example.com/diagram.png)
lexicon rather than to a more peripheral level. First, her oral expression was very reduced but well articulated and without phonemic errors. Furthermore, MH performed very poorly in tasks designed to assess “inner speech”—that is in tasks that do not involve overt production but nonetheless require internal access to lexical phonology, such as judging whether two pictures correspond to rhyming words or not (for other cases see Hier & Mohr, 1977; Levine, Calvanio, & Popovics, 1982; Tainturier, Moreaud, David, Leek, Pelat, in press).

Another pattern of impaired performance supporting the orthographic autonomy hypothesis was reported by Caramazza and Hillis (1990). The patient they described, RGB, produced many semantic errors in oral naming of pictures (e.g., naming a picture of a tiger as a lion) but none in written naming. It seems unlikely that semantic errors could arise as a result of a postlexical phonological deficit, phonemic errors or neologisms being generally considered as the characteristic error types at this level. Rather, spoken semantic errors are usually considered to have a lexical origin, resulting from impairments to either the semantic system itself or, as was argued in the case of RGB, to the phonological lexicon. Under the phonological mediation hypothesis, one would therefore expect that a patient producing semantic errors in his spoken output would also produce them in his spelling. However, RGB produced no such errors in spelling (other similar cases include Beaton, Guest, & Ved, 1997; Hillis & Caramazza, 1995a; Miceli, Benvegnù, Capasso, & Caramazza, 1997; Miceli, Capasso, & Caramazza, 1999; Nickels, 1992; Rapp et al., 1997; Shelton & Weinrich, 1997).

Finally, cases of modality and grammatical category-specific deficits have been reported. These cases also support the orthographic autonomy hypothesis, as grammatical category-specific impairments are likely to have a lexical origin. For example, PBS (Rapp & Caramazza, 1997a) had a spoken-output deficit which predominantly affected open-class words (i.e., nouns, verbs, and adjectives). In striking contrast, he showed the opposite dissociation in spelling, with content words being relatively well preserved and function words and affixes very impaired. For instance, when asked to describe a picture of a boy washing a car, PBS wrote “BOY WASHED CAR” but said “the /wæd/ are /tæk/ the /tædʒ/ with /læd/ and /tæv/ in a /rɛdɪd/ .” Similarly, HW’s spoken-naming deficit was much more severe for verbs than for nouns but his spelling of both categories of words was preserved (Caramazza & Hillis, 1991). Note that this dissociation between nouns and verbs in spoken naming was observed even when the stimuli were homonyms (e.g., the cut/a cut) which makes it even more unlikely that the deficit had a postlexical origin (see also Rapp & Caramazza, 1998).

In summary, evidence from cognitive neuropsychology suggests that there are direct connections between semantics and orthography and that these connections are sufficient to support accurate spelling performance. It could perhaps be argued that due to persistent deficits in accessing phonology, these patients have developed alternative pathways to spelling that are not normally available. However, a cortical stimulation study of two individuals with normal language abilities (Rapp, Boatman, & Gordon, 1999) recently showed that written naming can be preserved in the context of a temporary and reversible incapacity to access lexical phonology. For example, when stimulated in the left inferoposterior frontal area, subject STS scored 100% correct in written naming but only 29% in spoken naming. This dissociation was not due to a post-lexical articulatory/phonological deficit, as STS remained perfectly capable of reading words aloud.

Of course, the fact that spelling can be produced on the basis of semantics to orthography links alone does not mean that spelling does not involve phonology when phonological information is available, as it might be for unimpaired subjects. One possibility is that phonological mediation may be optional, another is that it may even be obligatory under specific circumstances—such as writing sentences rather than single words.

One source of relevant evidence comes from slips of the pen. The fact that normal subjects occasionally produce homophone substitution errors (e.g., there → their) as well as phonologically plausible nonword errors (e.g., error → errer) suggests that phonology is somehow in-
volved in spelling (Ellis, 1979; Hotopf, 1980). Note, however, that nonphonologically-related slips of the pen (e.g., error → error) are also very common, so that it is difficult to establish how many "true" phonological errors there really are. In addition, slips of the pen are usually obtained from text samples. As a matter of fact, homophone substitutions are often characterized by some blending of adjacent words "...if the lie is not too greater (great a) one to tell" (Hotopf, 1980, page 179). Some recent studies have attempted to show an influence of phonology on reaction times in single-word spelling tasks (that is, in experimental conditions that are closer to those used in testing patients), but these have failed to show reliable effects (Bonin, Fayol, & Gombert, 1997; Bonin, Fayol, & Peereman, 1998). This raises the interesting possibility that phonology is more heavily involved in writing sentences than in writing single words. In line with this suggestion, it seems noteworthy that patients with preserved written naming despite poor access to phonology usually produce "agrammatic" written sentences. That is, they tend to produce short sentences with omissions and/or substitutions of function words and affixes (see, e.g., Bub & Kertesz, 1982b; Rapp & Caramazza, 1996). The apparently greater involvement of phonology in sentence/text writing might be related to the demand on short-term memory being greater for sentences than for single words, since rehearsal in STM is generally believed to involve phonological codes.

In conclusion, there are indications that phonology may be involved (or even obligatory) in writing sentences. However, current evidence does not support the view that phonological mediation is obligatory in writing single words. As a matter of fact, there is no real evidence of phonological effects in single-word spelling in normal adult spellers, although several recent lexical processing models clearly predict that such effects should occur (e.g., Van Orden et al., 1997).

THE INDEPENDENCE OF LEXICAL AND SUBLEXICAL PROCESSES

As mentioned earlier, virtually all accounts of spelling abilities assume the existence of two major processes or routes for translating between phonology and orthography—the lexical and sublexical or nonlexical processes. Although the existence of two processes with these general characteristics has been assumed in most written language research, there is little consensus concerning the specific nature of these processes and the relationships between them. In this section, we will specifically address the following questions: What is the evidence for distinct procedures for spelling familiar versus unfamiliar words? Is there evidence that the two processes interact or integrate information in the course of spelling?

Evidence in Favor of Distinct Lexical and Sublexical Routes to Spelling

The strongest evidence in support of the view that spelling involves at least two distinct sets of processes comes from the observation of brain-damaged individuals who seem to have selectively lost their ability to use one process or the other. Several patients have been reported with spelling impairments indicative of a lexical deficit. Given the framework depicted in Figure 11.1, a breakdown somewhere in the lexical process should: (a) result in greater difficulties spelling words versus nonwords, and (b) manifest itself by the production of phonologically plausible errors (PPEs), since spellings that can not be accessed lexically would have to be generated sublexically. As a consequence, under conditions of lexical damage, words with common (or high-probability) phoneme–grapheme mappings (e.g., cat) should be more likely to

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1British speakers will appreciate the homophony.
2Homophone confusion errors do occur in single-word spelling tasks in patients (e.g., Goodman & Caramazza, 1986). However, this does not inform the debate of the normal involvement of phonology in spelling because these patients clearly have impaired access to orthographic information and, as a result, they may resort to some form of phonological mediation that they would not have used before their disease.
be spelled correctly than words with uncommon (or low probability) mappings (e.g., *yacht*). Furthermore, *yacht* is likely to be spelled in an incorrect though phonologically-plausible manner (e.g., *YAT*, *YATT*, or *YAGHT*).\(^2\)

Beauvois and Derouesné (1981) published the first detailed description of a selective impairment of lexical spelling in a French patient with acquired dysgraphia. Although RG had no difficulty in providing plausible spellings for nonword stimuli, his spelling of words was clearly abnormal and spelling accuracy was a function of the degree of orthographic ambiguity of the words. That is, words that included only high probability mappings were spelled more accurately (93% correct) than words with low–probability mappings (38% correct). Furthermore, most of the errors were phonologically plausible (e.g., *cypres* (cypress) → *sipré*; *rideau* (curtain) → *ridot*). This pattern was clearly indicative of a lesion somewhere along the lexical spelling route. Note however that it could have resulted from a deficit to one or more components along this pathway. More specifically, deficits disrupting access to either the phonological lexicon, the orthographic lexicon or even the semantic system may all lead to selective difficulties in spelling words with low probability mappings. In the case of RG, it was argued that the locus of damage was the orthographic lexicon because (a) spoken and written comprehension were normal (making phonological or semantic deficits unlikely), and (b) he showed a similar pattern of performance in all word spelling tasks, independently of the modality of input (e.g., spontaneous writing, written picture naming, spelling to dictation). Several other cases of dysgraphia reflecting a selective (or predominant) disruption of lexical spelling have been reported since (Baxter & Warrington, 1987; Behrmann & Bub, 1992; De Partz, Seron, & Van der Linden, 1992; Goodman & Caramazza, 1986; Goodman-Shulman & Caramazza, 1987; Hatfield & Patterson, 1983; Parkin, 1993; Sanders & Caramazza, 1990; Weekes & Coltheart, 1996). These cases are often referred to with the label of “surface dysgraphia,” or “lexical agraphia.” Note that in most cases the deficit is only partial and that the probability that a word will be spelled correctly is usually a function of its regularity and of its lexical frequency.

In contrast to a lexical deficit, a selective deficit to sublexical POC processes should manifest itself when spelling unfamiliar words or nonwords, that is with stimuli for which no stored spelling is normally available. Shallice (1981) reported the first case of a brain-damaged patient whose spelling errors were consistent with such a deficit. PR was only 18% correct in spelling nonwords to dictation whereas he was within normal limits (94% correct) in spelling both regular and irregular words. Furthermore, the author noted that when correct production of nonwords occurred, it often seemed to result from the application of some lexically based strategy; for example, when asked to write down the nonword /slm/, PR produced “SYM,” described as the first syllable of “symbol.” In addition, PR was also poor at spelling individual phonemes (56% correct), suggesting that he had lost knowledge of individual phoneme–grapheme mappings. Several other cases of selective or predominant deficit to sublexical processes have been reported since (e.g., Bub & Kertesz, 1982b; Goodman-Shulman & Caramazza, 1987; Roeltgen, 1985; Roeltgen, Sevush, & Heilman, 1983). These cases are often referred to under the label of “phonological dysgraphia.”

In summary, there is strong evidence from cognitive neuropsychology in support of the existence of distinct lexical and sublexical spelling processes. In addition, an interesting outcome of these studies is that they reveal that the lexical system stores the spellings of all familiar words, whether irregular or regular. As argued earlier, the spelling of irregular words must be stored in some way since applying phoneme–grapheme conversion would lead, with some probability, to phonologically plausible errors. It is less obvious whether or not the spelling of regular words are stored as well. An interesting aspect of cases like PR is that they tend to spell all words correctly, regardless of their degree of orthographic ambiguity. Therefore, these cases indicate that all word spellings are stored in the lexical system, provided they

\(^2\)American speakers will appreciate the homophony.
are familiar enough. Were this not the case, a deficit to the nonlexical procedure should affect not only the production of nonwords but also the production of regular words such as "cat." The observation of selective deficits to nonword spelling in languages with shallow orthographies, like Spanish, would strengthen this point, because there is a less obvious need for a lexical spelling process in such languages. However, we are not aware that any such cases have been reported yet, although a selective deficit in nonword reading has been described in a Spanish patient (Cueto, Valle-Arroyo, & Suarez, 1996).

Evidence Suggesting that Lexical and Sublexical Processes are Not Fully Independent

The studies that we have just reviewed clearly support the notion that there are distinct procedures for spelling familiar and unfamiliar stimuli (i.e., words vs. nonwords). It is commonly assumed that, although the two processes may run in parallel, the output of one of these "routes" will ultimately be selected (and the other one suppressed if needed) and then "transferred" to the graphemic buffer in preparation for more peripheral production processes. However, recent evidence from both normal and impaired performance suggests that lexical and sublexical processes are not fully independent (for a review of similar evidence regarding reading, see Rapp, et al. this volume).

Evidence from Dysgraphia

Hillis and Caramazza (1991, 1995a) presented results from four brain-damaged subjects who showed better oral reading and/or spelling to dictation performance than would have been expected based on the level of functioning of either their lexical or sublexical processes alone. For example, JJ (Hillis & Caramazza, 1991) presented with a severe deficit in spoken and written picture naming tasks which primarily resulted in semantically related responses (e.g., a picture of grapes named "banana"). In addition, he often chose the semantic distracter in spoken and written word/picture verification tasks (tasks that do not require producing a word). This pattern points to a deficit at the level of the semantic system, as all input and output modalities were affected in a comparable way (he produced 30–40% semantic errors across tasks). Yet, JJ's ability to read words aloud and to spell them to dictation was largely preserved; crucially, this was true even for words with low-probability spellings (e.g., sweater, stomach, moustache, etc.). JJ's naming and comprehension performance suggested that when he had to rely on the lexical process alone he could no longer select the appropriate response out of a set of semantically related concepts activated by the stimulus (e.g., a picture of a pear or the word PEAR may have yielded a semantic representation equally consistent with bananas, grapes, or pears). However, spelling to dictation differs from naming and comprehension in that sublexical processes can be engaged in addition to lexical ones. If, in spelling to dictation, JJ relied only on the lexical process, he should have produced as many semantic errors as in written picture naming. Alternatively if he relied only on the sublexical process, he should have produced many phonologically plausible errors (PPEs) in response to words with ambiguous spellings (e.g., pears → PARES). Hillis and Caramazza (1991) accounted for the absence of semantic errors and the low rate of PPEs in JJ's writing to dictation by suggesting that the outputs of lexical and sublexical processes were combined to avoid such errors. More specifically, they proposed that the relatively imprecise information provided by the damaged lexical process "summated" with preserved sublexical information to allow correct responses. For example, for the stimulus pear, a sublexically generated output (e.g., PARE) could serve to select the most compatible item among a set of lexically-generated candidates (e.g., banana, grapes, pear, etc.) (See also, Miceli, Capasso, & Caramazza, 1994; Miceli, Giustolisi, & Caramazza, 1991; Miceli et al., 1999).
Further support for the summation hypothesis was provided by case RCM whose semantic errors in spelling tasks seemed attributable to a deficit in accessing the orthographic lexicon (Hillis, Rapp, & Caramazza, 1999). Consistent with this postsemantic (rather than semantic) locus of impairment, RCM made no semantic errors in spoken picture naming or in reading and her comprehension was well preserved. RCM’s word and nonword spelling abilities were evaluated at two times. At Time 1, she produced many semantic errors in both writing to dictation and written picture naming. According to the summation hypothesis, semantic errors in spelling to dictation should have been eliminated (or nearly eliminated) by input from the sublexical system. However, RCM’s sublexical abilities were extremely poor at Time 1: She could not spell any nonwords completely correctly and only 42% of the individual target letters were present in her responses. As further evidence of the severity of the sublexical damage, RCM never produced PPEs when spelling words. Therefore at Time 1 there was little opportunity for sublexical information to reduce semantic error rates. However, by Time 2, RCM’s sublexical processing had significantly improved. Not only did she start producing PPEs (e.g., leopard → LEPORD), but her nonword spelling also significantly improved (67% of target segments were spelled correctly). Crucially, as predicted by the summation account, the improvement in sublexical spelling was accompanied by a substantial reduction in the rate of semantic errors, which dropped from 56% at Time 1 to only 10% at Time 2.

A second line of evidence against strict lexical/sublexical independence comes from the analysis of PPEs. As indicated earlier, studies concentrating on this type of errors (e.g., Baxter & Warrington, 1987; Beauvois & Derouesné, 1981; Goodman & Caramazza, 1986; Sanders & Caramazza, 1990) have revealed that PPEs generally consist in replacing low probability mappings with the most frequent phoneme/grapheme mappings in the language. However, these studies also show that PPEs sometimes include lower probability mappings (e.g., cake → CAIK). This has been interpreted as an indication that that the sublexical conversion process encodes multiple correspondences for each phoneme (e.g., /f/ → F or FF or GH or PH) rather than only the most common one. If correspondences are selected on the basis of their frequency in the language, then frequent mappings should be produced with a high probability but low-frequency mapping should also be observed occasionally.

In addition to these basic observations which are consistent with an independent dual process framework, there have been some indications that PPEs reflect an influence of residual lexical knowledge. This would be more problematic for independent dual process account. For example, Hatfield and Patterson (1983) reported that patient TP, who made primarily PPEs in spelling, also made some errors that suggested partial lexical knowledge (e.g., cough → COUFE and sword → SWARD; see also Ellis, Miller, & Sin, 1983; Miller & Ellis, 1987; Hughes, Graham, Patterson, & Hodges, 1997). The bolded elements in these responses are unlikely to have been generated by the sublexical system and thus these errors suggest a combination of information from lexical and sublexical sources.

This possibility was directly examined in the case of LAT, a patient with probable Alzheimer’s disease whose dysgraphia was characterized by the production of PPEs (Rapp, Epstein, & Tainturier, in press). As we have seen, such errors point to a failure of the lexical process with an increased reliance on sublexical processes when spelling words. However, LAT’s errors often contained lexically correct elements that were of such low PG probability that it was very unlikely that they could have been generated by the sublexical process alone (e.g., bouquet → BOUKET; certain → CERTAINE, knowledge → KNOLIGE). In order to confirm that these low frequency elements corresponded to partial lexical knowledge, LAT was asked to spell words containing low-probability mappings as well as highly similar nonwords that were derived from the word stimuli by substituting a single phoneme (e.g., /l u k El/ derived from bouquet and / fi n o/ from certain). Rapp, Epstein, and Tainturier (in press) found that LAT produced significantly more low frequency target mappings (e.g., /el / → ET, / θ n/ → AIN) in his phonologically plausible yet erroneous responses to words than in his spelling of nonwords.
(e.g., BOUKEt vs. LOKAY; CERTAIN vs. FERTIN). This can be understood if we assume that many of LAT's phonologically plausible errors resulted from the integration of partial lexical knowledge with sublexical information, a conclusion that provides strong support for the hypothesis that lexical and sublexical processes share information during the course of spelling.

Converging Evidence from Studies of Normal Spelling

In summary, an increasing body of evidence from the neuropsychological literature indicates that there is not a strict independence between lexical and sublexical processes. Rather, the results indicate some form of interaction/integration between the routes that goes beyond a mere competition for output. This conclusion is also supported by evidence from nonword spelling in unimpaired adults. Here again, under the hypothesis of a strict independence between the two routes, one would expect that nonword spellings should seldom include very low probability phoneme-grapheme mappings. However, some results suggest otherwise.

Of particular relevance are a series of experiments showing that the orthographic choices that subjects make when spelling nonwords are influenced by the similarity between the nonword target and a neighboring word. It has been demonstrated that nonword spellings can be influenced by the prior presentation of a rhyming “prime” word (Barry & Seymour, 1988, Burden, 1989; Campbell, 1983). In the Campbell study, for example, the spoken nonword /pri:t/ was more likely to be spelled PREET if it followed the spoken word “sweet” and to be spelled PREAT if it followed “meat.” Similar results have been obtained in languages with almost entirely transparentorthographies, such as Spanish (Cuetos, 1993) and Italian (Barry & de Bastiani, 1997).

Although these studies all point to some degree of lexical influence on nonword spelling, it could be that the results do not reflect processes that are normally engaged when people process unfamiliar stimuli. That is, the tasks may have triggered atypical spelling-by-analogy strategies. However, a lexical influence on nonword spelling has been observed even under more indirect priming conditions which seem less susceptible to strategy-based responding (Dixon & Kaminska, 1994; Seymour & Dargie, 1990). That is, significant (though smaller) priming effects were obtained when nonwords were preceded by a semantic associate of a word that rhymed with the nonword target. For example, /bop/ is more likely to be spelled BOPE when it is preceded by Vatican (a semantic associate of POPE) and as BOAP when preceded by detergent (a semantic associate of SOAP). In addition, Tainturier, Bosse, Valdois, and Rapp (in preparation; see also Bosse, Voldois, & Tainturier, submitted for publication) obtained converging results in French using a task that was designed to minimize lexical activation. In all prior experiments subjects heard a list composed of both words and nonwords and had to make a lexical decision before writing down the nonwords. In the Tainturier et al. study, only nonwords were presented and participants were simply requested to write down each nonword using the first spelling that came to mind. Nonwords varied according to whether they did or did not have a close phonologically similar word neighbor. Results revealed that low-probability mappings (e.g., /I/ → il, /o/ → aud) were used more often in spelling nonwords with a close phonological neighbor with that spelling (e.g., /ʒutɪ/ derived from gentil, /ʒati/; /krepo/ derived from crapaud, /krapo/) than in spelling nonwords with no close neighbors (e.g., /myti/; /frapo/).

The effect of lexical neighborhood was relatively small. That is, even though subjects produced more low-probability spellings when nonwords had a word neighbor including that spelling, they did overall use high-probability mappings much more often than low-probability ones.

Mechanisms of Lexical-Sublexical Interaction

Several strands of evidence undermine the view that lexical and sublexical processes are strictly independent from one another and that a single output originating from only one of
these processes is held in the graphemic buffer. First, some patients with lexical deficits produce fewer errors on ambiguous words than would be expected on a strict independence account. Second, PPEs sometimes indicate the integration of residual lexical information with sublexical information. Third, the orthographic choices of unimpaired adults when spelling nonwords to dictation are not a mere function of phoneme/grapheme probabilities but also show a lexical influence.

In attempting to account for such findings, some authors (e.g., Campbell, 1983) have argued against the notion of lexical and sublexical processes altogether and have proposed that nonword spelling occurs entirely via lexical analogy. However, it is not clear how such processes would work and how this proposal can account for the striking dissociations in word versus nonword spelling reported in dysgraphia studies. Similarly, Hillis and Caramazza (1991; 1995a) did not propose a specific mechanism for lexical/sublexical interaction. They simply made the general claim that the sublexical process somehow contributes to the selection of a correct unit in the orthographic lexicon among multiple candidates generated by the lexical process. Although this hypothesis does account for the patterns of performance that these authors have reported (see above), it is not clear how it applies to other findings such as the partial lexical responses of patient LAT and the lexical influence on nonword spelling in normal adults.

Several authors (e.g., Barry, 1988; Kreiner, 1992, 1996; Kreiner & Gough, 1990) have made the general suggestion that lexical and sublexical processes, although not directly influencing each other, may interact at an output level. A more specific proposal for a mechanism of lexical/sublexical integration has been put forward by Rapp, Epstein, & Tainturier (in press; see also Bose et al., submitted; Houghton & Zorzi, submitted; Tainturier, 1996a; Tainturier et al., in preparation). This proposal is based on the notion that the graphemic buffer may be more than a mere short-term repository of outputs independently generated by the lexical or sublexical processes (see Introduction). Instead, the graphemic buffer may be viewed as a level at which graphemic units (i.e., letters, graphemes, orthographic syllables) are represented. Such units would be activated either by the orthographic lexicon, by sublexical POC processes, or both (Figure 11.3). The selection of a letter string for output would result from the integration of these two different sources of activation. This proposal reduces the degree of autonomy of lexical and sublexical processes, in the sense that both processes activate a common level of representation. That is, the spelling of either words or nonwords would be under the combined influence of lexical and sublexical processes (for a similar proposal applied to reading aloud see Coltheart, Curtis, Atkins, & Haller, 1993; Zorzi, Houghton, & Butterworth, 1998). Although various details of the integration process remain to be specified, this general proposal does account for the reviewed findings.

THE AUTONOMY OF READING AND SPELLING

The relationship between reading and spelling processes is one of the most debated and most difficult questions in written language research. One common view (e.g., Caramazza, 1988; Ellis, 1982) is that reading and spelling rely on distinct processing components, with the exception of an amodal semantic system (see Figure 11.4a). An alternative view (e.g., Allport & Funnell, 1981; Behrmann & Bub, 1992; Coltheart & Funnell, 1987), is that reading and spelling depend on shared processing components, with the exception of more peripheral processes (see Figure 11.4b). One issue that has been particularly debated concerns the status of lexical representations. According to the shared-components position, a single orthographic lexicon would be used both in reading and spelling, although the access procedures would probably be task (or modality) specific. In contrast, the distinct-components position distinguishes between an input orthographic lexicon necessary to recognize written words (reading) and an output orthographic lexicon necessary to produce them (spelling). One can similarly ask whether other components such as sublexical conversion or the graphemic buffer are shared in reading and spelling.
Associations between Reading and Spelling

If one excludes cases of peripheral reading disorders (e.g. neglect, visual analysis disorder) that should be “modality” specific and only affect reading under either account, most acquired dyslexic patients also show some form of spelling impairment (although the reverse is less true, see below). This could be taken as prima facie evidence in favor of the view that reading and spelling share some processing components. However, this high rate of associated deficits could merely reflect the fact that the neural substrates of reading and spelling are located in
adjacent or even overlapping brain areas, making it very likely for brain damage to affect both functions to some extent (e.g., Bub & Kertesz, 1982a). This is certainly a plausible hypothesis, although it is difficult to assess at the present time as relatively little is known about the neural bases of reading and especially of spelling.

Nonetheless, it is also true that not only does dysgraphia usually accompany dyslexia but that specific types of dyslexia often co-occur with the very same types of dysgraphia. For example, selective nonword reading disorders are often associated with nonword spelling disorders (e.g., Roeltgen, 1985). Similarly, selective deficits in reading irregular words are usually coupled with similar deficits in spelling irregular words (Baxter & Warrington, 1987; Behrmann & Bub, 1992; De Partz et al., 1992; Kremin, 1985; Hatfield & Patterson, 1983; Newcombe & Marshall, 1985; Parkin, 1993; Saffran, 1985). A similar association between deep dyslexia and deep dysgraphia has also been noted (for a review, see Coltheart, Patterson, & Marshall, 1987; and for more recent cases, Ferreres & Miravalles, 1995; Nickels, 1992; Tainturier, & Caramazza, 1996). These specific patterns of associations place further constraints on the hypothesis that anatomical proximity is responsible for the association of deficits, since this hypothesis must explain why brain damage is more likely to affect independent subcomponents of reading and spelling that perform similar functions (e.g., input and output orthographic lexicons), rather than affecting entirely unrelated reading or spelling components.

Certain studies have reported similarities that go even further. For example, some surface dyslexia/dysgraphia patients show a very high degree of consistency between the specific
Table 11.1
The case of MLB: Rate and Distribution of Errors in Nonword Reading and Spelling.

<table>
<thead>
<tr>
<th></th>
<th>Reading Aloud</th>
<th>Spelling to Dictation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of misspelled nonwords (n = 165)</td>
<td>99/165</td>
<td>98/165</td>
</tr>
<tr>
<td>Number of misspelled segments (n = 759)</td>
<td>127/759</td>
<td>155/759</td>
</tr>
<tr>
<td>Voicing errors (e.g., taple → DAPLE)</td>
<td>60/127</td>
<td>79/127</td>
</tr>
<tr>
<td>Vowel substitutions (nefo → NEFA)</td>
<td>46/127</td>
<td>38/127</td>
</tr>
<tr>
<td>Context errors (e.g., gubar → GIBAR)</td>
<td>10/127</td>
<td>23/127</td>
</tr>
<tr>
<td>Others</td>
<td>11/127</td>
<td>15/127</td>
</tr>
</tbody>
</table>

words that they can read and the specific words that they can spell, even when factors such as word length and frequency are partialed out (Coltheart & Funnell, 1987; Behrmann & Bub, 1992). The case of MLB, a French woman who presented with a severe dysgraphia following head trauma, provides another good example because she showed a striking parallelism in her pattern of errors in reading and spelling nonword stimuli (see Tainturier, 1996b, for a report of the spelling data). MLB seemed to rely almost exclusively on the sublexical process in spelling, such that virtually all lower probability spellings were replaced by more regular ones (e.g., bateau (boat) → BATO). In addition, she produced very specific and unusual substitution errors, indicative of an additional deficit to the sublexical process. In particular, most errors involving consonants consisted in the substitution of a voiced consonant for an unvoiced one and vice-versa (e.g., f → v, d → t, p → b), irrespective of visual similarity and despite the fact that MLB never produced such errors in nonorthographic tasks (e.g., nonword repetition). The results in Table 11.1 show the remarkable degree of similarity in terms of error rate and error types in reading and spelling nonwords to dictation.

The highly detailed way in which impairments in reading and spelling are similar makes it difficult to believe that these associations are purely fortuitous. Nevertheless, striking dissociations between reading and spelling disorders occur in a nonnegligible number of cases, and such dissociations are often taken as evidence of the independence of reading and spelling processes. Accordingly, the next issue we will consider is whether the dissociation cases are clearly incompatible with a shared-components position.

**Dissociations of Reading and Spelling**

Dissociations between reading and spelling are not uncommon following brain damage and they can take different forms. Broadly speaking, either only one of the two skills is noticeably altered, or else they are differentially impaired, either quantitatively or qualitatively. However, these dissociations do not necessarily speak to the issue of the autonomy of reading and spelling for several reasons.

First, as we have seen, peripheral processing components are viewed as modality-specific in all theories. For example, graphic motor deficits should not correlate with reading difficulties. Similarly, a visual deficit may affect reading but not spelling. Second, dissociations between reading and spelling sometimes result from deficits that do not actually involve orthographic components per se. For example, some reading deficits occur as a result of impaired access to phonological rather than orthographic representations. Caramazza and Hillis (1990) described cases HW and RGB, who presented with the characteristic features of deep dyslexia but only had a slight spelling deficit, mostly consisting of letter selection errors. On the surface, this pattern supports the notion of distinct reading/spelling components. However, the authors established that the orthographic lexicon was intact (both subjects had very good written comprehension) and that the semantic errors produced in reading originated from a deficit at
the level of phonological lexicon (semantic errors were also produced in spoken picture naming). Given the locus of the deficit, there is actually no reason to expect a relationship between reading and spelling performance.

Thus, the crucial question is: Do dissociations between reading and spelling occur following damage to components that could be assumed to be shared by both tasks—such as the orthographic lexicon? The answer is that they do (e.g., Beauvois & Derouesné, 1979, 1981; Bub & Kertesz, 1982a; Goodman & Caramazza, 1986; Sanders & Caramazza, 1990; Shallice, 1981). Although it would be beyond the scope of this chapter to review each of theses cases in detail, we will discuss a few points to bear in mind when evaluating such dissociations.

As first pointed out by Allport and Funnell (1981), dissociations between reading and spelling are perfectly compatible with a shared components position if it is the modality specific access procedures rather than the shared representations themselves that are impaired (as can be seen in Figure 11.4b, the orthographic lexicon has two sets of arrows corresponding to modality specific access processes). Unfortunately, it is far from straightforward to establish whether a given pattern of impairment is better accounted for by postulating an access deficit rather than a storage deficit (Rapp & Caramazza, 1993). In other words, at the present time it is very difficult to determine which patients suffer from deficits to the components themselves and, therefore, it is difficult to determine which cases are truly problematic for the shared-components view.

Furthermore, it is possible to reconcile many patterns of dissociations with shared-components models without having to establish whether the deficit is one of access or one of storage. Our main point in the reminder of this section will be that, whatever the exact nature of the deficit, it does not always follow from the shared-components view that reading and spelling disorders should be quantitatively or even qualitatively similar.

With respect to quantitative differences, several facts need to be considered. First, cases of isolated dysgraphia are more common than cases of isolated dyslexia (still excluding peripheral deficits). Second, when both deficits co-occur, the dysgraphia is typically more severe. Third, spelling deficits tend to be less severe when isolated than when associated with reading deficits. For example, case MS (Sanders & Caramazza, 1990) only made errors 9% of the time when spelling low-probability words and he read most words correctly. In contrast, case MP (Behrmann & Bub, 1992) produced a much higher rate of phonologically plausible spelling errors and frequently regularized words in reading. These asymmetries can easily be reconciled with shared representations models if one considers that reading and spelling do not present the same degree of difficulty. For example, damage to a single orthographic lexicon could affect reading less than spelling because in reading an incomplete lexical representation of the spelling of table (e.g., T_BL_) may be sufficient to support identification of the written stimulus. Problems will only arise if the partial information is compatible with more than one answer, that is when a word has close neighbors (e.g., c-t → cat or cot). In spelling, however, the full letter string must be produced and for this a complete lexical representation is required.

The case of MLB (Tainturier, 1996b), discussed earlier, provides a good example of how deceptive quantitative differences between reading and spelling can be. In spelling to dictation, she replaced virtually all low-probability spellings with higher-probability ones (e.g., crapaud/ Krapo/(toad) → CRAPO), indicating a severe deficit to the (output) orthographic lexicon. In reading, she produced similar errors but her performance was far superior (see Table 11.2). Furthermore, when tested in a standard visual lexical decision task in which she had to discriminate between real words (e.g., yacht) and visually related nonwords (e.g., yicht), she was only moderately impaired. Based on these data alone, one might postulate the existence of two distinct deficits, a severe deficit to the orthographic output lexicon, and a milder one to the orthographic input lexicon. However, we administered another lexical decision task in which we prevented the efficient use of partial lexical orthographic information by using homophonic
Table 11.2
The case of MLB: Percent Errors in Spelling, Reading and Word Recognition Tasks.

<table>
<thead>
<tr>
<th>Task</th>
<th>Percent of Errors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spelling to dictation of irregular words</td>
<td>92</td>
</tr>
<tr>
<td>Reading aloud of irregular words</td>
<td>31</td>
</tr>
<tr>
<td>Visual lexical decision with non-homophonic legal nonwords</td>
<td>12</td>
</tr>
<tr>
<td>Visual lexical decision with homophonic nonwords</td>
<td>49 (chance)</td>
</tr>
</tbody>
</table>

nonwords. If her superior performance in reading aloud were really due to better preserved input orthographic representations, then she should be able to distinguish words and nonwords based on their spelling alone, at least in a majority of cases. However, she proved entirely incapable of distinguishing correct from incorrect spellings, suggesting that her capacity to access lexical orthographic representations from print for reading was actually just as impaired as her capacity to access them from sound or meaning for spelling.

Qualitatively different patterns of performance in reading and spelling might also be expected following damage at a common level. For example, we have seen that damage to the orthographic (output) lexicon can give rise to semantic errors in written output tasks because access to the orthographic lexicon for production is semantically driven. However, damage to the orthographic lexicon should not result in semantic errors in reading since the search, in this case, is driven by the letter string. Thus, one might expect confusion among visually-orthographically-related words in reading (e.g., cable → table).

In addition, damage to a common level of processing may not affect word and nonword stimuli to a similar extent. A good illustration of this point comes from recent studies of reading in individuals with damage to the graphemic buffer. Although the graphemic buffer was originally conceived as a component dedicated to spelling (Caramazza, Miceli, Villa, & Romani, 1987), more recently, it has been proposed that it might also be involved in maintaining the level of activation of input representations of a letter string for reading (Caramazza, Capasso, & Miceli, 1996; Hillis & Caramazza, 1995b; Tainturier & Caramazza, 1994). The main empirical motivation for this proposal comes from observations of nonword reading disorders in patients with hypothesized graphemic buffer impairments.

For example, MC (Tainturier & Caramazza, 1994) presented with a characteristic graphemic buffer deficit following surgery to remove a left parietal tumour. That is, he produced spelling errors that reflected a loss of information about the identity and/or order of the letters to be produced (e.g., congress → CONGROSS, giraffe → GRAFFIE). In addition, his performance was comparable for words and nonwords and was not affected by the modality of input (pictures vs. spoken words) or output (written vs. oral spelling). Finally, his spelling showed a marked length effect and accuracy across letter positions within words was a U-shape function, both being typical of graphemic buffer deficits. In contrast to his spelling, MC's reading of words was well within normal limits; he remained an avid reader and only complained about his spelling difficulties. However, he was only about 50% correct in reading nonwords. At first glance, this suggested an additional deficit to sublexical OPC processes. Interestingly though, his nonword reading presented many similarities with his spelling. The errors he made in nonword reading and in spelling were of the same type (letter substitutions, deletions, insertions, and transpositions) and were produced in comparable proportions. MC also showed a length effect and a letter-position effect in nonword reading. Given these similarities, it might be that both the reading and spelling disorders stem from a single deficit to the graphemic buffer. This hypothesis is supported by the fact that other graphemic buffer cases also show poor nonword reading (Annomb, Lemay, de Mattos Pimenta, & Lecours, 1998; Caramazza et al., 1996; Jónsdóttir, Shallice, & Wise, 1996; Katz, 1991), the only clear exception being the case of SE (Posteraro, Zinelli, & Mazzuchi, 1988).
It is commonly assumed (e.g., Ans, Carbonnel, & Valdois, 1998) that in reading access to the orthographic lexicon is based on parallel processing of the letter sequence, whereas sublexical conversion of unfamiliar letter strings involves sequential processing of sublexical units. In contrast, the spelling of both words and nonwords is thought to be a sequential process beyond the level of the graphemic buffer. Poorer performance in reading nonwords versus words may be due to the fact that sequential processing requires that the activation of the letter string representation be maintained over a longer period of time than does parallel processing. If this were the case, one might expect reading performance to deteriorate if familiar words were presented in a format likely to interfere with parallel processing of the input. Consistent with this hypothesis, we observed that MC's word reading accuracy dropped from 99% in standard format to 78% in mirror-reversed format and 68% in recognition of aurally spelled words. In contrast, performance with nonwords was not significantly affected by mode of presentation, as would be expected.

We have considered several examples of differences between reading and spelling that are nonetheless compatible with a shared-components view. However, there are some more problematic cases. Perhaps most striking is the case of RG (Beauvois & Derouesné, 1979, 1981) who presented with opposite patterns of deficits in reading and spelling. That is, RG had selective difficulties reading nonwords (phonological dyslexia) while at the same time he was good at spelling nonwords but poor with irregular words (surface dysgraphia). In this case, a deficit to the orthographic output lexicon and to POC processes was proposed. However, such cases are still subject to alternative interpretations within the shared-components view (i.e., by postulating multiple access deficits).

Converging Evidence from Skilled Readers

The question of whether reading and spelling rely on shared or distinct lexical representations has been addressed in several experiments involving skilled adult readers. One approach has been to look for cross-modal priming effects under the hypothesis that reading a word might facilitate later spelling of the same word and vice versa. Monsell (1987) had subjects write words to dictation without visual feedback. Significant repetition priming was later obtained in a word recognition task. This is consistent with the view that the same lexical entries were activated in both tasks.

Another approach has been to investigate the degree of consistency between reading and spelling errors. In short, the rationale for these studies is that if there is a single lexicon mediating reading and spelling, there should be a systematic relationship between the errors made in both modalities. Holmes and Carruthers (1998) expanded on previous work by Campbell (1987) and Funnell (1992) to investigate this question. They reasoned that the well known superiority of reading over spelling might reflect the fact that partial cues (e.g., incomplete lexical representations) may often provide sufficient information for reading but not for spelling (see above for a similar argument applied to neurological cases). Consequently, item by item consistency might also appear lower than it really is. Holmes and Carruthers (1998) observed that subjects could easily read words that they could not spell. Importantly, however, they could not discriminate between correct spellings and their own misspellings. That is, they failed on an input task that required more precise information than simply reading aloud.

Conclusions

Although the issue of the autonomy of reading and spelling is far from settled, the preponderance of evidence favors a shared-components view or is at least compatible with it. Neverthe-

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1In this task a subject hears sequences of letter names and is asked to say the word to which they correspond (e.g., /di:/ou/ /ˈdʒi:/ → “dog”).
less, future studies may provide cases of dissociations that are clearly incompatible with a shared-components view, especially if more detailed hypotheses about reading and spelling processing are developed. Furthermore, it will be important to consider that while certain components (such as the orthographic lexicon) may be shared, others (such as sublexical conversion processes) may not.

In addition, studies of the effects of remediation on reading and spelling should contribute to the debate, as different predictions can be made with respect to the generalization of treatment effects across modality. In particular, shared-components proposals predict that certain techniques should improve both reading and spelling even if the training itself is limited to one modality. For example, Phillips and Goodall (1995) trained a patient with dyslexia and dysgraphia to read a set of nonwords. Once he had learned to pronounce these printed nonwords accurately, he was then asked to spell them to dictation. He had no problem doing so, using the very same spellings that had been used during the reading training phase. This suggests that the patient had stored the spelling of these nonwords in a lexicon accessible for the purpose of reading or spelling (but see Weekes and Coltheart, 1996).

THE STRUCTURE OF ORTHOGRAPHIC REPRESENTATIONS

What is it that we know when we know the spelling of a word? The original assumption regarding the structure of output orthographic representations was that they merely consisted of linear sequences of abstract letter identities—[R+A+B+B+I+T] (e.g., Caramazza et al., 1987; Wing & Baddeley, 1980). However, several lines of evidence now support the idea that orthographic representations encode more than just letter identity and order.

Evidence from Dysgraphia

Most of the evidence pertaining to the structure of orthographic representations comes from the analysis of the errors patterns of dysgraphic patients. Studies of graphemic buffer deficits have proved particularly revealing. Recall that the role of the graphemic buffer is to maintain the level of activation of orthographic strings generated by the lexical and/or sublexical spelling processes while more peripheral, sequential processes are taking place. Deficits at this level lead to letter substitutions, omissions, additions, and transpositions that are taken to reflect a loss of information about letter identity, order or both. If orthographic output representations were merely linear sequences of letter identities, one would not expect that the nature and position of errors should be affected in any way by the internal organization of the letter strings. Yet, several results suggest the contrary.

First, there is evidence that morphemic structure is encoded in orthographic representations. A first demonstration was provided by the analysis of serial positions effects in the misspellings of case DH (Badecker, Hillis, & Caramazza, 1990). In addition to the characteristic features of a graphemic buffer deficit, DH’s spelling also showed a serial position effect such that the probability of an error on a given letter increased quasi linearly as a function of the position of that letter in the word. Strikingly, however, this pattern only held for monomorphemic words such as “table.” In the case of bimorphemic words such as “darkness,” error rates increased up to the end of the word stem (dark) but then dropped on the first letter of the suffix to increase again on subsequent letters. Badecker et al. (1990) interpreted this finding as an indication that the units retrieved from the orthographic lexicon and later held in the graphemic buffer consist of productive morphemes rather than whole words (see Allen & Badecker, this volume, for a discussion of morphological effects in spelling and other domains).

Caramazza and Miceli (1990) have proposed that orthographic representations also encode information about syllabic structure (see Figure 11.5). They reached this conclusion on the basis of a detailed analysis of the factors that constrained the misspellings of case LB, an
Italian patient with a graphemic buffer deficit. Among other things, LB showed a marked
tendency to simplify the structure of words with complex syllables. For example, letter omis-
sions were frequent in the context of letter clusters, which usually lead to the production of a
simpler syllabic structure (e.g., strada \(\rightarrow\) STADA). However, omissions virtually never occurred
in simple CV sequences, where an omission would create a more complex syllable (that is LB
did not produce errors like creatura \(\rightarrow\) CREATRA). Caramazza and Miceli (1990) have inter-
preted this to mean that the graphosyllabic structure of a letter string forms a distinct dimen-
sion of orthographic representations (but see Jónsdóttir et al., 1996).

In addition, there is strong empirical support for distinct and dissociable representations of
letter identity and of letter doubling information (Caramazza & Miceli, 1990; McCloskey, Badecker,
Goodman-Shulman, & Aliminosa, 1994; Miceli, Benvegnü, Capasso, & Caramazza, 1995; Tainturier
& Caramazza, 1996). For example, the case of SFI (Miceli et al., 1995) had a selective deficit in
the production of double letters leading to errors like leggo \(\rightarrow\) LEGO. The case of FM (Tainturier
& Caramazza, 1996) showed the reverse pattern, with doubling information being much better
preserved than letter identity and order (e.g., umbrelle \(\rightarrow\) UMMOUCAN, ribbon \(\rightarrow\) BROLLLOW).
This relative preservation was specific to double letters and did not apply to other superficially
similar groups of letters such as nonadjacent repeated letters (e.g., CaCtus) or digraphs (e.g.,
roCKet).

Finally, several studies of graphemic buffer deficits have shown that information about
specific letter identities can be lost while knowledge of the consonant/vowel status of these
letters is preserved, suggesting that letter identity and consonant/vowel status may be rep-
resented separately. In several cases (Caramazza & Miceli, 1990; Jónsdóttir et al., 1996; Miceli,
Silveri, & Caramazza, 1985; McCloskey et al., 1994) substitution errors virtually always oc-
curred within class, with consonants being substituted for consonants and vowels for vowels.
That is, errors like table \(\rightarrow\) TACLE were common, but errors like table \(\rightarrow\) TAILE were very
rare. In addition, Cubelli (1991) described two Italian patients who were disproportional-
lly impaired in their production of vowels. CW, a graphemic buffer case, mostly produced substi-
tution errors involving vowels (e.g., davante \(\rightarrow\) DEVUNTA; perduta \(\rightarrow\) PARDETA). Case CF
dropped vowels altogether, yet leaving a blank space between correctly written single conso-
nants or clusters (e.g., bologna \(\rightarrow\) B L GN ).

Converging Evidence from Normal Spelling

Few empirical investigations of the structure of orthographic representations have been car-
ried out in nonbrain-damaged adults. However, what little evidence is available is generally
consistent with neuropsychological research and suggests that orthographic representations

<table>
<thead>
<tr>
<th>Linear hypothesis</th>
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<tbody>
<tr>
<td>(&lt;r&gt; + &lt;a&gt; + &lt;b&gt; + &lt;b&gt; + &lt;i&gt; + &lt;t&gt;)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Multidimensional hypothesis</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\alpha_1)</td>
</tr>
<tr>
<td>(\alpha_2)</td>
</tr>
<tr>
<td>C (\downarrow) V (\uparrow) C</td>
</tr>
<tr>
<td>r (\downarrow) a (\downarrow) b (\downarrow) i (\downarrow) t</td>
</tr>
<tr>
<td>D</td>
</tr>
</tbody>
</table>

Figure 11.5: The structure of orthographic representations.
encode more than just letter identities and order. Some of these results come from the analysis of the temporal time-course of spelling in tasks like handwriting or typing. Using a digitizing tablet to record handwriting movements, Orliaguet and Boé (1993) have studied the production times of French homonyms presented auditorially in a disambiguating context. The context could either point to a monomorphemic use of the word or to an inflected use [e.g., je vais vers (I go 'toward') versus j'aime les vers (I like 'worms'; plural of ver)]. Reaction times and total production times were longer for inflected words, which the authors interpreted as evidence of a cost associated to the application of grammatical rules in the course of spelling (but note that the items were not matched for frequency). In a typing study, Zesiger, Orliaguet, Boé, & Mounoud (1994) also demonstrated an influence of syllabic structure on the temporal course of spelling. More specifically, they showed that the interval between two strokes was shorter if the two corresponding letters belonged to the same syllable (for example, the interval between “a” and “l” was shorter when subjects typed ‘pâl-mier’ as opposed to ‘pa-llette’).

Discussion

In summary, there is considerable evidence that orthographic representations are more than simple linear sequences of abstract letter identities. In particular, various factors such as morphological and syllabic structure, letter doubling and CV status can affect the patterns of errors of dysgraphic subjects or the temporal properties of normal spelling. To account for these various findings, it has been proposed that the relevant processing units may be morphemes rather than words. Furthermore, as indicated in Figure 11.5, the orthographic representations of morphemes may be viewed as having a multidimensional rather than purely linear structure (Caramazza & Miceli, 1990; McCloskey et al., 1994), a proposal inspired from autosegmental phonology (e.g., Clements & Keyser, 1983). The fundamental assumption is that different features of a word's orthography are encoded at functionally distinct levels. An important implication is that each dimension can be selectively damaged, leading to a characteristic pattern of errors. In the case of letter doubling, information about letter quantity is distinct from information about letter identity. This explains how it could be that some patients suffer from a selective loss of doubling information (Miceli et al., 1995) while others present a selective preservation of this feature (e.g., Tainturier & Caramazza, 1996). Multidimensional proposals also explain why some patients retain good knowledge of the consonant/vowel status of letters without being able to access their specific identity.

Although the multidimensional view of orthographic representations has been developed to account for the performance of dysgraphic subjects, it could in principle also guide research on the influence of orthographic structure in normal spelling. For example, this framework makes specific predictions as to which types of errors are more or less likely to occur in slips of the pen.

THE DISTINCTION BETWEEN FORMAT-INDEPENDENT AND FORMAT-SPECIFIC REPRESENTATIONS IN THE SPELLING SYSTEM

A fundamental assumption of most theories of spelling is that the representations manipulated by the more central components of the spelling process—the orthographic lexicon, the POC system and the graphemic buffer—are distinct from those manipulated by the more peripheral letter shape and letter name conversion mechanisms (see Figure 11.1). Furthermore, it is specifically assumed that this difference corresponds to a distinction between abstract, format-independent representations of letter identity and format-specific ones. In this framework, orthographic information represented in a format-independent manner serves as the basis for a subsequent translation into specific formats, that is into letter shapes for written spelling and letter names for oral spelling. Although this is certainly computationally sensible, it is by
no means the only logical possibility (for example, see Lesser, 1990). An alternative hypothesis is that the central processes represent letter identities in a format-specific code, as either letter names or letter shapes. This format-specific code could then be translated into other format-specific codes depending on task demands. The question we will consider in this section is: What is the empirical evidence for the format-independent/format specific representational distinction?

The claim that central spelling mechanisms represent letter identity in an abstract, format-independent manner gains some support from individuals whose performance with both words and nonwords is strikingly similar in written and oral spelling, both in terms of error rates and error type distribution (Caramazza & Miceli, 1990; Caramazza, et al., 1987; Hillis & Caramazza, 1989; Jónsdóttir et al., 1996; Katz, 1991; McCloskey et al., 1994; Piccirilli, Petrillo, & Poli, 1992; Posteraro et al., 1988). This evidence suggests a common format for the oral and written spelling of words and nonwords, but does not specifically indicate if the representations are format independent or specific, and if the latter, whether they consist of letter names or letter shapes. More informative in this regard is the finding that damage that affects spelling in one format (e.g., letter names) need not affect spelling production in the other format (letter shapes). For example, Kinsbourne and Warrington (1965) described a subject whose accuracy in oral spelling was only 7% while written spelling accuracy was 93% (see also Bub & Kertesz, 1982). In a complementary manner, individuals have been described whose oral spelling was relatively intact but who, although they exhibited no generalized motor deficits, had difficulty with written spelling (Anderson, Damasio, & Damasio, 1990; Baxter & Warrington, 1986; Black, Behrmann, Bass, & Hacker, 1989; De Bastiani, & Barry, 1989; Friedman & Alexander, 1989; Goodman & Caramazza, 1986; Kinsbourne & Rosenfield, 1974; Patterson & Wing, 1989; Rapp & Caramazza, 1989, 1997; Rothi & Heilman, 1981; Zangwill, 1954).

Rapp and Caramazza (1997b) provided strong support for the distinction between format-independent and format-specific representations by comparing the characteristics of errors arising from failures of the letter-shape conversion mechanism and those arising from graphemic buffer deficits. Rapp and Caramazza (1997b) first examined the written letter substitution errors of two subjects, HL and JGE, who produced substitutions errors almost entirely in written and not oral spelling (e.g., when asked to spell eye, JGE said "i, wat, /" but wrote F-Y-E). The largely intact oral spelling indicates that the orthographic lexicon and graphemic buffer are relatively intact and, thus, the written spelling errors indicate a deficit in letter-shape conversion. Their errors were analyzed to determine if targets and responses (e.g., E → F in the example above) shared visuo-spatial and/or motoric characteristics. For example, A and R are visuo-spatially similar, but not motorically; in contrast, L and T are motorically similar but not visuo-spatially. The results indicated that for both subjects the proportion of letter substitutions that shared motoric characteristics far exceeded what might be expected by a random pairing of letters, whereas rates of visuo-spatially similar substitutions occurred at chance level rates (panels A & B of Figure 11.6). Therefore, these findings specifically argue for an abstract motoric encoding of shape information by the letter-shape conversion mechanism. This conclusion is consistent with the observations by other investigators that targets and errors in the written letter substitutions of impaired (and unimpaired) subjects share what could loosely be described as a physical resemblance. Previous work did not, however, specifically distinguish between visuo-spatial and motoric resemblance (Black et al., 1989; De Bastiani & Barry, 1989; Hatfield & Patterson, 1983; Lambert, Viader, Eustache, & Morin, 1994; Weekes, 1994; Zangwill, 1954). The Rapp and Caramazza (1997) results do not, of course, preclude the possibility of there being multiple levels of letter shape representation. Thus, some researchers have suggested that letter shape information is represented in both visuo-spatial and abstract motor codes (e.g., Ellis, 1979, 1988; Margolin, 1984). The Rapp and Caramazza findings do, however, reveal that letter shape is, at a minimum, represented in an abstract motoric format.

Rapp and Caramazza then reanalyzed the written substitution errors produced by two previ-
Figure 11.6: Comparison of observed levels of different errors with rates expected by chance for J.G.E. (panel A), H.L. (panel B), L.B. (panel C), and H.E. (panel D). Adapted with permission from, "From Graphemes to Abstract Letter Shapes: Levels of Representation in Written Spelling," by B. Rapp and A. Caramazza, 1997, Journal of Experimental Psychology: Human Perception and Performance, 3(4), 1130–1152. Copyright © 1997 by the American Psychological Association.
ously reported individuals, LB (Caramaza & Miceli, 1990) and HE (McCloskey et al., 1994). In contrast with JGE and HL, LB and HE exhibited a highly similar pattern of response in written and oral spelling and their deficits were localized to the graphemic buffer. If the representations at this level are indeed format-independent, then neither motoric nor visuospatial similarity between targets and responses would be expected. Indeed, it was found that neither LB nor HE produced visuo-spatially similar or motorically similar substitutions at a rate higher than chance (panels C & D, of Figure 11.6).

Finally, Rapp and Caramazza (1997) considered the rates of consonant/vowel status preservation in the substitution errors of these four subjects. As indicated above, the substitution of consonants for consonants and vowels for vowels has been observed in a number of cases with graphemic buffer damage, supporting the hypothesis that abstract, format-independent letter representations encode abstract features such as consonant/vowel status. Consistent with this, LB and HE’s errors exhibited extremely high rates of preservation of C/V status (99% and 90%, respectively). There is, however, no reason to assume that C/V information should be included in letter-shape representations and thus high C/V preservation rates would not be expected for JGE and HL’s written substitution errors. This is, in fact, what Rapp and Caramazza found: JGE and HL’s consonant/vowel preservation rates were 59% and 73%, respectively (well below the rates observed for LB and HE and well within chance rates for JGE, and only just slightly above chance levels for HL).

In sum, cognitive neuropsychological evidence provides strong support for the distinction between format-independent and format-specific representational types that is a fundamental assumption of most current theories of spelling. Although there is considerable work in the normal literature concerned with investigating the nature of the motoric codes used in handwriting (e.g., Ellis, 1982; Teulings, Thomasen, & van Galen, 1986; Viviani & Terzuolo, 1980), this literature has not been specifically concerned with distinguishing format-specific from format-independent codes. Presumably, however, questions concerning representational format and when in the course of spelling different representational types are deployed can also be investigated with unimpaired subjects.

CONCLUSION

As indicated at the beginning of the chapter, spelling is perhaps the cognitive domain where the study of deficits most clearly constitutes the predominant source of evidence. In this chapter, we have shown how this research has revealed a highly structured system with a rich representational structure. It is our hope that work with impaired and unimpaired subjects will build upon these developments to investigate the very large number of yet unanswered questions regarding our ability to retrieve and produce the spellings of words.

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