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## The processing of inflected and derived words in writing

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### ABSTRACT

We report on an English-speaking, aphasic individual (RB) with a spelling deficit more severely affecting orthographically irregular words for which phonologically plausible errors (PPEs) were produced. PPEs were observed for all word forms, with the exception of inflectional suffixes, despite the irregular sound-print mappings of many inflectional suffixes (e.g., *walked* → /wɔkt/). RB's pattern replicates that reported in Badecker, Rapp, and Caramazza (Badecker, W., Rapp, B., & Caramazza, A. (1996). Lexical Morphology and the Two Orthographic Routes. *Cognitive Neuropsychology*, 13, 161–176). We extended their investigation by examining RB's spelling of derived words and found a selective deficit for derived words compared to inflected words in writing. This selective deficit did not appear to reflect differences in morphological transparency or suffix frequencies that exist between inflection and derivation. This is the first evidence that distinct neural mechanisms support inflection and derivation in spelling.

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Words encode multiple features of meaning and grammar, which might result in an extremely large number of words that speakers and writers need to acquire. Morphology represents a solution adopted by languages, in varying degrees, to meet this challenge. As morphology introduces systematic and predictable variations of existing words, speakers and writers need to acquire fewer new words to express some aspects of semantics and syntax. For example, *paint*, *paints*, *painted*, and *painting* are variations of the same English word, each denoting when and how many participate in the event of painting. Therefore, no new words have to be coined for communicating this information. Linguists have long recognized that even within individual languages, morphology takes different forms. A major distinction concerns inflection and derivation, of which the words *paints* and *painted* and the words *painter* and *paintable* represent corresponding examples. This distinction is the focus of the present study, in which we specifically investigate the extent to which different neuro-functional mechanisms underlie the processing of inflections and derivations.

The standard intuition in linguistics is that inflection is concerned with syntactically driven word-formation whereas derivation is used to create new words. Linguistic research has traditionally concentrated on

identifying whether specific linguistic features distribute contrastingly between inflection and derivation (Anderson, 1992; Booij, 2006; Haspelmath, 2002; Katamba & Stonham, 2006; Scalise, 1988). One of the most cited differences, for example, is that while derivations change word-class (as in *paint*, verb → *painter*, noun), inflections do not. Despite the many linguistic observations supporting this claim, several cases of inflections also undergoing word-class change have been identified cross-linguistically (Haspelmath, 1996; Scalise, 1988). A noticeable example is found in English with *-ing* verbs (e.g., *raising*) that can be used as (deverbal) nouns (as in *my raising of this issue*). This is not an isolated case, as contravening examples have been found for other proposed criteria (Booij, 2006; Haspelmath, 2002; Katamba & Stonham, 2006; Stephany, 1982). The difficulties encountered in defining clear-cut criteria have led researchers to question the approach in which inflection and derivation are viewed as completely distinct typologies. Alternatively, it was proposed to view this distinction as a graded one, in which some forms represent prototypical cases of inflections and derivations. These prototypical cases are the end-points of a continuum on which intermediate cases exist as well (Dressler, 1989; Plank, 1994; Stephany, 1982). Another solution, advanced by Booij (1996), is to split inflection into

two components so that, along with derivation, we have a tripartition. One component, contextual inflection, includes forms that are obligatorily determined by syntax (e.g., in agreement), whereas the other component, inherent inflection, comprises forms encoding discretionary features like number or tense that in part depend on the meaning speakers want to express rather than being entirely dictated by syntax. In yet another approach, the distinction between inflection and derivation has been portrayed in terms of different forms of interactions with semantics (Bybee, 1985) or syntax (Anderson, 1992; Perlmutter, 1988). In sum, while a strong case has been made against the approach in which inflection and derivation are distinct morphological forms, no unifying hypothesis has emerged from the linguistic debate on what differentiates inflection from derivation. This does not mean, however, that in linguistics the distinction has been rejected.

The distinction between inflection and derivation is rooted not only in the linguistic features described above, but also in variables related to language use potentially affecting word processing, including frequency and morphological transparency (Amenta & Crepaldi, 2012; Baayen, Milin, Đurđević, Hendrix, & Marelli, 2011; Bauer, 2001; Bybee, 2007; Clahsen, 1999; Cholin, Rapp, & Miozzo, 2010; Ford, Davis, & Marslen-Wilson, 2010; Marslen-Wilson, Tyler, Waksler, & Older, 1994). In many languages inflectional suffixes typically occur more frequently than derivational suffixes. In this respect, English represents an illustrative example, in part because with most of the words in a given grammatical category (e.g., verbs) a specific inflectional suffix is required to express certain syntactic or semantic features (Haspelmath, 1996; Scalise, 1988), a constraint that does not apply so rigidly to derivational suffixes, as derivation is one of the options speakers have to encode certain meaning. Thus, the occurrences of the inflectional suffixes appearing with English nouns and verbs greatly outnumber the occurrences of the most frequent derivational suffix, *-er* (Hay & Baayen, 2003). Differences between inflection and derivation could arise from word processes sensitive to frequency. Similar differences could emerge from morphological transparency, the degree to which the meaning of the whole word is inferable from its components. To illustrate this point with examples from English, inflected words are typically highly transparent,

whereas only some derived words are comparably transparent and many others are rather opaque—compare *painter*, who is someone who paints, and *waiter*, who is not necessarily someone who waits. To the extent that there is evidence suggesting that morphological transparency affects word processing (Amenta & Crepaldi, 2012; Baayen et al., 2011; Marslen-Wilson et al., 1994; Seidenberg & Gonnerman, 2000; Taft, 1994), this feature could contribute to the appearance of a distinction between inflection and derivation. Importantly, because frequency and morphological transparency are both graded in nature, distinctions between inflections and derivations stemming from these variables would also be graded.

Evidence supporting the distinction between inflection and derivation was found in neuropsychology, taking the form of a double dissociation, with deficits more severely affecting either inflection or derivation. In the first report of this kind (Miceli & Caramazza, 1988), the inflection deficit observed in an Italian speaker appeared in spontaneous and elicited speech, though it was especially distinctive in repetition. Repetition errors, most of which (96.5%) resulted in the production of incorrect morphological forms, were common with inflections (96%) but very rare with derivations (4%). Other investigations using a variety of tasks have also described deficits more severely affecting inflections (Kohn & Melvold, 2000; Laine, Niemi, Koivuselkä-Sallinen, & Hyönä, 1995). In another report (Badecker & Caramazza, 1987), the deficit in speaking for inflected words was systematically investigated in tasks where words were read aloud. The contrasting deficit—problems with derivation—was observed in the speech of patients with right hemisphere lesions affecting subcortical regions, primarily the *caudate nucleus* and the *corona radiata* (Marangolo & Piras, 2008). It is important to note that the deficits more selectively affecting inflection or derivation appeared in the context of impaired speech and were interpreted as being caused by deficits to the semantic, morphological, and phonological processes involved in speaking. A question these studies raise is whether the dissociation between inflection and derivation appears in deficits selectively affecting writing, a finding which would suggest that inflection and derivation are distinctly represented and processed within the morphological system specifically dedicated to writing.

Neuropsychological findings have revealed that morphology is duplicated in the systems supporting spoken and written production, respectively. Strong evidence comes from modality-specific morphological deficits (Rapp, Fischer-Baum, & Miozzo, 2015) in which inflections were incorrectly produced primarily in one modality (e.g., writing) but preserved in the other modality (e.g., speaking). While these data reveal that morphology is distinctly encoded in both writing and speaking, they also motivate the question whether morphological information is similarly organized in writing as in speaking. Crucial data for this question were collected in prior neuropsychological studies (for review see Rapp & Fischer-Baum, 2014). For example, it was shown that writing errors reflect word morphological organization, and thus errors might differ in rate and typology between stems and affixes (Badecker, Hillis, & Caramazza, 1990; Shuster & Miozzo, 2016). In this respect, the orthographic representations of words accessed in writing appear to be as sensitive to morphology as those accessed in speaking. Determining whether the distinction between inflection and derivation found in speaking extends to writing would further our understanding of the extent to which morphology is similarly processed across production modalities.

The findings of Badecker, Rapp, and Caramazza (1996) provided the starting point for the present investigation. They reported on an individual with acquired surface dysgraphia, a spelling deficit more severely affecting orthographically irregular words for which phonologically plausible errors (PPEs) are produced (Rapp & Fischer-Baum, 2014). Alternative sound-print mappings are used in PPEs, as shown by the example *soap* → *sope*. Although incorrectly spelled, *sope* can be read as /sɒp/ like the target word *soap*. Badecker et al. (1996) found that PPEs were conspicuously rare with suffixes and confined to stems. A typical error was *surf*ed → *sourphed*, in which the suffix -ed was spelled correctly despite its orthographic irregularity as, in this case, the suffix -ed maps onto the phoneme /t/ of /sɜrft/. Suffixes like -ed and -s are orthographically irregular because they realize different phonemes (and allomorphs) depending on the phonological makeup of the stem. Thus, the phonemes corresponding to -ed are /t/ (*camped*, [kæmpt]), /d/ (*called*, [kɔld]) or /əd/ (*reported*, [rɪpɔrtəd]), whereas the phonemes corresponding to -s are /s/ (*cats*, [kæts]) or /z/ (*dogs*, [dagz]; *vases* →

[veɪsəz]). Badecker et al. (1996) focused on inflected words. It is presently unknown whether PPEs would also be rare with derivational affixes for which similar PPE opportunities exist in English. Take, for example, the suffix -al that marks nouns derived from verbs, as in *arrive* → *arrival*. Alternative spellings of -al that would result in PPEs include, for example, -le and -el. Whether or not derivational suffixes are subjected to PPEs in acquired surface dysgraphia would shed light on whether inflection and derivation are differently processed in writing. Evidence that PPEs are similarly rare with inflection and derivation would support the hypothesis of shared morphological mechanisms. In contrast, evidence that PPEs occur with derivational suffixes would indicate that derivation is processed separately from inflection. These alternative predictions were tested with an English speaker whose acquired spelling deficit showed the characteristic features of surface dysgraphia and, crucially, relative preservation of inflectional suffixes. The primary goals of the present investigation were to determine whether or not the spelling deficit affected derivation and/or inflection and to understand what may be causing this disparity. In particular, specific tests were conducted to establish whether the discrepant abilities to write inflected and derived words reflected differences with suffix frequencies or transparency, graded variables for which systematic differences exist between these two classes of words.

## Case presentation

RB is a male native English speaker who received a college degree and worked as a payroll specialist for a large company. At the age of 61, RB suffered a middle cerebral artery infarct that, as revealed by a CT scan, caused brain damage to left temporal and parietal lobes, with mass effect on the posterior horn of the left lateral ventricle. RB participated in the current study five years post stroke. RB's speech was fluent with occasional hesitations, word-finding failures, and, rarely, lexical errors. In the latter type of responses, RB produced either semantically related words (*violin* → "harmonica") or phonologically related words (*harshly* → "hardly") that he eventually recognized as incorrect. Writing was intelligible but impaired. Preliminary tests aimed to assess RB's writing impairment and determine the presence of

language deficits that could affect RB's performance in the writing tasks used in our investigation.

### Spoken word recognition and repetition

Recognition of spoken words was tested using a spoken word-picture matching task (PALPA 47; Kay, Lesser, & Coltheart, 1992). Foils in this task consisted of (a) two semantically related distractors differing in degree of relatedness, (b) one visually related distractor, and (c) one unrelated distractor; for example, the foils of *button* were *zipper*, *bow*, *coin*, and *banknote*. RB responded correctly on every trial (40/40). We also tested the repetition of monosyllabic, monomorphemic words and monosyllabic non-words ( $N = 80$ ). His two errors were *got* → "gut," and *plea* → "plead."

### Spoken production of inflections and derivations

Different tasks were used to assess RB's production of inflections and derivations in speaking. In one task, RB was presented with sentences read aloud by the experimenter in which RB would complete an inflected or derived word whose stem was cued. For example, when presented with "The dog barks. Yesterday the dog \_\_\_\_" RB was expected to say "barked," whereas for the sentence "He likes to teach. He is a \_\_\_\_" the correct response was "teacher." The variety of inflectional and derivational suffixes we tested in this sentence completion task was as diverse as the one examined in spelling (see below). Accuracy was comparably high for inflected and derived words (112/113, 99% vs. 84/87, 97%). RB's four errors were: *aggressive* → "aggressiveness," *yellowish* → "yellowing," *citizenship* → "citisism," *grill* → "grills."

The spoken production of verb and noun inflections was further tested using a picture-naming task. Pictures of actions were also presented with a sentence to prompt the verb tense (e.g., Yesterday he \_\_\_\_). We tested words with overt inflections (plural for nouns; present singular, present active, and past tense for verbs;  $N = 113$ ) and zero inflections (singular

for nouns; infinitive for verbs;  $N = 54$ ). RB invariably produced the correct inflection. Additionally, pictures were shown to prompt the naming of derived nouns carrying the suffixes -al, -er, -ery, and -or, such as *sailor*, *toaster*, and *urinal*. No sentence was provided for the derived nouns. Since there are fewer depictable derived nouns, RB was tested on only 21 pictures. RB correctly named 21/21 derived nouns.

### Written production

Writing was mainly assessed using a dictation task. RB was instructed to repeat the auditorily presented word before writing. On the rare occasions in which RB appeared to have misheard the target word, the experimenter presented it again. Disambiguating information was provided when requested. RB's first complete response was scored. (Note: the same procedure was used in every writing-to-dictation task that RB performed).

### Words

Length and frequency effects were examined using the Johns Hopkins Dysgraphia Battery (Goodman & Caramazza, 1985). Accuracy was comparable across words varying for length (4–8 letters;  $\chi^2(4) = 3.1$ ,  $p = .54$ , Yates' correction applied) but was greater for high vs. low frequency words (89% vs. 59%;  $\chi^2(1) = 25.79$ ,  $p < .001$ ). Effects of orthographic regularity were examined using word lists designed to assess this feature that were included in the Johns Hopkins Dysgraphia Battery and PALPA (Kay et al., 1992). Both lists were tested twice. Words were grouped by frequencies (high vs. low) using counts from the HAL corpus and the corpus mean as a cut-off mark (Balota et al., 2007). Greater accuracy with orthographically regular words was found with low frequency words (74% vs. 53%;  $\chi^2(1) = 6.26$ ,  $p < .02$ ; see summary in Table 1). Furthermore, a frequency effect (high > low) appeared with orthographically irregular words (84% vs. 53%;  $\chi^2(1) = 21.92$ ,  $p < .0001$ ).

The errors RB made in the tests presented above were classified as either phonologically plausible, simple, complex, or morphological. Phonologically plausible errors (PPEs) consisted of misspelled responses that maintained the correct pronunciation of the word, as in *giraffe* → *jurraf*. As in previous studies (e.g., Badecker et al., 1996; Rapp, Epstein, & Tainturier, 2002), PPEs were determined based on the sound-letter mapping

**Table 1.** Number of words (%) varying for sound-print mapping probability and frequency spelled correctly by RB.

Frequency	Sound-print Mapping Probability	
	High	Low
High	42/50 (84%)	79/94 (84%)
Low	37/50 (74%)	55/104 (53%)



probabilities listed in Hanna, Hanna, Hodges, and Rudorf (1966). Here, as in every other analysis, we used mapping probabilities corresponding to specific syllable positions. Incorrect responses that could not be considered PPEs were classified as simple errors when a word consisted of only one type of the following errors: substitution (e.g., *chief* → *chiaf*), transposition (e.g., *extend* → *exdent*), addition (e.g., *abuse* → *abusie*), or omission (e.g., *friend* → *frind*). Complex errors were characterized by a combination of simple errors (e.g., *pigeon* → *pidgent*). Morphological errors were responses in which an affix was incorrectly added, substituted, or omitted (e.g., *drive* → *driving*). PPEs accounted for the majority (60%) of the 198 errors made by RB. The remaining incorrect responses included complex errors (21%), simple errors (15%), morphological errors (4%) and one “don’t know” response. Most of the simple errors (67%) resulted from letter substitutions.

Written picture naming was evaluated using items from the Johns Hopkins Dysgraphia Battery. RB correctly spelled 36/50 (72%) of the words. Similar to his performance in writing-to-dictation, the majority of errors were PPEs (64%; 9/14). The remaining errors consisted of substitutions ( $N = 2$ ), complex errors ( $N = 2$ ), and a single lexical error (*tiger* → *zebra*).

A more direct test of orthographic regularity was undertaken by examining phonemes that, in English, map onto various graphemes with different probabilities. For example, /m/ is more likely to correspond to *m*, as in *clam*, than *mb*, as in *comb*. We selected 38 word-pairs in which the same phoneme is realized in different ways, one with a mapping probability lower than .05, the other with a mapping probability higher than .05, according to data from Hanna et al. (1966). Word pairs were matched for length and surface frequency. Furthermore, phonemes mapped onto a comparable number of letters in high vs. low probability mappings. The critical phonemes were spelled more accurately when corresponding to high vs. low probability mappings (71% vs. 42%;  $\chi^2(1) = 8.22, p = .004$ ). In 16/22 of the low probability errors, the incorrect letter(s) had a higher mapping probability than the correct letter(s), as in the example *cello* → *chellor*.

### Non-words

The writing of non-words was assessed using items from the Johns Hopkins Dysgraphia Battery. RB produced phonologically plausible spellings for 16/34

(47%) non-words. RB’s nonword errors consisted of two lexicalizations (*wundoe* → *window*; *murnee* → *murmur*), 13 simple errors (e.g., *boke* → *doke*), and three complex errors (e.g., *haygrid* → *cadger*).

### Summary

RB’s writing deficit comprises multiple components. Various features of RB’s writing—such as the frequency effect, the predominance of errors with letters having low probability phoneme-grapheme mappings, and the high incidence of PPEs—indicate a reduced availability of word orthography that characterizes surface dysgraphia. This problem led RB to rely on sound-print transcoding procedures, particularly with low frequency words. As shown by RB’s low accuracy with non-words (47%), sound-print transcoding procedures were impaired, although to a degree that still permitted them to contribute to spelling, as evidenced by the numerous PPEs.

## Experimental investigation

### Inflected words

We first determined whether RB could correctly write inflections as Badecker et al. (1996) demonstrated with their participant whose dysgraphia was in many respects similar to RB’s. We tested the inflections of plural nouns and past-tense verbs, morphemes that are orthographically ambiguous as shown by the fact that they correspond to multiple sounds: -s maps onto /s/ (*lamps* → [læmps]) or /z/ (*chairs* → [tʃɛrz]; *vases* → [veisəz]); -ed maps onto /d/ (*arrived* → [əraɪvd]), /t/ (*camped* → [kæmpt]), or /əd/ (*rented* → [rentəd]).

The -s and -ed inflections we tested mapped onto all possible allomorphs (-/s/, -/z/, and -/əz/; -/t/, -/d/, and -/əd/). The verbs bearing the different allomorphs were matched ( $p > .05$ ) for number of letters, and surface and lemma frequencies (see summary in Table 2). Nouns were similarly matched with the exception of lemma frequency ( $F(2, 127) = 4.52, p < .05$ ). As revealed by post-hoc analyses, the difference reflected the higher frequency of words bearing the -/əz/ allomorph relative to those words bearing the allomorph -/s/. In this and all other analyses, log-transformed frequency counts were used for matching. All of the words were produced in both writing-to-dictation and sentence completion. The words tested in

**Table 2.** Inflected nouns and verbs tested in writing to dictation and sentence completion.

Sound-print Mapping	N	Number of Letters <sup>a</sup> Mean (SD)	Lemma Frequency <sup>b</sup> Mean (SD)	Surface Frequency <sup>b</sup> Mean (SD)
<i>Plural Nouns</i>				
/s/ → -s	50	4.4 (1.0)	32 (65)	7 (9)
/z/ → -s	50	4.3 (1.0)	46 (75)	12 (18)
/əz/ → -es	30	4.8 (1.1)	69 (112)	15 (24)
Differences (range)		0.1–0.5 (0–0.1)	14–37 (47–10)	3–8 (9–15)
<i>Past Tense Verbs</i>				
/t/ → -ed	30	6.5 (0.9)	107 (281)	10 (25)
/d/ → -ed	30	6.4 (1.1)	67 (92)	6 (8)
/əd/ → -ed	30	6.7 (0.8)	66 (89)	6 (8)
Difference (range)		0.1–0.3 (0.1–0.3)	1–41 (3–192)	0–4 (0–17)

<sup>a</sup>For nouns we report the number of letters in the stem; note that nouns carrying the -es suffix were one-letter longer.

<sup>b</sup>Counts per million words (from CELEX; Baayen, Piepenbrock, & Van Rijn, 1993).

writing-to-dictation were embedded in longer lists that were comprised of mono- and multimorphemic words. Words were elicited in the sentence completion task by showing pictures of objects or actions along with written sentences read out loud by the experimenter. Sentences were intended to prompt noun plural inflections (e.g., “Here are two \_\_\_” [vases]) or verb past-tense inflections (e.g., “Yesterday, the dog \_\_\_” [barked]). Although nouns and verbs were presented in sentence completion only with other nouns or verbs, a mix of other inflections was included as fillers (e.g., singular nouns or verbs bearing the inflectional suffix -ing or -s).

Since RB’s responses differed neither for accuracy nor error type between writing-to-dictation and sentence completion, combined analyses were performed within each word type.

Stems and inflections were analyzed separately. Stem accuracy was comparable between nouns and verbs (76% vs. 71%). Many of the stem errors were PPEs, both with nouns (64%) and verbs (47%). In marked contrast to stems, inflections were produced quite accurately (382/400; 96%, nouns and verbs combined).

The inflections -s and -ed are orthographically irregular because the mappings s → /z/ and d → /t/ are inconsistent when compared with the more predictable mappings s → /s/ and d → /d/. Another source of irregularity concerns the letter e in -ed, which does not map onto any phonemes—consider, for example, *moved* → /muvd/ or *camped* → /kæmpt/. RB correctly spelled 192/200 (96%) of the letters s and d corresponding to the phonemes /z/ and /t/,

and 113/120 (94%) of the silent e vowel in -ed. It is worth mentioning that RB was similarly correct when the letter d of -ed corresponded to /d/ (98%) or to /t/ (95%;  $\chi^2(1) < 1$ , Yates’ correction applied). The same pattern was found with the letter s of the noun plural inflection -s (s → /s/: 99% correct; s → /z/: 96% correct;  $\chi^2(1) < 1$ , Yates’ correction applied). As revealed by these results, the production of inflections did not vary as a function of the consistency of phoneme-grapheme mappings.

The few errors involving inflections consisted mostly of PPEs (13/18); the remaining errors were three omissions (e.g., *spoons* → spoon), one suffix substitution (*badges* → badging), and one unrelated response (*vase* → ear). By inspecting the inflection PPEs shown in Table 3, it is clear that 10/13 errors could alternatively be classified as letter omissions (e.g., *booed* → bood), letter substitutions (e.g., *lunches* → lunchis), or letter transpositions (e.g., *prayed* → prade). That is, only 3 of the 400 inflections produced by RB are unequivocally classifiable as PPEs (*bumped* → bumpt; *clipped* → clipt; *tapped* → tapt).

Inflections were further examined using pseudo-words introduced either as nouns or verbs. For each pseudo-noun, we first presented the picture of a made-up object and its name (e.g., “This is a *snard*”), followed by two of those objects and the plural name (“These are two *snards*”). With pseudo-verbs, RB was shown a picture of, for example, a person balancing a ball on his nose, while the experimenter said: “This person likes to *dif*. Yesterday, he *diffed*.” RB repeated the inflected pseudo-word before writing it. All pseudo-words were monosyllabic. The noun plural inflection corresponded to either /s/ (N = 5) or /z/ (N = 8), whereas the past-tense verb inflection

**Table 3.** PPEs produced by RB with inflectional suffixes.

Sound-print Mapping	Target Word	RB’s Response
<i>Plural Nouns</i>		
/z/ → -s	<i>cri<u>s</u></i>	cr <u>i</u> se
/əz/ → -es	<i>lunch<u>e</u>s</i> <i>ax<u>e</u>s</i> <i>bench<u>e</u>s</i>	lunch <u>i</u> s ax <u>i</u> s bench <u>i</u> s
<i>Past Tense Verbs</i>		
/t/ → -ed	<i>bump<u>e</u>d</i> <i>clipp<u>e</u>d</i> <i>tapp<u>e</u>d</i>	bump <u>t</u> cl <u>i</u> p <u>t</u> tap <u>t</u>
/d/ → -ed	<i>bo<u>o</u>ed</i> <i>hammer<u>e</u>d</i> <i>pr<u>a</u>yed</i>	bo <u>o</u> d hammer <u>r</u> pr <u>a</u> de
/əd/ → -ed	<i>pr<u>a</u>yed</i> <i>count<u>e</u>d</i> <i>end<u>e</u>d</i>	pr <u>a</u> id count <u>i</u> d end <u>i</u> d

corresponded to either /t/ ( $N = 27$ ) or /d/ ( $N = 15$ ). RB was correct with 50/55 (91%) stems. Crucially, 52/55 (95%) inflections were spelled correctly. The only 3 errors were due to an omitted e (“geeled” → geild; “beeled” → beald; “troed” → trod).

RB’s highly correct production of inflections closely replicated the findings previously reported by Badecker et al. (1996). The preservation of inflections might reflect their morphological status. However, there are “non-morphological” explanations one has to rule out before reaching this conclusion. Below we examine whether RB’s accuracy with inflections stemmed from graphotactic constraints or, as suggested by Badecker et al. (1996), the preservation of ambiguous letters occurring in final word position, and/or the possibility that specific morphological forms were used instead of certain phonemes (e.g., -ed for /t/ in word final position, so that *camped* [kæmpt] would be written as *camp* but *smart* as *smared*).

### Graphotactic constraints?

The PPEs occurring so profusely with stems might not have surfaced with inflections because they typically violate graphotactic constraints of English orthography in this environment. The inflected verb *barked* illustrates this point: RB may not have produced the PPE *barkt* because the letter sequence *kt* is not legal in English. The account that RB’s correct spelling of inflections stemmed from graphotactic constraints gains plausibility if we consider that children who otherwise depend extensively on phoneme-to-grapheme conversion in the early stages of spelling acquisition write inflections quite accurately (Nunes, Bryant, & Bindman, 1997), relying on their knowledge of letter-combination frequencies (Kemp & Bryant, 2003; Pacton, Fayol, & Perruchet, 2005). To test whether graphotactic constraints determined the lack of PPEs observed in RB with inflections, we examined past-tense verbs in which PPEs would not violate such constraints. An example is the PPE *failed* → *faild*. The past-tense verbs we tested ended with the phonemes /ld/ ( $N = 19$ ), /rd/ ( $N = 19$ ), /pt/ ( $N = 13$ ), and /st/ ( $N = 3$ ) and were presented along with a variety of other inflectional and derivational forms tested in writing-to-dictation. PPEs occurred in 15/54 stems, accounting for 62% (15/24) of the errors involving the verb stems. RB was correct with 94% of the verb inflections and all 3 errors were phonologically plausible errors (*mailed* → *maild*; *hammered* → *hammerd*;

*bumped* → *bumpt*). It is also worth mentioning that, throughout the whole corpus of words written, RB made errors in which graphotactic violations occurred (e.g., *axxis*, *arrivle*, *sqwel*, *ywon*), suggesting that this type of error could not be easily blocked. In essence, even when graphotactically plausible, PPEs were rarely produced with inflections.

### Letter position?

Another possibility is that RB is especially accurate with ambiguous letters occurring in final word position(s). This was tested using words bearing one of three final phonemes that can be written in multiple ways: /k/ → *c*, *ck*, or *k*; /n/ → *n* or *gn*; /f/ → *f*, *ff*, or *ph*. RB was correct with 48/120 (40%) of these words and with 72/120 (60%) of their final phonemes. Errors with final letter(s) consisted primarily of PPEs (41/47, 87%). These results reveal that orthographically ambiguous letters in final position were produced less accurately than inflections (61% vs. 96%).

### A morphological spelling?

A third possibility is that RB tended to write the phonemes /d/ and /t/ occurring in word final position as inflectional morphemes, thus mapping /d/ and /t/ onto *ed*. Under this sort of account, the letters *d* and *t* in word final position would be replaced by *-ed* even in monomorphemic words like in *recommend* [rɛkəmənd] → *recommened* or *erupt* [ɪrʌpt] → *eruped*. We tested this prediction using “unique” verbs—i.e., verbs that did not have homophonic/homographic twins in another grammatical category. Verbs were presented in their uninflected, bare forms, and ended with the letter *d* ( $N = 20$ ) or *t* ( $N = 30$ ). In only one instance did RB incorrectly produce the letters *ed* in word end position (*consult* [kənsʌlt] → *consuled*).

To summarize, we replicated the key findings of Badecker et al. (1996). First, PPEs were confined to stems and virtually absent in inflections. Second, the preservation of inflections seems to derive from their morphological status.

### Derived words

In multiple writing-to-dictation tasks we examined whether suffixes of derived words were similarly immune to PPEs as inflected words. To this end, we tested derivational suffixes that were orthographically



irregular and therefore could lead to PPEs. The words tested in these tasks were embedded in longer lists that also comprised inflected and monomorphemic words.

In a first task, RB wrote to dictation a total of 191 words containing a variety of derivational suffixes (-able, -ful, -less, -ness, -ize, -ment, -ive, -ity, and -ist) that could result in PPEs, since alternative plausible spellings exist for them in American English (Venezky, 1999). Examples include *-less* → *les*, and *-ize* → *ise*. RB correctly spelled 95/191 (50%) of the derived words and 141/191 (74%) of their suffixes. PPEs accounted for most of the errors with stems (52/67; 78%) and suffixes (36/50; 72%). Of the errors that were not PPEs only 4 were morphologically related (e.g., *finalist* → *finalize*).

The second task was undertaken not only to replicate the results of the first task but also to directly compare derived and monomorphemic words. Specifically, we tested words in which the letters -al, -er, -ery and -or represent suffixes (e.g., *arrival* and *camper*) and those words in which they do not (e.g., *crystal* and *corner*). Importantly, the incorrect spelling of these letters can result in PPEs, as shown by the alternative spelling of *arrival*: *arrivle*, *arrivel*, *arrivil*, and *arrivo!* (Hanna et al., 1966). We reasoned that if suffixes are preserved because of their morphological status, letters should be produced correctly within the derived words but not within the monomorphemic words. Derived words ( $N = 169$ ) and their monomorphemic pairs ( $N = 169$ ) were matched ( $p > .05$ ) for number of letters, and surface and lemma frequencies (see summary in Table 4).

Whole word accuracy was comparable between derived and monomorphemic words (44% vs. 42%;  $\chi^2(1) < 1$ ). Critically, the production of letters comprising the derivational suffixes were similar to the corresponding letters in monomorphemic words, in terms of both accuracy (62% and 66%;  $\chi^2(1) < 1$ ) and PPE

rates (88% and 96% of the errors;  $\chi^2(1) = 2.14$ ,  $p > .05$ , Yates' correction applied). See summary in Table 5 of RB's accuracy and PPE rates for words carrying each of the four final letter combinations. As in the other task, very few of the non-PPEs errors with mono- and multimorphemic words were morphologically related ( $N = 5$ ).

Further analyses aimed to establish more firmly whether RB's spelling of derivational suffixes was driven by sound-print mapping probabilities. We expected RB to be more accurate with those letters in the derivational suffixes that were more strongly associated with the corresponding sounds as compared to those letters with weaker associations. The letters we examined comprised derivational suffixes from both tasks that were produced correctly ( $N = 246$ ) or induced errors with clear sound-letter correspondences (PPEs,  $N = 92$ ; simple errors,  $N = 8$ ). Letters were sorted into two groups, depending on their probability mappings from Hanna et al. (1966). Letters in one group ( $N = 550$ ) had the highest mapping probabilities. An example is *l* in *-ful*; */l/* → *l* was the most frequent mapping involving the letter *l* (.94) in final position. The letters in the other group ( $N = 306$ ) did not have the highest mapping probabilities (e.g., */z/* → *z* in *-ize* was .25, while the highest probability mapping, */z/* → *s*, was .64). Letters for which there is a more probable mapping were expected to be more vulnerable. Indeed, they were spelled significantly less accurately than those with the highest mapping probabilities (8% vs. 27%;  $\chi^2(1) = 32.13$ ,  $p < .001$ ), a result revealing that the spelling of derivational suffixes was strongly affected by the predictability of their sound-print correspondences. Other results showed that mapping probabilities were also at play with the PPEs produced with derivational suffixes. First, these PPEs were more likely to involve those letters with relatively low mapping probabilities compared to those with the highest mapping probabilities (18% vs. 6%;  $\chi^2(1) = 33.03$ ,  $p < .001$ ). Second, letters with relatively low mapping probabilities were consistently replaced, in these PPEs, by letters with higher mapping probabilities ( $t(56) = 20.59$ ,  $p < .001$ ), even though other mappings were possible for those letters. To the extent that effects of mapping probabilities indicate a reliance on non-lexical mechanisms of spelling, evidence that such probabilities reliably predicted the occurrence and types of PPEs reinforces the conclusion that non-

**Table 4.** Matched derived and monomorphemic words tested in writing to dictation.

Type of Words	<i>N</i>	Number of Letters Mean (SD)	Lemma Frequency <sup>a</sup> Mean (SD)	Surface Frequency <sup>a</sup> Mean (SD)
Derived ( <i>arrival</i> , <i>camper</i> )	169	7.3 (1.2)	16 (20)	11 (13)
Monomorphemic ( <i>crystal</i> , <i>corner</i> )	169	7.1 (1.3)	18 (28)	13 (0.5)
Difference		0.2 (0.1)	2 (8)	2 (12.5)

<sup>a</sup>Counts per million words (from CELEX; Baayen et al., 1993).

**Table 5.** Correct responses and PPEs with derived and monomorphemic words bearing identical final letters (e.g., *arrival*, *camper* vs. *crystal*, *corner*) tested in writing to dictation.

Final Letters	N	Derived				N	Monomorphemic			
		Accuracy		PPEs <sup>a</sup>			Accuracy		PPEs <sup>a</sup>	
		Whole Word	Final Letters	Whole Word	Final Letters		Whole Word	Final Letters	Whole Word	Final Letters
-al	50	38%	56%	58%	95%	50	28%	56%	64%	86%
-er	50	62%	86%	58%	57%	50	58%	86%	62%	100%
-or	50	38%	52%	68%	92%	50	40%	62%	70%	100%
-ery	19	26%	42%	79%	82%	19	42%	53%	55%	100%

<sup>a</sup>PPEs are calculated out of the total number of errors.

lexical mechanisms were primarily responsible for the PPEs observed with derivational suffixes.

Additional analyses were conducted to determine whether morphological transparency and the frequency of derivational suffixes were additional variables affecting RB's spelling accuracy with derivational suffixes from both tasks. Morphological transparency ratings were obtained from 10 English speakers who judged how easily the meaning of the whole word could be inferred by its morphological elements. Ratings were expressed on a 5-point scale, where 1 corresponded to "very opaque," and 5 to "very transparent." The (mean) morphological transparency ratings ranged, across words, from 1.4 to 5 (quartiles: 1st = 3.7; 2nd = 4.3; 3rd = 4.6). Suffix frequencies were obtained from Hay and Baayen (2003). Morphological transparency ratings and (log-transformed) suffix frequencies were entered in a binomial regression as predictors of RB's accuracy with the derivational suffixes along with word length (number of letters), (log-transformed) word frequencies (CELEX; Baayen et al., 1993), and a measure of sound-print mapping probabilities. Because probabilities were not available for the mapping /i/ → y, 332 words were used for the analysis. Consistent with the finding presented above, which showed sensitivity to letters with low mapping probabilities, we used the lowest mapping probabilities (Hanna et al., 1966) of letters forming the derivational suffix. For example, for the letters in -ful, we used the mapping probability of the letter u, which was the lowest (f = .88; u = .08; l = .84). The model was significant ( $\chi^2(5) = 22.433$ ,  $p < .001$ ), with Nagelkerke  $R^2$  equal to .09. Confirming the results reported above, there was an effect of mapping probabilities ( $p = .02$ ). However, neither morphological transparency nor suffix frequency appeared to be significant predictors.

To summarize, the letters forming derivational suffixes were indistinguishable from matched letters in monomorphemic words, for both accuracy and

PPE rates, and analyses revealed that the spelling of derivational suffixes depended on how strongly sounds were associated with letters. In these respects, derivational suffixes contrasted sharply with inflectional suffixes. Furthermore, there was no evidence that morphological transparency or suffix frequency affected the spelling of derivational suffixes. It therefore seems unlikely that these variables underlie the stark differences we found between inflection and derivation in RB's spelling. Nevertheless, the role of these variables was tested further in the task presented in the next section.

### Inflection vs. derivation

The English morpheme -er corresponds either to an inflection marking the adjectival comparative form, as in *higher*, or to a derivational suffix denoting an agentive noun derived from a verb, as in *teacher*. Furthermore, both of these suffixes typically appear in morphologically transparent words. Importantly, counts for CELEX (Baayen et al., 1993) show that these morphemes have very similar type frequencies, occurring in 870 adjectives and 819 derived nouns. Furthermore, (log-transformed) surface frequencies were comparatively higher for -er derived nouns ( $t(1649) = 7.86$ ,  $p < .001$ ). Its double status, frequency distributions, and morphological transparency make -er an ideal test case for determining whether the advantage found with inflections reflected their frequencies.

RB was presented with 68 -er adjectives and 68 -er derived nouns, matched ( $p > .05$ ) for number of letters and surface frequency (see summary in Table 6). These words were embedded in lists that contained the derived and inflected words we tested in the writing-to-dictation tasks described above. Stem accuracy was similar between -er adjectives and -er derived nouns (74% vs. 70%;  $\chi^2(1) < 1$ ). Importantly,

**Table 6.** Matched inflected and derived words bearing the suffix -er tested in writing to dictation.

Suffix	N	Number of Letters Mean (SD)	Surface Frequency <sup>a</sup> Mean (SD)
Inflectional -er ( <i>higher, smaller</i> )	68	6.5 (0.8)	10 (19)
Derivational -er ( <i>teacher, camper</i> )	68	6.7 (0.9)	12 (16)
Difference		0.2 (0.1)	2 (3)

<sup>a</sup>Counts per million words (from CELEX; Baayen et al., 1993).

RB wrote -er more often correctly as an inflection than as a derivational suffix (99% vs. 88%;  $\chi^2(1) = 4.28$ ,  $p < .05$ , Yates' correction applied). A further difference emerged with PPEs, which occurred in 6/9 errors with derivational suffixes but never with inflections. In short, no support for explanations based on morpheme frequency or morphological transparency was found from -er adjectives and -er derived nouns. Instead, the discrepancies between the -er morphemes provide strong evidence that inflection and derivation can be distinctly impaired.

### The orthographic representation of inflections

Although differing in many respects, models of writing generally agree that writing is supported by two basic mechanisms: lexical, which has access to memorized information about the specific orthography of a word, and sub-lexical, which relies on procedures for sound-print transcoding that typically yield the most probable spelling (Ellis, 2016; Graham, Patterson, & Hodges, 1997; Houghton & Zorzi, 2003; Rapp & Fischer-Baum, 2014). These basic assumptions provide a framework for interpreting a deficit including many of the features of surface dysgraphia. Problems with orthographically irregular words and low frequency words would result from impaired lexical mechanisms, whereas PPEs would originate from responses supplied by sub-lexical mechanisms. As observed by Badecker et al. (1996), these basic assumptions would also provide the basis for a possible explanation of the preservation of inflections in surface dysgraphia. To the extent that the spellings of orthographically irregular inflections like -s and -ed are available in the lexical mechanisms, then these inflections will be fairly impermeable to the contribution of sub-lexical mechanisms that would otherwise produce PPEs. Although this represents a plausible explanation, it would be desirable to have evidence probing more directly at the nature of the

contribution of sub-lexical mechanisms on RB's writing of inflections. Such evidence was pursued using articulatory suppression, a procedure that has been proved to successfully hinder sub-lexical spelling mechanisms (Damian, Dorjee, & Stadthagen-Gonzalez, 2011; Folk, Rapp, & Goldrick, 2002; Zhang & Damian, 2010). The effect of articulatory suppression on RB's writing of inflections will shed light on the role played by sub-lexical mechanisms.

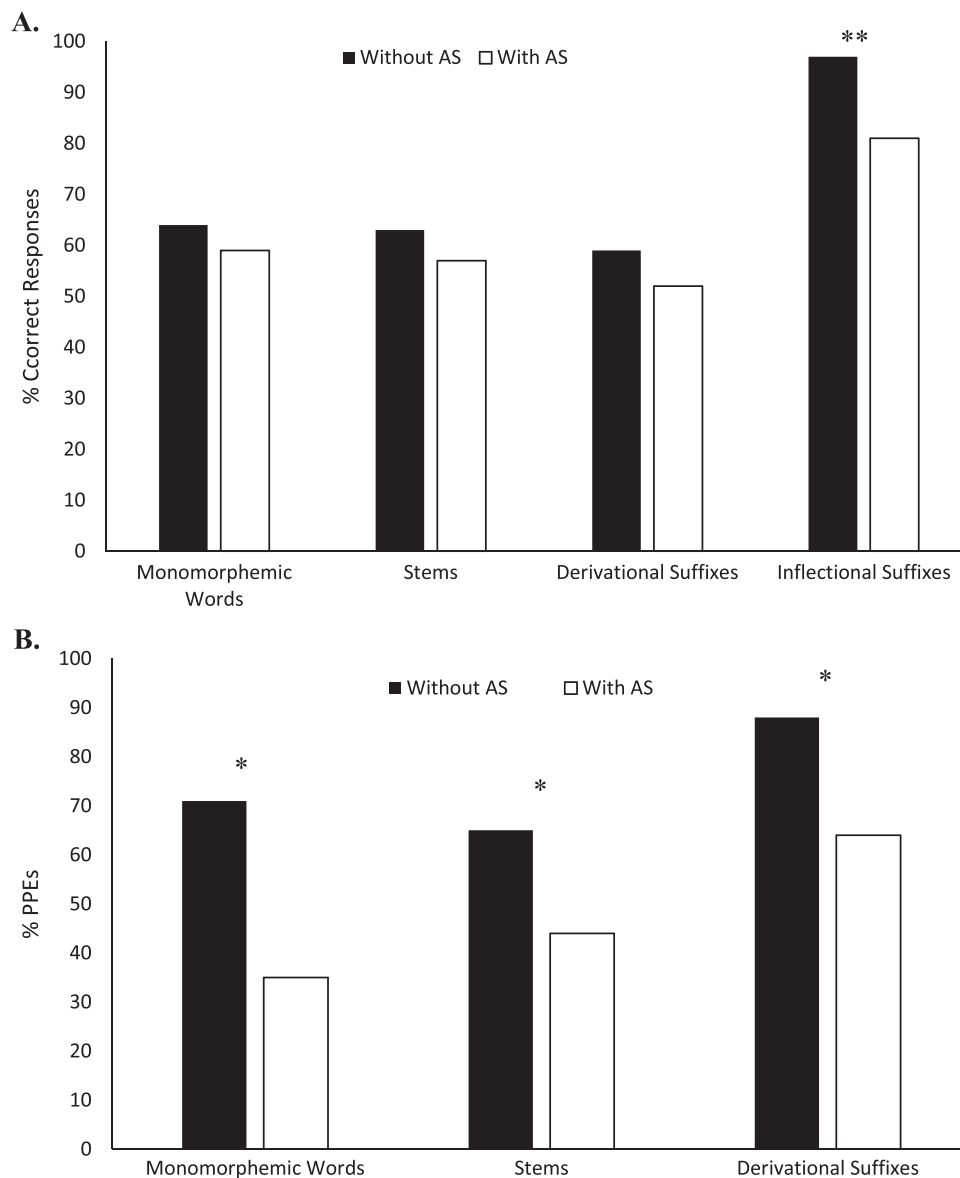
Articulatory suppression, which can be induced by the continuous repetition of a syllable (e.g., "ba, ba, ba...") during writing, hampers rehearsal, which in turn weakens the phonological trace held in the articulatory buffer (Baddeley, Thomson, & Buchanan, 1975). As a phonological trace needs to be available while sound-print transcoding takes place, weakening of the phonological trace should adversely affect sub-lexical spelling mechanisms. Crucially, articulatory suppression affects the types of errors produced in surface dysgraphia, reducing PPEs but increasing other types of errors, as demonstrated by Folk et al. (2002; but see also Papagno & Girelli, 2005). In particular, articulatory suppression was found to increase the number of errors in which another word from the lexical neighborhood was produced (e.g., *loaf* → *leaf*). The change in error pattern can be explained by assuming a parallel change in the contribution of sub-lexical spelling mechanisms. Without articulatory suppression, the spelling supplied by the sub-lexical mechanisms would determine the PPEs, which, in turn, might reduce the occurrence of errors resulting from impaired lexical spelling mechanisms. However, as fewer PPEs should occur with articulatory suppression, it is likely that the rate of lexically based errors would increase. The replication of these findings is a benchmark result for showing the effectiveness of articulatory suppression, which we planned to achieve by testing items that we found to induce PPEs with RB.

Words were presented in two variants of a writing-to-dictation task: one with articulatory suppression, the other without it. Three groups of words were tested in both variants of the task: (a) monomorphemic words ( $N = 105$ ) that were classified as orthographically irregular in published lists (e.g., Johns Hopkins Dysgraphia Battery); (b) derived words ( $N = 105$ ) carrying the orthographically irregular suffixes -al, -er, and -or that, as shown above, induced PPEs; and (c) inflected words ( $N = 105$ ) that were either past-tense verbs taking the allomorphs -/d/, -/t/, or

-/əd/, or plural nouns taking the allomorphs -/z/, -/s/, or -/əz/. As in Folk et al. (2002), articulatory suppression was induced by instructing RB to say “ba, ba, ba” while writing the word. An ABBA design was used to counterbalance task conditions.

Effects of articulatory suppression were determined by comparing RB’s responses with articulatory suppression and without it (see Figure 1). Articulatory suppression did not affect accuracy with monomorphemic words ( $\chi^2(1) < 1$ ), the stems of derived words ( $\chi^2(1) = 2.86, p > .05$ ), the stems of inflected words ( $\chi^2(1) < 1$ ), and derivational suffixes ( $\chi^2(1) < 1$ ). However, fewer inflectional morphemes were

correctly produced with articulatory suppression (81% vs. 97%,  $\chi^2(1) = 14.11, p < .001$ ). PPEs accounted for fewer of the errors caused by articulatory suppression with monomorphemic words ( $\chi^2(1) = 10.57, p = .001$ ), the stems of derived words ( $\chi^2(1) = 3.11, p = .08$ ), the stems of inflected words ( $\chi^2(1) = 3.64, p = .06$ ), and derivational suffixes ( $\chi^2(1) = 7.38, p = .007$ ). With inflectional suffixes, PPEs occurred as rarely as without articulatory suppression ( $N = 2$ ). Errors in which another word from the lexical neighborhood was produced (*sword* → *source*) replaced the PPEs with monomorphemic and derived words, and in part explained the error increase with inflected



**Figure 1.** Correct responses (Panel A) and PPEs (Panel B) made by RB while writing monomorphemic words, stems, and affixes with and without articulatory suppression (AS). Derivational and inflectional stems combined. \*  $p < .01$ ; \*\*  $p < .001$ .

words. For all the words tested, the rate of this type of lexical error increased (monomorphemic: 8% vs. 21%; derived: 3% vs. 13%; inflected: 8% vs. 24%; all words combined: 6% vs. 19%,  $\chi^2(1) = 11.14$ ,  $p < .001$ ).

By showing that accuracy was unchanged by articulatory suppression due to the decrease in PPEs and the contrasting increase of lexical errors, the results with monomorphemic words, stems, and derivational suffixes replicated previous findings with articulatory suppression (Folk et al., 2002; Papagno & Girelli, 2005). Altogether, our results showed the effectiveness of articulatory suppression in weakening the contribution of sub-lexical mechanisms in RB's spelling. Furthermore, the fact that fewer PPEs occurred with a procedure designed to affect sub-lexical mechanisms strengthens the interpretation that, without articulatory suppression, sub-lexical mechanisms compensated for the reduced availability of word orthography due to RB's spelling deficit. Results with inflectional suffixes differed from the other results in this task. Inflectional suffixes were in fact spelled less accurately under articulatory suppression, a finding suggesting that sub-lexical mechanisms may have occasionally contributed to their correct production. What is more important, however, is that even with articulatory suppression, however, inflectional suffixes were produced more accurately than derivational suffixes (81% vs. 52%;  $\chi^2(1) = 19.28$ ,  $p < .001$ ). The persistence of this discrepancy in conditions minimizing the contribution of non-lexical mechanisms further suggests that the advantage for inflectional suffixes should at least in part reflect differences between the processing of inflectional and derivational suffixes arising from lexical mechanisms.

## General discussion

The spelling errors most commonly produced by RB were PPEs, which occurred for letters with inconsistent sound mappings. Inflections were a noticeable exception: RB wrote them very accurately, rarely producing PPEs. This is remarkable in light of the many inconsistencies existing with English inflections: no phonemes correspond to the letter e in -ed for consonantal allophones, whereas multiple phonemes correspond to the letters s and d in the inflections -s, -es, and -ed—not only the predictable phonemes /s/ and /d/, but also the less predictable phonemes /z/ and /t/. Nevertheless, RB was correct with the letter e in -ed

94% of the time, and highly accurate with the inflections -s, -es, and -ed, whether or not they formed predictable mappings. Our findings parallel those of Badecker et al. (1996), who documented the sparseness of PPEs with English inflections in a spelling deficit similar to RB's. Our investigation of RB's written responses led us to a novel finding: Whenever opportunities arose, PPEs were commonly produced with derivational suffixes but not inflectional suffixes. We thus found a stark dissociation between suffixes marking derivation vs. inflection: PPEs appeared with derivational suffixes but not inflectional ones. However, RB's spoken production of derived words was extremely accurate, thus showing a dissociation in output modalities. As we discuss next, the findings of our investigation have implications for understanding how inflected and derived words are processed in spelling.

### *The inflection/derivation distinction*

To the extent that inflectional and derivational morphemes are both encoded at the orthographic level, RB's results suggest that there are different neural networks supporting the processing of each of these morphological forms, so that either of them can be selectively spared or impaired following brain damage. Similar explanations were advanced for the dissociations between inflection and derivation described in speaking (Badecker & Caramazza, 1987; Kohn & Melvold, 2000; Laine et al., 1995; Marangolo & Piras, 2008; Miceli & Caramazza, 1988). It is worth mentioning that 97% of derived words were correctly produced by RB in speaking. Therefore, the dissociation between inflection and derivation we observed with RB was specific to writing. Altogether, the finding of similar dissociations in writing and speaking reveals clear similarities in the way morphology is processed across modalities and, more generally, demonstrates further commonalities between the functional organization of writing and speaking. As pointed out by several researchers (e.g., Anderson, 1992; Badecker & Caramazza, 1989; Booij, 2006; Bozic & Marslen-Wilson, 2010), this distinction is possibly rooted in the different roles inflection and derivation play in grammatical vs. lexical processes, respectively. In this perspective, for example, inflection would depend on a closer interaction with grammatical processes than derivation. As the interaction with



grammatical processes could serve as one of the primary forces for functionally differentiating inflection from derivation, it could also draw a neuroanatomical separation, so that inflection would be specifically supported by the neural network underpinning grammar. This form of interaction would be at play both in speaking and writing.

Importantly, our results also enable us to rule out alternative hypotheses about what marks the distinction between inflection and derivation. First, one plausible explanation of RB's dissociation between (spared) inflection and (impaired) derivation relates to frequency and morphological transparency. Sensitivity to these features could potentially explain the relative intactness of inflectional suffixes, which typically occur far more commonly than derivational suffixes and give rise to morphologically transparent combinations. An account based on frequency or morphological transparency, however, did not stand the test we conducted with the suffix *-er*, which is either inflectional (as in the adjective *colder*) or derivational (as in the noun *painter*). Both *-er* suffixes typically appear in morphologically transparent words. Although the derivational *-er* variant is morphologically transparent and occurs more frequently, RB was more accurate and produced fewer PPEs when *-er* was an inflection. Furthermore, neither the frequency nor the morphological transparency of derivational suffixes resulted to be significant predictors of RB's spelling of derivational suffixes. Our results, however, cannot lead us to rule out that these variables do not affect the spelling of inflected and derived words, especially in light of a host of data showing that these variables underlie morphological processing in other language tasks (Amenta & Crepaldi, 2012; Baayen et al., 2011; Bauer, 2001; Bybee, 2007; Clahsen, 1999; Cholin et al., 2010; Ford et al., 2010; Marslen-Wilson et al., 1994; Seidenberg & Gonnerman, 2000; Taft, 1994). Rather, our results do not provide support to accounts that view the distinction between inflection and derivation in spelling as simply a reflection of variations in suffix frequencies and morphological transparency.

A second alternative explanation of RB's dissociation between inflection and derivation relates to the hypothesis that only inflected words have stems and suffixes distinctly represented within the orthographic system. This account posits that, for derived words, distinct representations for stems and

suffixes exist only in the spoken lexicon. This hypothesis correctly predicts that inflections could be spared when writing is damaged. It also assumes that letters are represented similarly when comprising derivational suffixes or as part of morphologically simple words. Accordingly, the final letters *e* and *r* in *painter* and *corner* are, in all respects, identical. The finding that PPEs occurred with similar rates for the letters *e* and *r* in *painter* and *corner* lends some support to this account. This explanation, however, is untenable in light of other neuropsychological results showing that morphological errors with derivational suffixes can be incorrectly produced in either speaking or spelling (Miozzo, Shuster, & Fischer-Baum, 2018). These findings, which show that the morphological structure of derived words is also encoded within the orthographic system, are incompatible with the hypothesis discussed here, which assumes that the morphological structure of derived words is not represented at this level. There is also neuropsychological evidence that information accessed in spelling encodes the morphological structure of both inflected and derived words. The finding that inflected and derived suffixes are relatively spared in spelling deficits sensitive to word length as a result of a graphemic buffer deficit suggests that the suffixes are produced separately from the stems (Badecker et al., 1990; Shuster & Miozzo, 2016), and implies that morphological structure is "visible" to the orthographic system.

### ***The interaction of lexical and sub-lexical mechanisms in the processing of inflected words***

Within the framework of dual-route accounts of spelling (Graham et al., 1997; Houghton & Zorzi, 2003; Miceli & Costa, 2014; Rapp & Fischer-Baum, 2014), certain features of RB's spelling deficit can be explained in terms of damage to the lexical route, such as the word frequency effect and the difficulties experienced with orthographically irregular words. The sub-lexical route, which contributes to spelling to the extent that its functioning is relatively preserved, is responsible for the PPEs, which was confirmed by the fewer PPEs RB produced under articulatory suppression, a procedure hindering sub-lexical mechanisms (Folk et al., 2002; Papagno & Girelli, 2005). Consistent with this characterization of RB's spelling deficit, one way to explain RB's exceptional accuracy with inflectional suffixes is to assume that inflectional suffixes are

available through the lexical route and can be written accurately if spared by the deficit affecting the lexical route. Furthermore, the reliance on the lexical route would prevent PPEs from appearing with inflectional suffixes. We tested this account and expected inflectional suffixes to be unaffected by articulatory suppression if—by hypothesis—their spelling does not depend on the sub-lexical route. Results were, however, inconsistent with this prediction, showing instead a decrease in correct responses for inflections with articulatory suppression. One could rightly suspect that RB was less accurate because spelling was more difficult during articulatory suppression. We can rule this out, however, because overall accuracy did not change with any of the word forms we tested with RB. In sum, RB's results appear to be more consistent with the alternative hypothesis that the sub-lexical route may contribute to the spelling of inflectional suffixes but not derivational suffixes, as a comparable number of errors occurred for derivational suffixes with and without articulatory suppression. This hypothesis would in fact correctly predict lower accuracy with inflectional suffixes when the sub-lexical route is functioning less efficiently, as it was under articulatory suppression.

The question raised by our findings with RB concerns the nature of the contribution that the sub-lexical route provides to the spelling of inflectional suffixes. It could be proposed that the sub-lexical route makes available information about the morphological make-up of the word as well as the correct phoneme-to-grapheme correspondence for the inflectional suffix (e.g., /t/ → ed). Under this account, the sub-lexical route yields distinct orthographic mappings for the /t/ in *missed* (/t/ → ed) and the /t/ in *cost* (/t/ → t) because it has information as to whether the word bears inflectional suffixes. A sub-lexical route so “morphologically empowered” would depart considerably from current proposals that conceive it as only comprising probabilistic procedures for sound-print mapping. A hypothesis more consistent with current proposals that has also found empirical support (Folk et al., 2002; Papagno & Girelli, 2005) is one that assumes that the contribution of the sub-lexical route consists in constraining selection among alternative candidates available at the lexical level (Alario, Schiller, Domoto-Reilly, & Caramazza, 2003; Caramazza & Hillis, 1991; Folk et al., 2002; Folk & Jones, 2004; Hillis & Caramazza, 1995; Hillis, Rapp,

& Caramazza, 1999; Miceli, Capasso, & Caramazza, 1999; Miceli & Costa, 2014; Rapp et al., 2002). Candidates receiving the additional support from the sub-lexical route are more likely to be selected, especially when the impairment weakens support from lexical mechanisms. The outcome of the contribution received by the sub-lexical route is entirely probabilistic, as it depends on the frequencies of sound-print mappings and whether the support converges on the correct letter(s). Because of the many inconsistencies existing with the sound-print mapping of inflectional suffixes, the support from the sub-lexical route is effective with inflectional suffixes only if it targets the correct letter(s). The frequent occurrences of inflectional suffixes compounded with the sensitivity of the sub-lexical route to mapping probabilities makes it plausible that along with t, ed would be one of the spelling alternatives supplied by the sub-lexical route for the phoneme /t/ in /mist/ (*missed*). Under this account, selection is also interactive, as it depends on the joint contribution of information derived from both lexical and sub-lexical routes. Interactivity is especially critical with inflectional suffixes because of their orthographic inconsistencies. For example, it might be hard to select the letters ed for the word *missed* without the support from the lexical route and only on the basis of the contribution from the sub-lexical route, as this route would also activate the letter t. In the end, the lexical route needs to provide a certain amount of support to the letters ed in order to ensure that, as with RB, the sub-lexical route contributes to their selection and the letter t is discarded. Some support from the lexical route is also essential for preventing the t in *post* to be spelled as ed, an option available from the sub-lexical route that RB did produce. It is worth noting that if the support of the sub-lexical route depends on the frequency of the phoneme-grapheme mapping, inflectional graphemes are likely to receive stronger support than derivational suffixes. This, in turn, would contribute to the greater accuracy with which RB wrote inflectional suffixes in contrast to derivational suffixes.

Sub-lexical mechanisms rooted in sound-print mapping probabilities could also be instrumental in detecting letter sequences violating graphotactic regularities (Deacon, Conrad, & Pacton, 2008; Hayes, Treiman, & Kessler, 2006; Kemp & Bryant, 2003; Nunes et al., 1997; Pacton et al., 2005; Treiman &

Kessler, 2006), a feature potentially useful with the spelling of inflectional suffixes that quite often gives rise to phoneme sequences with an illegal orthographic counterpart. For example, recognizing the illegality of the letter sequence rkt would lead to the blocking of barkt—the spelling of /barkt/ derived from sound-print mapping—thus boosting the chance of producing /t/ as ed. However, the test we implemented revealed no evidence that RB relied on graphotactic regularities when spelling inflectional suffixes. Although this negative finding does not warrant the conclusion that information of graphotactic regularities is not involved with inflectional suffixes, it is fair to conclude that its contribution is unlikely to be as substantial as that provided by other types of information received from the sub-lexical route.

### ***A morpho-orthographic process: When sub-lexical mechanisms cannot be relied on***

When a suffix is added to certain word endings, the final consonant is doubled—e.g., *tipped* or *runner* (Venezky, 1999). This occurs with monosyllabic words and multisyllabic words stressed on the last syllable that, in spelling, end with single vowel + single consonant. This form of morphologically driven gemination is common in English to the point that it has been described as a rule (Venezky, 1999), although exceptions to this rule exist. The gemination determined by suffixation, which lacks any phonological correspondence and is thus purely orthographic, cannot rely on sound-print transcoding. Inflected words in which RB failed to double the consonant were plentiful (e.g., *shopped* → *shoped*, *flipping* → *fliping*), occurring in 24/43 (56%) inflected words requiring it. When these errors involving geminates are contrasted with the virtual intactness of inflectional suffixes in RB's spelling, it is apparent that consonant gemination is not part of the same information about the suffix that is available to RB. Instead, it seems that in most cases the inflectional suffix was just added to the stem without making the adjustment the rule requires.

One might suppose that consonant gemination occurred especially with frequent words for which the spelling of the entire inflected word, including gemination, is fully specified. We tested this hypothesis using a binomial regression and found no evidence that correct gemination varied in inflected words, as a

function of (log-transformed) word frequency counts from CELEX (Baayen et al., 1993) ( $\chi^2(1) = .089, p = .765$ ; 43 words analyzed). Results from RB suggest that consonant gemination is unlikely to be encoded in an orthographic representation of the whole inflected word that is retrieved from memory.<sup>1</sup> RB's specific difficulties with consonant gemination appear instead to arise from a problem in adjusting the orthography once the suffix is added. RB's problem is reminiscent of a recently described deficit of spoken production (Shuster & Miozzo, 2017) that selectively affected vocalic inflections (/əz/, /əd/). Errors consisted of the omission of vocalic inflections, so that *skated* was produced as "skate," *benches* as "bench"—noticeably, consonantal inflections (/s/, /z/, /t/ /d/) were accurately produced. This very specific deficit stemmed from a problem in inserting the vowel, which is required in English to avoid unlawful consonant sequences occurring when the suffix is added in certain phonological environments (\*skett; \*bentʃz). If the deficit with vocalic inflections in speaking is morpho-phonological, and thus arises from failures to introduce a phonological repair after morphological processes take place, RB's deficit with consonant gemination appears to be morpho-orthographic, thus resulting from a failure to adjust orthography after a morphological transformation has occurred.

### **Conclusions**

Our findings converge with a growing body of evidence showing that morphology is fundamental in shaping the brain mechanisms involved in spelling (Badecker et al. 1990; Badecker et al., 1996; Miozzo et al., submitted; Rapp et al., 2015). It is clear from our investigation that morphology drives the distinct processing of major morphological categories as well as differentiations across spelling mechanisms. Furthermore, what is emerging from spelling research is that several similarities exist with morphological processing in speaking and spelling. Finding cross-modal similarities is likely to lead us to identify the conditions that determine if morphology will emerge in the language.

### **Note**

1. This may also be the case for derived words. Although we did not extensively test gemination with derived words,

the finding of correct letter doubling with only 2/10 derived words indicates a rather pervasive problem with gemination required by suffixation.

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No potential conflict of interest was reported by the authors.

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